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THE
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A MANUAL FOR ALL ENGAGED IN THE MANUFACTURE OF ARTICLES FROM CLAY.

BY

ALFRED B. SEARLE

CONSULTING EXPERT ON CLAYS AND CLAY PRODUCTS; LECTURER ON BRICKMAKING
UNDER THE CANTOR BEQUEST.
AUTHOR OF
"MODERN BRICKMAKING," "BRITISH CLAYS, SHALES AND SANDS,"
"THE NATURAL HISTORY OF CLAYS," "CLAYS AND CLAY
PRODUCTS," "REFRACTORY MATERIALS, THEIR
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PREFACE TO FOURTH EDITION.

THE third edition of this book having been exhausted, and as the subject continues to attract much attention and to receive detailed consideration in many aspects, it was thought desirable, in view of the standard position the book has attained, to include some of the additional information available without extending the book beyond what is justified by its title.

As the book is intended primarily for works' managers and others engaged in the manufacture of articles from clays and allied materials, and not for people engaged in research, it has been thought to be undesirable to encumber it with numerous references to books and journals inaccessible to most readers, dealing with the more scientific aspects of the subject. A list of useful documents, which is lengthy yet far from complete, will be found in the Appendix.

The generous reception accorded to the book throughout the British Empire and the United States of America emboldens the author to hope that the present edition may continue to serve those for whom the book is written.

ALFRED B. SEARLE.

440 GLOSSOP ROAD,
SHEFFIELD, *May* 1929.

PREFACE TO FIRST EDITION.

DURING recent years the manufacture of bricks, tiles, pottery, and other articles from clay has extended considerably, and along with the growth of numerous factories has sprung up a considerable literature on the subject of clayworking. This information is, however, contained almost entirely in a number of large and expensive volumes (which are beyond the reach of most of those engaged in the actual manufacture), and in a large number of trade and scientific journals and papers, many of which, being in French and German, are quite inaccessible to the ordinary worker.

The present volume embodies an attempt to sift out from this mass of material such information as an extensive experience in clayworking has shown to be of value, and to express it, as far as it is possible to do so, in language which will be understood by any intelligent man. Various matters. especially in the section devoted to Tests and Control, are inserted chiefly with a view to showing something of the amount of checking and control which is possible. The trouble and exactitude required in order to carry out several of the tests mentioned may be beyond the power of the ordinary reader, but may prove useful to that increasing class of clayworkers—those who have passed through some training in a technical school.

The information is necessarily somewhat condensed, and those who wish for more detailed information are referred to the larger standard works—a list of which is given; but it will be found that much of the material (being original contributions of the author and others to various learned societies and technical papers) is not contained in any of those books.

Although care has been taken to mention authors and discoverers whenever their names have been known, it is not possible to include all in so short a volume; but the author hereby acknowledges his thanks to all those clayworkers, known and unknown, who have enabled him to place this information before the public.

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THE CLAYWORKER'S HAND-BOOK.

CHAPTER I.

THE MATERIALS USED IN CLAYWORKING.

Clays.

CLAY deposits vary so greatly in physical condition and chemical composition that it is extremely difficult to group them into classes; and the methods employed in working them, as well as the uses to which the different kinds of clay are put, are also so numerous, that in order to obtain the best results each clay must be treated according to its individual requirements and those of the particular branch of trade for which it is intended. On this account, it is not here proposed to describe at great length the properties of each of the different clays used in clayworking, but simply to deal with certain considerations which are otherwise apt to escape attention.[1]

The primary object of the clayworker is to use the clay he has at his disposal rather than to pay undue regard to the constancy of its composition; and although every care should be exercised to render the variations as small as possible, it is, as a rule, a waste of time to analyse the clay which is being used for bricks, blocks, tiles, and. pipes. Very frequent tests are, however, advisable in the case of refractory clay, and of the clays used in the production of porcelain and other high-class wares, unless they are bought from an outside firm, under contract as to quality. The composition of the paste used in the manufacture of the best class of ware requires, indeed, the closest attention, not only as regards the clays used, but also as regards the other materials employed, without which clay is almost useless to the potter.

Common Clay, chiefly used for making bricks and unglazed tiles, is usually worked as a surface deposit, or it is quarried from moderate depths. In some districts it is covered with an 'overburden' or 'callow' of unsuitable material which must be removed. Mining methods are also employed in the working of some shales and more valuable clays. Not infrequently the 'refuse heap' of one generation of miners forms the surface-material for a later generation of brick or pipe manufacturers, particularly in districts where coal and iron ore occur.

According to its behaviour on mixing with water, drying, and in the kiln, common clay is known as 'strong clay' or 'mild clay.' 'Malm' or 'marl' and 'shales' are other forms of clay. Other local names are given in different parts of the country.

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[1] Fuller details of the characteristics of these clays will be found in the author's *British Clays, Shales, and Sands* (C. Griffin & Co., Ltd., London).

Strong clay is generally fairly free from stones, but bricks made from it, although often hard and sound, are apt to warp and crack in the drying and burning, owing to the large amount of contraction which such clay undergoes. On this account, it is often mixed with sand, chalk, vegetable mould, and ashes, or even with burnt ballast. Strong clay is usually found near the surface.

Boulder clay is a variety of clay—usually strong—containing a variable proportion of stones, gravel, and sand—all very irregularly distributed. It is extensively used in many parts of the northern and midland counties. The material must be carefully selected so as to secure a mixture of approximately regular composition, the larger stones being discarded and the smaller ones crushed in a suitable machine or removed by washing.

Loamy clays are much milder than strong clays, but often contain so much sand, gravel, and small stones that they have to be washed before being used. The quantity of sand they contain renders them less liable to contract or warp than the stronger clays; but, on the other hand, their texture is often so loose that an addition of chalk is necessary in order to bind them.

Marls[1] or *malms* are clays containing, in the natural state, a considerable proportion of chalk or other flux, and may often be made into bricks without any admixture; but as clays containing exactly the desired proportions of clay and chalk are somewhat scarce, it is usual to prepare artificial marls by adding chalk to clays otherwise suitable. The action of the chalk is threefold: in the first place, it acts mechanically in diminishing the contraction of the clay during the drying and burning; secondly, it acts chemically as a flux during the burning, combining with the silica of the clay so that a much harder and more durable material is produced; and thirdly, it changes the colour of the clay on heating, enabling white or very light-coloured bricks to be produced. The securing of this colour-effect is the chief object of the Suffolk, and some other, brick-makers in the addition of chalk to the clay.

As lime compounds form a yellowish substance with oxide of iron, it is impossible to get a good red brick when much limestone or chalk is present. On the other hand, the colour due to 5 per cent. of iron in the clay may, to a large extent, be removed by the addition of about 10 per cent. of limestone or chalk, when, under suitable conditions of firing, a buff instead of a red-coloured product will result.

It is very important that the chalk or limestone, added or naturally present in the clay, should be in a sufficiently fine state of division, as the presence of lumps far smaller in size than a pea will sometimes cause a brick to fall to pieces. This is because the quicklime (calcium oxide) formed in the brick gradually absorbs carbonic acid from the air, and, in the presence of moisture, tends to cause such expansion that, with the first sharp frost, the brick is unable to withstand the strain and is disintegrated. With certain clays, pieces of limestone as small as $\frac{1}{25}$ inch have been found capable of bringing about the destruction of the article in which they occur, but much depends on the plasticity and binding power of the clay, a lean material being more affected than a strong one. When sufficiently finely ground, as much as 25 per cent. of chalk may be present in a clay; but for bricks intended to resist the action of the weather, 12 per cent. is usually the upper limit. Much, however, depends on the original composition of the clay used. Such

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[1] The term 'marl' is also used for a number of clays which contain no chalk, but are of a friable nature, *e.g.* the Midland and Welsh 'marls.'

clays are always difficult to burn, as when the finishing temperature is reached vitrification takes place very rapidly, and the bricks are particularly liable to lose their shape.

Gault clays contain about one-third of their weight of calcium carbonate, and are, for this reason, preferably mixed with sandy; red-burning clay. They are much used in Suffolk.

Triassic clays or red marls of Leicestershire, Warwickshire, and Wales are quite different from the marls used in southern England. They contain comparatively little lime, but it is in a nodular form, and is liable to cause trouble by "blowing." When comparatively free from lime compounds these clays are extremely valuable for the manufacture of terra-cotta. Ordinarily they require great care in selection, especially when bricks of a special nature, such as the well-known blue bricks, are to be manufactured.

London clay is well known and difficult to work unless accompanied by sand; and the *Reading* and *Bagshot clays* are well-known materials for the manufacture of red bricks, roofing tiles, and chimney-pots; but these and many other clays cannot be described in detail in the present volume, for the reason already stated (p. 1).

Shales are clays which have been compressed since their deposition, and usually have undergone some amount of change, so that they are laminated in structure, and only develop plasticity when ground and moistened. Shales are very abundant in Great Britain, and are largely used. Their occurrence at Accrington and Fletton, near Peterborough, have made these two districts exceptionally famous centres of clayworking; but similar clays occupy large areas of country, much of which is, as yet, untouched by brickmakers. Some shales are too siliceous and others are too carbonaceous to be used.

Shales are of many kinds and possess a variety of widely differing characteristics in different districts, the "Oxford Clay" at Fletton and further west being entirely different from some of the Yorkshire and Scottish red-burning shales.

Amongst the most highly prized shales are those which are refractory, and form one variety of the 'fireclays.'

Fireclay may be regarded as a variety of impure kaolin. Fireclays are specially valuable for their capacity for withstanding high temperatures. As many contain upwards of 50 per cent. of silica and about 20 per cent. of alumina, their general formula[1] is $Al_2O_3 6SiO_2$, with varying amounts of water, and small, but noteworthy, proportions of lime, potash, and soda; the last two compounds are commonly grouped under the heading of 'alkalies.' These are important, because the refractoriness of the clay depends, to a large extent, on the absence of more than a very small proportion of lime and alkalies. The fireclays are found in such abundance, and are used in such large quantities, especially in the manufacture of glazed bricks and other sanitary appliances, that they constitute one of the most important materials of the clayworking industry. A table showing the results of the analysis of samples of fireclay from various parts of the United Kingdom will be found in the Appendix, but it must be remembered that clays which may appear to have a similar composition (so far as an analysis will reveal it) may behave very differently in practice, owing to no figures being given for the relative proportions of combined silica, sand, 'true clay substance,' etc.

An *underclay* from the Coal Measures will also behave quite differently from a *shale* of apparently similar composition.

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[1] There is no single formula which can represent all fireclays.

As fireclay is largely used for objects of considerable size, it is generally mixed either with clay burned specially ('grog') or with the broken and damaged goods from the factory, in order to lessen the shrinkage on drying and firing. The proportion of burned material to be added varies with the nature of the goods to be made. For some purposes, and where the clay is required to be very 'open,' equal weights of raw and of burned clay are used. If, however, non-plastic material exceeding 25 per cent. of the weight of the clay be added, the loss in plasticity will prevent the clay being made up into articles requiring a high finish.

The refractoriness of a fireclay is its most important characteristic, and the ability to resist corrosion and abrasion and to withstand sudden changes of temperature is sometimes equally essential. As these qualities are to some extent imcompatible, it is usually necessary to mix several clays and grogs together in order to obtain a first-class 'fireclay.' (For further information on fireclays, see the author's *Refractory Materials: their Manufacture and Use* (C. Griffin & Co., Ltd., London).)

Potter's Clay (*plastic clay*) may be described as intermediate between the white-burning kaolins (china clays) and the coloured-burning common clays. The plastic clays are seldom used alone, as they shrink and crack too much in drying, no matter how carefully the operation is carried out, if articles of any size are made of them. To prevent this, various substances, which contract but slightly or not at all, and do not combine with water to form a plastic mass, are mixed with the clay, and sometimes fluxes, such as felspar or Cornish stone, are added in order that the material may be better bound together during the firing. The composition of these mixtures varies according to that of the particular plastic clay used, and the purpose for which it is intended. It is in the successful production of such mixtures that much of the potter's skill lies.

China Clays, *Porcelain clays*, or *Kaolins* include the purest clays known, and consist almost exclusively of alumina, silica, and water.[1] They are less plastic than the common or 'plastic' clays, and generally burn to a very white porous mass; but even the less pure forms are greatly valued on account of their refractory nature, and, under the name of 'fireclay,' are in great demand for the production of ware intended to withstand high temperatures, *e.g.* the lining of furnaces, etc. It is generally thought that the kaolins are produced by the action of the weather on felspar, but their origin is still unsettled. Although the composition of kaolin is generally represented by the formula $Al_2O_3 2SiO_2 2H_2O$, corresponding to 46 per cent. of silica, 40 per cent. of alumina, and 13 per cent. of water, this is only partially true, even of the carefully purified material. In its native state, it is usually contaminated with varying proportions of mica and porphyry, and with some undecomposed felspar. These impurities are removed, when necessary, by washing, the impurities being allowed to settle, and the clay and water run off into tanks or hydro-extractors wherein the greater part of the water is separated. The remainder is removed by drying.

In its raw state, commercial china clay is white or creamy in colour, often with fine blue or brown markings running through it, caused by traces of organic matter, which are burned out in the kiln, leaving a perfectly white, dry, unvitrified mass with little power of cohesion.

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[1] The state in which the elements or oxides are combined in clays is still unknown. All that can be stated as certain is that, where clays are decomposed under some conditions, they yield alumina, silica, and water, or compounds of these oxides.

The kaolins are notable for their great resistance to heat, their whiteness when fired, and their slight plasticity. They cannot be used alone as engobes for coloured clay, as they do not bind sufficiently well. They are, therefore, mixed with various fluxes when used in this way. Their plasticity is increased when necessary by the addition of the more plastic blue, or 'ball,' clays. The quality of china clay can be ascertained from its chemical composition (especially its freedom from iron and alkalies), its colour on burning, its softening point, its suspensibility, and its appearance when freshly cut with a knife.

Porcelain is made of a mixture of kaolin with felspar, chalk, and some form of pure silica such as flint or quartz, heated until the mass becomes partially vitrified and translucent when cold. The mixture is often kept in cellars for a long time before it is used, in order that it may 'mature' by a process of 'fermentation,' and so become easier to work. The addition of a little honey, or sugar, is sometimes made in order to assist this 'fermentation': the nature of the changes which take place in maturing is by no means clearly understood, but whatever it may be, its chief effects are to distribute the water present more uniformly throughout the mass and to increase the amount of colloidal gels present.

Blue or Ball Clays.—The chief shipping-place for the clays of Dorset is Poole, while those of Devonshire are sent to Teignmouth. The Devonshire ball clays are, as a class, freer from iron compounds, and, therefore, produce a somewhat whiter body.

Before firing, ball clays are dark-coloured, sometimes approaching black, owing partly to the organic matter they contain, which probably has some connection with their extraordinary degree of plasticity. In composition, the ball clays do not differ greatly from the kaolins, except that they often contain a rather larger proportion of silica. When freshly dug they contain upwards of 30 per cent. of water, of which about 20 per cent. is removed on drying at steam heat, but the remainder only at a dull red heat. Ball clays do not burn so white as the kaolins, so that their use is limited in the production of white engobes; some ball clay should, however, usually be introduced into the engobe in order to fix it to the body ware more securely than can be done by means of a china clay alone. Owing to the great variety in composition of the different ball clays, it is highly needful to test them before use; and where a chemical analysis is not feasible, a sample of the clay should be moulded into a small cone and fired in the hottest part of the kiln, its appearance after firing being compared with that of a high-class sample similarly treated. The contraction of the clay on firing should also be measured, and the fineness of the raw clay noted. When mixed with three times its weight of water, neither a china clay nor a ball clay should leave any residue on a sieve of 120 holes per linear inch, after gently brushing the sieve with a soft brush and applying a stream of water to the residue, though some of the coarser 'stoneware' ball clays may do so.

Impurities present in Clays.—The chief impurities found in clay are 'alkalies,' soda and potash, vegetable matter, iron and lime compounds, the amounts of these impurities being shown by analysis. Without knowing the particular purpose for which a clay is destined, it is impossible to fix any satisfactory limit to the percentage of these impurities, but, as a general rule, it may be assumed that in a refractory clay the alkalies should not exceed 2 per cent. (in the best fireclays they will be far less), the lime and magnesia 2 per cent., as compared with up to 25 per cent. in marly clays, and the iron

2 per cent.,[1] although the permissible limit of the iron will depend on the fineness of the grinding of the clay; and in red-burning clay, three times this amount is not uncommon. The amount of organic matter permissible will depend on the uses of the clay.

Special care is required when firing goods containing a large proportion of carbonaceous matter, or the combustion of this matter may reduce the goods to a mass of clinker.

Many clays also contain free silica (sand), gravel, and stones. Some of these ingredients may be really valuable to one clayworker, but to another they may be objectionable, so much depends on the utilization of the clay. Thus, London clay is almost useless unless it contains a sufficient quantity of sand, whilst a sandy loam may have, for some purposes, to be washed before use.

It is, therefore, extremely difficult to define what materials really constitute 'impurities' in clays.

The removal of coarse impurities, such as gravel and stones, is described later under the caption 'Cleaning Clay' (p. 49); the removal of sand is effected by 'washing' (p. 49). Lime compounds, when in a finely divided state, can seldom be profitably removed on a commercial scale, unless by 'washing.'

Ironstone, or more correctly 'pyrites,' may, to a large extent, be removed from fireclays, before they are ground, by hand-picking and careful sorting. A skilled picker will often separate three-quarters of the ironstone present, but the work must be entrusted to a thoroughly conscientious man.

Other iron compounds cannot be removed commercially, though metallic iron may be removed by means of magnets.

So far as is known, no alkalies can be removed commercially from clays unless it pays to use settling tanks similar to those used for china clay. Consequently, it is seldom possible to materially raise the refractoriness of a clay by any merely mechanical or electrical process of purification which is commercially feasible.

From what has already been stated, it will be seen that the varieties of clay are almost endless, and, indeed, it is difficult to find any plastic mineral, from the pure kaolin to the commonest of soil, which has not, at one time or another, been termed 'clay.' On this account it is scarcely possible to generalize respecting the impurities in clay. Thus, iron compounds which are 'poison' in china clay are necessary to the maker of red-burning terra-cotta. There are, however, certain adventitious foreign materials, the presence of which may cause trouble. *Metallic iron* from filings, bolts or nuts from the mill, and other similar sources, is apt to cause trouble when goods of fair surface are to be produced, as in the sanitary and sink trades. In the production of earthenware, such impurities are specially sought for and removed by means of magnets. Contamination of the clay by wood-shavings or matches is also a source of difficulty in some works where the workmen are not carefully watched. Such pieces of *combustible material* will burn out in the kiln, and, if near the surface of the article, will leave an unpleasant hollow, which is worse if the article has been glazed in the green state. Fragments of food should never be allowed to get mixed with the clay, although they are sure to do so if the workmen are allowed to take their

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[1] In chemical analyses the percentage of iron compounds is usually expressed in terms of *ferric oxide*. The precise compounds of iron which exist in clays are by no means fully known. Any of the commoner iron-bearing minerals may be present, together with others not definitely identified but resembling *nontronite*, $H_4Fe_2Si_2O_9$.

meals in the making shops, and the sweepings from these sent back to the mills. Certain other impurities occurring naturally rather than from carelessness in the manufacture will be found described in the chapter on 'Defects.'

The Coloration of Clay is partly due to organic (vegetable) matter and partly to the minerals it contains; the latter, especially the iron compounds, exercise the greatest influence on the colour of the fired material.

The grey, bluish, black, red, and other tints of unburned clay, although usually due to mineral impurities, are, in some cases, of vegetable origin, the composition of the colouring matter being often imperfectly understood. It is not improbable that it is partly due to finely divided coal, or to some dye-like material formed—like the brown colouring matter of peat—by the decomposition of vegetable matter.

These organic colouring matters are destroyed on firing, so that a clay may be strongly coloured in the green state and yet burn perfectly white. Use is sometimes made of this fact in keeping special bodies and pastes separate from the other classes of clay by mixing with them some strong aniline dye, such as methylene blue, which will burn off in the kiln.

The colour produced by mineral matters in the clay is also changed by firing, and it is usually more intense in the finished goods than in those which have not been through the kiln. There are, however, some exceptions to this statement, as, for instance, a clay containing both iron and lime compounds. At a low heat, such a clay will burn red owing to the oxide of iron present, but if fired hard the lime will unite with the iron to form a double silicate of iron and lime of a yellowish or cream colour.

The colour of clay goods and pottery may be (*a*) natural and due to the effect of the heat of the kiln on the materials of which the goods are made, as in the case of red and buff terra-cotta; or (*b*) the colour may be produced by the application of certain metals or metallic oxides or other colouring materials to the surface of the ware, as in most ordinary pottery. The second class of coloured ware (decorated ware) is divided into several classes, according to whether the colour is applied *under* the glaze, mixed *with* the glaze, or applied *over* the glaze on the articles.

The effect of heat and of oxidizing and reducing atmospheres on the colours of various clays will be found described under 'Firing.'

The extent to which the conditions of firing will also affect the colour of the goods is often important; thus, certain classes of clay, containing iron compounds, will burn red in an oxidizing atmosphere, whilst, if the clay be mixed with coal before firing and the air be excluded as far as possible from the kiln, black or 'blue' bricks will result—the difference in colour being due to the formation of less highly oxidized iron compounds owing to the reducing atmosphere employed. This subject has been studied with particular care by Professor Orton, and his paper, on "The Rôle played by Iron in the Burning of Clays,"[1] constitutes the standard monograph on the subject. As the result of his researches, Professor Orton concludes that, although the presence of iron, in a finely divided form, is necessary to the production of a buff or red colour, its mere presence and the size of the particles do not appear to fully explain all the reactions and colours that are produced by its aid. The colouring power of iron in the state of granules is practically nil, but its presence in this form often causes trouble to the clayworker through the production of spotted, mottled, and rough, unsightly ware.

The chief compounds of iron found in clays are ferric oxide (combined with

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[1] *Transactions of the American Ceramic Society*, vol. v., 1903.

more or less water), ferrous carbonate, and ferric sulphide or pyrites. Less frequently, ferrous silicates and ferric sands are identified in clays. The precise mineral form of the iron compound is of importance on account of the greater tendency of some minerals to gather into concrete masses, and also on account of the different treatment which the different minerals require on burning. Hence, although an equally good red may be produced from a clay containing the iron in the form of carbonate as from one in which the iron is present as oxide, in practice it is found that the ferrous carbonate has a greater tendency to granulate, and so produce goods containing black or brown specks. In such a case, the ferrous carbonate being relatively soft, it will generally be found that a finer grinding of the material with greater care in preparation will remove the defect. With ferric sulphide (pyrites), on the other hand, the granules are of varying size, and never small enough to give a red colour to the clay, but invariably show up as black or slagged spots, even after passing through the finest sieves.

Reducing agents, such as carbon compounds, all burn out from a clay under favourable conditions, and, of themselves, neither enhance nor diminish the coloration produced by the iron, but, by virtue of their superior affinity for oxygen, they prevent, or delay, the iron from playing its customary rôle, and consequently may cause untold trouble in the burning. This is especially the case with the pyritic and bituminous fireclays, the sulphur in these acting as a reducing agent.

It is not usually sufficiently realized that the rôle of iron in the burning of clays is more affected by the method of burning than by the actual proportion present, for, according to the conditions during the burning, the products may be beautifully coloured and of pleasing shades, or they may be swelled up, deformed, rough, or spongy and weak—in fact, worthless. In this connection it may be pointed out that an error made in the early stages of the firing can seldom be fully repaired later. Thus, if the iron oxide has been reduced by the carbon in the clay and is afterwards fully oxidized, it never assumes its original colour again.

Pyrites (FeS_2) is a mineral particularly responsible for much of the difficulty incident to clay burning. When heated from 400° to 600° C., only half of its sulphur is expelled. The remainder of the sulphur can be driven off at 900° C. by prolonged roasting. When the temperature rises quickly to 900° C. the reduction product, FeS, fuses to a black slag.

Ferrous Carbonate ($FeCO_3$) when heated from 400° to 450° C. loses its carbon dioxide (CO_2), and the resulting FeO, being unstable, is rapidly oxidized to the red ferric oxide Fe_2O_3 if the atmosphere inside the kiln is suitable; if otherwise, mere exposure for any length of time to hot gases will not effect the desired oxidation. It is of the utmost importance, therefore, that between 700° and 900° C. the atmosphere inside the kiln should be strongly oxidizing, and as free as possible from carbon dioxide. The length of time required for the oxidation will depend on the porosity of the clay; the finer the clay, the longer the time necessary. If the closeness of the clay is increased by the presence of an unusual proportion of fluxes, the difficulties will be so great as to prevent economical manufacture.

The oxidation of the iron in the clay must be completed before vitrification is allowed to occur, otherwise oxidation will never be finished, and the clay will either be black or will contain large black cores. Sometimes, if the reduction of the iron has taken place late in the burning, it will show as a dark ring ¼ inch wide, surrounding a red core. This is particularly noticeable in certain sewer pipes when the fires have been pushed during the salt-glazing. When clays are burned at temperatures approaching 1200° C., it is practically impossible to admit any excess of air without a special regenerator, and, consequently, it is impossible to prevent an occasional reduction at this temperature. This will not matter much if the clay has been properly oxidized at 900° C. or thereabouts. On the other hand, it may be generally assumed that goods not oxidized at or near this temperature will never be oxidized.

One of the chief difficulties encountered, requiring great care in carrying out the oxidation, is that ferrous oxide[1] combines with silica at comparatively low temperatures, and the resulting silicate melts and weakens the structure. The evolution of gases from the imprisoned slag is a further cause of trouble. Clays which simultaneously contain carbon, carbonates, sulphides, and iron are especially troublesome in this respect, particularly as the volume of the gases produced is so very large in proportion to the weight of the substance from which they are evolved.

If the clay be alternately heated in an oxidizing and a reducing atmosphere, a change of colour, increasing with the number of alternations, is produced. This operation—known as 'flashing'—is now frequently employed in the production of certain classes of goods, and with small kilns and at moderate temperatures it is not difficult to obtain very satisfactory results. The difficulties increase rapidly, however, with an increase in the temperature and size of the kilns. The great point is to secure the complete oxidation of the carbon in the clay (if any be present) at a sufficiently low temperature, so that it cannot combine, and so reduce the iron in the clay to such an extent that subsequent oxidation becomes impossible.

Too rapid heating of the kiln when it is just below 900° C. is the cause of thousands of facing bricks being spoiled, because the carbonaceous matter they contain is decomposed and 'set' in such a way that it forms *hearts* or *cores* and cannot afterwards be burnt out without spoiling the colour of the goods.

Seger classified clays, according to the colour they possessed when fired, as follows:—

(*a*) Rich in alumina and poor in iron compounds—burn white or cream colour, as kaolins, pipeclay, etc.

(*b*) Rich in alumina (20 to 30 per cent.), moderate amount of iron oxide (1 to 5 per cent.)—burn yellow to brown, as most plastic clays and fireclays.

(*c*) Poor in alumina and rich in iron compounds—burn red, violet, or black, according to temperature.

(*d*) Poor in alumina, but rich in iron and lime compounds—burn yellow, owing to the formation of the double silicate of calcium and iron, as certain brick earths and marls.

There is also another class of clays to which some artificial colouring matter ('stain') has been added, so as to produce a special tint on burning. These are the coloured bodies or 'engobe' clays, and the colours used in connection with them are mostly metallic oxides, with or without a flux of

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[1] The lowest oxide of iron—*i.e.* that in which the proportion of oxygen is least—is known as ferrous oxide, and is represented by the formula FeO. The highest oxide is Fe_2O_3, or ferric oxide. A third oxide is Fe_3O_4, or magnetic oxide. All three forms may occur simultaneously if the burning is improperly conducted.

some kind. Being somewhat difficult to prepare, these stains are best procured from dealers in potters' materials. Occasionally beds of coloured clays are found in which the colouring oxide occurs naturally in a clay of low fusing point, so that it may be used directly for covering clay of a different nature; such clays are generally too valuable to be used for making directly into goods. Certain clays of this nature, which are rich in manganese, are used on the Continent in the manufacture of brown glazed bricks.

Plasticity.—The plasticity of clay is the property which pre-eminently distinguishes it from all other substances, for, although there are some other materials which become plastic on the addition of water, they do not possess this property to anything like the same degree as clay. The cause of this plasticity remains to a great extent a mystery, though it is generally understood to be connected in some way with the 'combined water' of the clay, as it disappears when clay has been heated to a temperature just sufficient to drive off the 'combined water' (415° C. or above). Several authorities have advanced the theory that bacteria are the cause of plasticity in clay, but Hecht and Kosmann find that there is not sufficient evidence to prove this, and its probability is made more doubtful by the failure, up to the present, to render lean clays plastic by inoculation. Bischof, an eminent authority on the subject, considers that there is a kind of 'felting' of the particles, partly due to their minuteness, which enables them to adhere more closely to each other than do equally small particles of other substances.

There are also several theories attributing plasticity to peculiar properties of the 'clay molecule' and to the existence of colloidal material.[1]

The ancient practice of improving the plasticity of clay by 'ageing' is now seldom practised to anything like the extent which was formerly thought necessary. Where hollow-ware goods of very fine clay are made, there is an undoubted advantage in storing the clay for some time before it is made up into goods, but the keeping of the clay in air-tight boxes for several years, as practised by Wedgwood and other famous potters, is no longer considered essential. Storing the clay paste used for making refractory goods in a cool place for a few days is usually advantageous, and appears to increase the plasticity of the material. The greater smoothness of paste so stored or 'soured' may, however, be simply due to a more uniform distribution of the water present.

Some very interesting experiments by Acheson and Ries on the effect of a 2 per cent. solution of tannin (gallo-tannic acid) on clay show that the addition of this substance notably increases the plasticity of the clay, and at the same time apparently deflocculates it and breaks it up into much finer particles. No wholly satisfactory explanation of this curious action is forthcoming.

Plasticity may be increased by the addition of glycerin or of syrups and certain gummy substances to the water used in mixing the clay, and a permanently plastic (non-drying) clay of great value for modelling purposes may be made by the use of a mixture of plastic clay, vaseline, and a little oil.[2]

Very plastic clays dry unequally and with difficulty; they tend to lose their shape and so crack, both in the drying and burning of the wares,

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[1] The chief theories as to the causes of plasticity in clay are described in the author's *British Clays, Shales, and Sands*.

[2] The 'plasticine' sold for kindergarten and educational purposes is a mixture of this nature, rendered non-drying by the addition of glycerin.

because the particles cannot move over each other with sufficient freedom, and at the same time they have not sufficient rigidity to remain in their original position. Hence, it is necessary to introduce non-plastic material into such clays in order to overcome these defects, and the correct adjustment of the plastic and non-plastic materials composing the clay mass requires the most careful attention. This subject will be referred to later.

Contraction.—Closely connected with the plasticity of clay is the contraction or shrinkage it undergoes in drying and in the kiln. This loss in volume is mainly due to the volatilization of water and to the volatilization and combustion of organic matter in the clay. If the clay be homogeneous, and not subjected to draughts, the contraction will take place equally in all directions and the shape of the article will be retained.

That shrinkage ceases before the clay is completely deprived of its water has been shown by Aron and Brongniart to be characteristic of many, but not of all, clays. The clay shrinks until the particles are practically in contact with each other, so that any further water which may be driven off does not make any noticeable difference in the volume of the clay. Aron has further shown that the 'pore-space' is constant for each kind of clay, and is independent of the amount of water added to the clay to make it plastic.

If the same amount of water is used the addition of non-plastic material to a clay makes it shrink more than the raw clay does, and the porosity diminishes at the same rate until a certain point (that of maximum density) is reached. After this, the more 'grog' added to the clay the less will it shrink and the greater will be the porosity.

The nature of the non-plastic material added will also affect the shrinkage to some extent, and will exercise a considerable influence on the quantity of water which must be mixed with the clay, especially if a porous burnt clay be used to reduce the plasticity of the clay.

The use of burned ballast, 'grog,' or sagger material is of great importance in some cases, as by this means a fat, highly plastic clay can have its natural shrinkage reduced to practicable limits; and further, in the case of large goods especially, the addition of such material opens up the body of the clay and provides easier channels for the water to pass from particle to particle of the mass, thus securing a greater homogeneity as well as greater facility for rapid and even drying, and less liability to 'jumping' or 'dunting' in the kilns. Various materials may, of course, be mixed with the clay in order to produce these effects; where it can be obtained cheaply enough the addition of burned clay of the same composition to that used in the works in an unburned condition has the advantage of conferring greater strength and rigidity without altering the composition of the clay used. This burned clay (grog or sagger) is largely used in the manufacture of bulky fireclay goods for the reasons just stated, and because it forms a kind of skeleton which holds the plastic clay to the intended form. Such burned clay may be obtained from the waste and broken goods on the works; or where there is not a sufficient supply it may be burned specially for the purpose in a limestone or shaft kiln. It is important that the grog should be fully burned, and yet not sufficiently so to vitrify it and so destroy its binding properties. When broken goods are used, the glazed portions (if any) should be used with care, as they are a source of weakness rather than of strength to the clay with which they are mixed, for grog only acts as a refractory agent up to its vitrifying point. Whenever possible, such glazed portions should be discarded.

The fineness of the particles of burned grog which should be added to a clay depends on the purpose and nature of the article to be manufactured. For withstanding sudden variations of temperature, the coarser the grog the better. When once a suitable size of grain has been found, great care should be taken that the grinding is carried out so as to obtain a similar result. In testing the fineness of burned grog it is not necessary to sift it through a variety of sieves: if two pounds, accurately weighed, be carefully poured into a litre measure, and water run into the latter from a burette or similar accurately graduated measure until the mark on the flask is reached, the amount of water necessary to fill the flask up to the mark will give, indirectly, but with sufficient accuracy, the fineness or otherwise of the grog. In practice it is not necessary to calculate the actual volume-weight of the material; it is sufficient to know that it is of such a nature that "so many" measures (c.c.'s) of water must be added. If more than this predetermined volume of water be required, it indicates that the material has been too finely ground; if less water be needed, the grinding must be continued. Unless recourse be had to an expert, the amount of grog which should be added, and the fineness of its particles to obtain the best results with a particular clay, can only be ascertained by experiment. Where sudden changes in temperature occur, the particles of grog should be relatively large (sometimes as much as $\frac{1}{4}$ inch and seldom less than $\frac{1}{50}$ inch), but the shape, and especially the ornamentation on the goods, will often prevent pieces so large being used. In such cases a compromise must be effected. Occasionally a mixture of fine and coarse grog is employed. The porous nature of properly burned grog materially assists in the drying of the goods, but, for some purposes, it is better replaced by other material—in order to produce goods of refractoriness greater than that of the original clay. The effects of improper contraction being shown in drying and firing, reference should be made to these headings and to 'Defects.'

Magnesia, *Chromite*, and other minerals are also used to confer certain properties on clay, as are also certain fluxes, such as felspar, Cornwall stone, etc., the particular uses of which are well known in the formation of engobes and glazes.

Bone Ash (commonly known as *Bone*) is also employed in the manufacture of china-ware in order to give translucency. Bone ash is the product obtained by the calcination of bones, and consists chiefly of calcium phosphate and carbonate, the latter being frequently added as an adulterant.

Homogeneity, or complete uniformity of composition of the clay mass, must be secured by a thorough treatment, either by tempering, pugging, or wedging, according to the nature and purpose of the clay or paste. The greatest uniformity will be secured when the material is most finely ground, but for various reasons this is not practicable in certain cases, as in clay for gas-retorts which must be made of very coarse materials. The most efficient means available for enabling a thoroughly homogeneous clay to be obtained is by weathering, which breaks the clay up into minute particles and allows of rapid and efficient grinding and tempering. This beneficial action is continued still further if the tempered clay is allowed to 'sour' (p. 10) for some time, and is again pugged or wedged before use. The thoroughness with which these operations can be carried out depends to a large extent on the purposes for which the clay is to be used and the expenditure which can profitably be allowed.

The Refractoriness of a clay depends upon its composition, especially its freedom from fluxes, and upon the size of its particles and the length of time during which it is exposed to the heat. Although Bischof and others have endeavoured to ascertain the relative heat-resisting powers of different clays by calculation from their composition, no really satisfactory formula has yet been published. Some progress in this direction has been made by Ludwig, who has arranged a diagram or chart, in which the composition of the clay is first expressed by a formula of the type

$$1{\cdot}0Al_2O_3 + xSiO_2 + yRO,$$

and the ordinates and abscissæ of the diagram are composed of the figures for the silica and base (RO) in the formula. A scale can be drawn by plotting the highest Seger cones as lines, when all clays 'bending' between the temperatures represented by any two cones will occupy a portion of the area between the lines representing the melting point (or rather the softening point) of these cones.

This only applies to clays and other silicates in which the fluxes are in relatively small proportion, and not to such compositions as glazes. In the study of this question, the investigation of the fusion points of blast-furnace slags and various mixtures of felspar, chalk, china clay, and flint—taken together or in groups of two or three of these materials—has shed some interesting light, but the results obtained cannot, at present, be summarized into any simple 'law' which will serve to determine the fusion points of clay mixtures from the results of a chemical analysis.

Porosity is the ability to absorb water in the pores of the material, and is due to the spaces between the particles of clay composing the mass. It is necessary that building bricks should be porous in order that they may allow air to pass through the walls; they must not be very permeable (p. 14), however, or they would not dry properly after rain.

Porosity is an essential characteristic of most refractory materials, such as fire bricks, retorts, etc., and to increase the porosity of some fireclays it is not unusual to add some form of combustible matter, such as coal dust, sawdust, naphtha, or grain (barley) to the clay, as these additions enable the goods to withstand rapid changes in temperature better than they would do if of closer texture (p. 16).

The addition of these materials does not affect the porosity of the clay before firing, but, by separating the particles further from each other than they are in the natural clay, the spaces produced when the combustible material burns away become filled with air, which, being a non-conducting medium, enables the porous ware to withstand better fluctuations in its temperature. The greater freedom with which the particles can move over each other in such ware is also of assistance in this respect. The use of coarser materials also increases the porosity of the clay in many instances, as large particles cannot be packed so closely as smaller ones. Consequently, as a rule, the purer the clay and the finer it is ground, the less will be its porosity. Overheating the clay will also diminish its porosity by causing a partial vitrification of the material, the resultant glaze or glass filling up some of the interstices formerly occupied by the air.

When other materials are mixed with the clay, with a view of lessening the contraction, the porosity is also affected according to the nature and proportion of the added ingredient.

The *total porosity* of a material includes the air spaces totally enclosed in the material, but these are usually neglected, and the term 'porosity' is ordinarily confined to what is strictly the *apparent* porosity.

The amount of (apparent) porosity possessed by a clay (after firing)[1] is calculated from the amount of water which the fired clay will absorb owing to the water replacing the air in the pores of the sample when the latter is allowed to soak in water for some time. Where water would affect the results, as in most raw clays, some other liquid, more suitable for the purpose, must be used in its place. Paraffin is very suitable. Methods of making this test are described in Chapter XIII. under the heading 'Porosity.' (See also p. 200.)

Although it is usual to calculate the amount of water absorbed in terms of the percentage by *weight*, it is really more correct to express it in percentages by *volume*, as it is the relative space occupied by the air which is really to be measured.

The porosity of clay is not only important in regard to its ability to withstand sudden changes of temperature, but also in 'dipping' and other operations of manufacture; and when burned clay goods, such as bricks, are used in the construction of buildings, the porosity of the material enables a certain amount of ventilation to be carried on, and at the same time prevents the condensed moisture from the atmosphere from running down the walls of the building. Specially porous vessels made of clay are used as drying or filtering media in certain kinds of work.

The firing of specially light and porous bricks is a matter of some difficulty, owing to the large proportion of combustible matter which must be present. The fire has a great tendency to go too fast and so to 'set the kiln on fire,' and in some of the most difficult cases the air supply to the fuel has to be stopped and the fires allowed to die nearly out, no further fuel being added until all danger of excessive heating is passed.

Permeability is a term seldom applied to raw clay, but it is an important characteristic of some bricks and tiles. It is closely connected with 'porosity' (above), but indicates not merely that a tile can absorb water, but that it will permit water to pass through it. Highly permeable roofing tiles allow rain to pass through them and to accumulate in the form of drops on the under side. Highly permeable building bricks and roofing tiles are unsatisfactory because they take so long to dry, and because of the disadvantages arising from water passing through them.

Non-Plastic Materials.

Sand, quartz, flint, and other siliceous materials are used to lessen the contraction of the clay during drying and firing when mixed with it; they are also used to prevent goods sticking to each other on the hacks, stacks, etc., or to the mould or drying floor. In the kiln they serve a similar purpose on account of their refractory power. These materials are nominally composed of pure silica (SiO_2), but they usually contain small varying amounts of other substances, particularly the sand. Sand, however, is a term used for a rock material rather than for a particular mineral, for, as is well known, sand is produced by the grinding together of a great variety of stones in river-beds and in the sea, and to the weathering of rocks. Its composition is, therefore, extremely varied, although in the best varieties the proportion of silica it contains is, considering the method of its production,

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[1] The porosity of unfired clay is a matter of little or no importance to the clayworker, but that of the material drawn from the kilns has an enormous influence on the quality of the ware, and its suitability for the purposes for which it is manufactured.

remarkably high. Sand is often useful in grinding clays, as it enables the mills to get a better 'grip.' When added to clay, its chief characteristics should be great refractoriness, 'sharpness,' and freedom from staining power, while a sand as free as possible from iron compounds should be used where the pale colour of the goods is important. Red-burning sand—rich in iron oxide—is largely used in brickmaking to produce bricks of a pleasant red colour.

Good sand may be rubbed on white paper without leaving any dirty mark, and, if stirred up with water, no permanent turbidity is produced. If a sand will not answer to this test it must usually be purified from clay and dirt by washing in a stream of water, with constant stirring. Special machines are made for this purpose. Sand, quartz, and other forms of silica used for glazes must be extremely finely ground, though the precise degree of fineness depends to some extent on the nature of the clay to which the glaze or engobe is applied: in some cases flint is objectionable if it is too finely ground. The finely ground material is very difficult to purify by washing, so that where a particularly pure 'dust' is required, some pure variety of silica, as quartz or flint, is used. It is seldom possible to employ an impure sand which has been ground and then washed, as this treatment will not remove all the impurities.

If much organic matter is present, it may be necessary to calcine the material before use.

Although so largely used on account of their high melting points, most forms of silica melt at considerably lower temperatures than alumina does, and their melting points are very materially lowered in the presence of certain metals or bases with which the silica can combine. The power of combining in this way varies with the condition of the silica and its origin, the amorphous variety, especially when in a jelly-like condition, being the most readily attacked, and crystallized quartz, in somewhat large pieces, the least readily affected. Silica acts, in fact, sometimes as a flux, and sometimes as a refractory agent. Practically, below 1000° C. only the finest particles of silica can enter into combination and so act as a flux, but at higher temperatures and on prolonged heating, much larger particles may do so.

As already explained, many sands, from the nature of their origin, contain impurities: if metallic oxides, such as lime and the alkalies, be amongst them, the value of the sand is materially diminished, as these oxides act as fluxes, and siliceous materials containing them in notable proportions may do more harm than good by being fused to the ware or by lowering the fusing point of the clay with which the sand is mixed. This is particularly the case in the manufacture of highly refractory clays, and it must be understood that the addition of sand or other forms of silica to an inferior clay only increases the refractoriness to a limited extent and only improves the clay for use at relatively low temperatures.

Silica tends to *expand* in the kilns, and hence, is liable to cause cracking if too much is added.

The fusibility of a sand is somewhat difficult to determine. Probably the best way of estimating it is to make it up into a paste with water containing a little dextrin, and from this to form 'cones,' which are then heated along with Seger cones in a kiln or special furnace, and the relative behaviour compared with a good sand similarly treated.

Dinas, ganister, and other bricks containing a large proportion of free silica are used for lining furnaces and for similar purposes where a highly refractory, non-contracting material is needed.

Carbonaceous material, such as coal, sawdust, or graphite, is used for a variety of purposes when mixed with the clay to the extent of 15 to 30 per cent. Sawdust is more particularly employed to form a porous ware, as the sawdust burns out and leaves corresponding hollow places. Graphite and coke are mixed with the clay in the formation of crucibles for metallurgical purposes, and serve not only to cause a more rapid heating of the metal, but also to enable the mixture of carbon and clay to withstand the high temperatures better than the clay alone. The manufacture of these crucibles is, however, an industry in itself, and requires special skill both in making and firing.[1]

Sawdust is generally used direct (after sifting to remove larger pieces of wood, etc.), but the graphite, coal, and coke must be ground and, in some cases, washed to free them from various impurities. Flaky graphite is more fire-resisting than that which is more finely powdered.

'Soil,' or sifted domestic cinders, is mixed with brick clay around London in order to prevent undue contraction during the drying, and it is also said that the sulphur contained in the 'soil' assists in the colouring of the bricks when burned.

Coal dust has been mixed with clay in order to make it more porous, but the gas given off by the coal proves to be a great disadvantage.

Barley and similar grains have been found useful by Mäckler in forming the large pores necessary to prevent scumming in certain kinds of clay. Other waste materials—as naphthalene—have also been employed (see p. 13).

Bauxite is a mineral containing a remarkably large proportion of alumina with a relatively small proportion of silica, iron, and other metallic oxides; it is consequently very refractory, but cannot be used alone on account of its lack of plasticity. Added to clay, it reduces the contraction both in drying and firing, and increases its power of resisting high temperatures. The bauxite must be mixed with about one-fourth its weight of clay, ground, tempered slightly with water, formed into rough bricks and burned, before it is fit for use. Care should be taken that it is not 'flashed' by the flame of the kiln, as pieces discoloured in this way by the reduction of the iron present will cause trouble when the material is ground up with more clay for use. The proportion in which this prepared bauxite is to be mixed with the ordinary fireclay of the works varies according to the nature of the goods to be made, but four parts of fireclay are frequently used to each part of bauxite—more bauxite being used for very refractory articles.

A mixture of clay and bauxite with the same proportions of alumina, silica, and fluxes as a high-grade fireclay will not behave like the latter, for in the mixture the whole of the alumina is not combined with the silica as in a true clay.

The value of bauxite, which depends on the proportion of alumina it contains, is seriously diminished by even a small increase in the proportion of other oxides. The unburned mineral often contains as much as 30 per cent. of water, so that, in comparing the results of analyses of different samples, the calculations should be made on the calcined samples. In this country, Irish bauxite is commonly used, good specimens of which will contain upwards of 75 per cent. of alumina after ignition. French and American bauxites sometimes contain as much as 96 per cent. of this constituent, and are, therefore, preferable.

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[1] See the author's *Refractory Materials: their Manufacture and Use.*

Felspar is sometimes added to clay to produce a non-porous ware (stoneware) (see p. 13).

Grog or burned fireclay is a very important non-plastic material (see p. 11).

Engobes and Glazes.

Engobes are materials used to cover clay goods and so hide the material of which the goods are made. Generally they consist of mixtures of clays with flint and Cornish stone or felspar which will burn to the desired colour, and so enable a material to be used which could not otherwise be employed on account of its colour. The word 'body' is sometimes used in this connection, but this is best avoided, and should only be used to denote the material of which the article is chiefly composed. The word 'slip' is also unsatisfactory because some engobes are applied in the form of a jelly (as in the manufacture of some sanitary ware), whereas 'slips' are always fluid.

Although the word 'engobe' may be rightly understood to include many glazes, yet it is most convenient in practice to regard only the unvitrified, or but slightly vitrified, coatings as engobes, and to regard the vitrified ones as glazes.

General Characters of Engobes.—The properties of an engobe must of necessity depend very largely upon the kind of body to which it is to be applied and the temperature at which it is to be fired: thus, a certain mixture may produce an excellent body at a low temperature, whilst, if the article were fired in a porcelain kiln, the same mixture would melt and form an equally excellent glaze. On this account, it is impossible to enter into details as to the compositions of particular engobes and glazes, and the student can refer to the larger works of Bourry, Seger, and others. These books, excellent as they are, generally describe experiments made only under certain conditions and with certain materials, and in our present state of knowledge it is not possible to prepare engobes or glazes suitable for every class of ware without altering their composition to suit the particular conditions existing in different works.

The chief points to bear in mind are that the engobe must adhere as perfectly as possible to the body. If it does not do so, it may be because of its being too refractory, or, on the other hand, because it is too fusible, and so contracts more than the material on which it is placed. In the former case, more fluxing material must be added to the engobe, and in the latter some of the flux must be removed or more refractory material added. It is generally much easier to adjust an engobe than it is to obtain a satisfactory glaze.

It will generally be found that one clay alone cannot be used as a white engobe, owing to its not burning to a sufficient degree of whiteness, especially on a coloured clay. A mixture of white burning clays and flint is, therefore, used with the addition of sufficient flux to enable it to adhere properly to the body. In some works, instead of a single fluxing material, 10 per cent. or more of glaze is added to the engobe clays.

Glazes are also materials used to cover the surface of goods—generally with a view to making the articles impervious to liquids or to dirt, but frequently the chief use of the glaze is to add beauty to the article and to increase its durability. The majority of glazed goods have a glossy appearance, but many glazed ornamental pieces have a dull or matt surface.

It is essential that glazes should adhere well both to the engobes and goods, and that they should resist the action of such changes of temperature as the goods may be reasonably subjected to during use. They must also resist the action of water, and, in special cases, of acids, alkalies, and other corrosive liquids, and also red ink, of which the colouring matter (eosin) is readily absorbed by some glazes. For sanitary goods, the surfaces must also be as smooth as possible to permit of easy and efficient cleaning.

To obtain these characteristics, there must be a certain amount of similarity in composition between the engobe or glaze and the clay body on which it is placed; and, other things equal, the more nearly a glaze approaches to the body in its composition the less likelihood is there of a defective article being produced.

Clays used for engobes approximate more or less to the composition of kaolin—an alumino-silicate with the formula $H_4Al_2Si_2O_9$, corresponding roughly to 40 per cent. of alumina, 46 per cent of silica, and 13 per cent. of water, with small amounts of metallic oxides as impurities. Glazes, on the other hand, are much richer in metallic oxides which form compounds with the alumina and silica having a low melting point compared with that of the clays. Engobes have an intermediate composition, but, provided that they adhere sufficiently well to the goods, their melting point is of less importance than that of the glazes.

In calculating how much of a particular material is to be used in the preparation of an engobe or glaze, it is necessary to pay particular regard to the purity of the material, and not to assume, for instance, that all clays correspond exactly to the formula for kaolin or ball clay. At the same time, it is necessary, in weighing out fritted materials, to remember that these will, in most cases, have lost considerably in weight during the fritting, and that to this extent their original composition will have been changed. Thus, borax, on heating, loses a considerable percentage of water, much in the same way as clays lose it in the kilns.

As already stated, glazes differ from engobes in being more completely vitrified and in having a more or less glossy surface. They may often be prepared by adding suitable fluxing materials to an engobe. The chief matter requiring attention is the durability of the glaze (see 'Defects').

Although lead glazes need contain no alumina, yet in glazes free from lead it seems necessary to have at least 15 per cent. of alumina to bring about effective vitrification of the mixture and to prevent the glaze from crystallizing into a dull, rough mass. Alumina is also of particular value in preventing peeling and other defects which occur when the ratio of bases (RO) to silica is outside the usual limits of 1 : 2·5. As it possesses such a highly refractory power, alumina is often used to raise the melting point of a glaze or to alter its coefficient of expansion, and so prevent crazing. It is seldom, if ever, added in the pure form, but kaolin, or china clay, is generally employed, and a suitable reduction made in the quantity of silica present in the glaze mixture.

Just as the composition of an engobe clay depends on the bulk or body-clay of which the goods are made, so it is not possible to produce one glaze which will suit all varieties of clay. It is in the adaptation of recognized glazes to suit the different classes of bodies used that the skill of the expert shows itself; and even if directions as to the general methods used for determining how these alterations are effected were given here, they would be of little use, owing to the inability of any written instructions to supply the place of practical experience.

The heating necessary for efficient glazing depends to a certain extent on the nature of the atmosphere inside the kilns, and its action on the materials composing the glaze.

The fusibility of a glaze depends upon five chief factors:—

1. The proportion and fineness of the materials.
2. The nature, proportion, and number of metallic oxides other than alumina.
3. The ratio between alumina and silica.
4. The proportion of boric acid.
5. The duration of heating; prolonged heating at a lower temperature frequently producing the same results as a shorter heating at a higher temperature.

No method of calculating the melting point of a glaze from its composition has yet been devised, owing to the fact that glazes have no definite melting point and seldom correspond to any definite chemical compounds. For low temperatures (below 1000° C.), glazes may frequently consist almost entirely of lead and silica in various proportions, but at higher temperatures lead cannot be so efficaciously used, and for many classes of ware its employment is to be discouraged. In such cases the composition of the glazes becomes of great importance, and, according to Seger, this lies within comparatively narrow limits, viz.:—

For white-ware glazes, RO, ·1 to ·4 Al_2O_3, 2·5 to 4·5 SiO_2;
For porcelain glazes, RO, ·5 to 1·25 Al_2O_3, 5 to 12 SiO_2;[1]

RO representing the total number of molecules of metallic oxides taken as unity. Thus, if RO represented ·2 molecule of soda (Na_2O) and ·8 molecule of lime (CaO), the composition of a white-ware glaze should, according to Seger, be between 100 and 400 parts by weight of alumina, and between 1500 and 2700 parts of silica for every 124 parts of soda and 448 parts of lime. Hence, for every 100 parts of soda and lime in the proper proportions, from 17 to 68 parts of alumina and from 253 to 456 parts of silica must be present to make a satisfactory glaze. If these proportions are noticeably

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[1] The use of formulæ by clayworkers differs somewhat from the use of the same symbols by chemists in that the clayworker bases the unit of his formula on a molecule of a hypothetical alkali metal oxide (symbolized by RO), and not on the indivisibility of the atom. Hence, fractions of atoms are quite permissible in formulæ representing the composition of glazes, etc., but are entirely prohibited from the ordinary chemical formulæ.

The symbol RO is understood to mean the sum of all the alkali metal oxide molecules contained in the glaze or engobe or clay divided by the number of such molecules. Hence, a glaze the composition of which might be represented as consisting of 2 molecules of Na_2O, 8 molecules of CaO, 4 molecules of Al_2O_3, and 35 molecules of SiO_2, would be expressed by the formula:

$$\left.\begin{matrix}2Na_2O\\8CaO\end{matrix}\right\}4Al_2O_3,\ 35SiO_2$$

by an orthodox chemist: but a clayworker would divide this formula by the number of molecules of the 'bracketed' metallic oxides it contains, viz. by $2+8=10$, so as to reduce the sum of these oxides to unity, and would write the formula:

$$\left.\begin{matrix}0{\cdot}2Na_2O\\0{\cdot}8CaO\end{matrix}\right\}0{\cdot}4Al_2O_3,\ 3{\cdot}5SiO_2.$$

This method of formula-writing, originally devised by Dr Seger, has many advantages for clayworkers, inasmuch as it renders comparisons of widely differing mixtures comparatively simple.

Further particulars of the various methods used in calculating the formulæ of glazes, etc., will be found in Jackson's *Ceramic Calculations* (see Bibliography).

altered, either the glaze will not fuse at a suitable temperature, or it will devitrify or will not be sufficiently durable for use. Even though it may be necessary to introduce other metallic oxides by replacing all or part of the soda or lime, the total proportion of the molecules must be kept within the limits given, no matter how many kinds of metallic oxides are present or in what proportions they are mixed with each other. As a general rule, however, it will be found that three different oxides will produce a glaze of lower melting point than a similar glaze in which the RO is represented by only two different bases.

Glaze and Engobe Materials.—The materials of which glazes and engobes are chiefly composed, naturally differ somewhat with the different kinds of ware which it is desired to produce. The following are, however, the most important:—

Clays, chiefly kaolin and ball clay, although red-burning clays, are used for some terra-cotta wares.

Lead is usually introduced in the form of red lead, litharge, or white lead (a basic carbonate). Galena or lead ore is sometimes employed. Lead compounds are all liable to adulteration with cheaper minerals, white lead in particular often being fraudulently mixed with barium sulphate, chalk, or plaster. The detection of these impurities requires some analytical skill, and if the materials are not analysed by the works' chemist, they should not be bought without a guarantee from a reliable firm as to their purity. Galena is particularly liable to vary in composition, and as it is a mineral, and not an artificially prepared product, its purity can seldom be guaranteed. In addition to this, the liberation of sulphur fumes on firing prevents its use for any but common goods.

The chief advantages of lead as a flux in glazes are—

1. Simplicity of composition, as flint and lead alone will often make a satisfactory glaze for common ware.
2. Insolubility in water without fritting (see p. 25).
3. Ready combination with other materials forming glazes melting at low temperatures.
4. Slight variations in composition not of great importance.
5. High refractivity, hence, great lustre (unobtainable with any other element, although barium compounds may sometimes be effectively substituted for lead in glazes containing soda and boric acid).
6. Great mobility, with consequent easy attainment of evenly glazed goods, a result much more difficult to obtain with leadless glazes.

On the other hand, lead glazes are not suitable for use at high temperatures, and the legal restrictions placed on their use owing to their poisonous nature renders a thorough study of leadless glazes imperative to the progressive clayworker.

Calcium compounds are usually added in the form of chalk, whiting, or plaster of Paris. Lime itself is seldom used on account of its solubility. As 100 lbs. of chalk, or whiting, are of equal fluxing power to 150 lbs. of plaster, the choice between these materials will depend upon their relative prices, and upon the other constituents of the engobe or glaze. For many purposes, materials containing sulphates should be avoided, and in such cases plaster cannot be used. When glazes of low melting point are required, borate of lime may sometimes be used.

Whiting, *Chalk*, *'Paris White'* ($CaCO_3$) should be practically pure carbonate of lime. Its value to the glazer depends on its freedom from impurities, especially iron compounds and others which produce stains.

When heated alone it is converted into quicklime and is most refractory, but if mixed with silica it is easily fluxed. Whiting is, in fact, one of the cheapest and most satisfactory fluxes known. It must not be confused with 'Paris Plaster' (more correctly 'Plaster of Paris'), which is a sulphate of calcium.

Plaster of Paris ($CaSO_4\frac{1}{2}H_2O$) of superfine quality is used in glazes. The presence of the sulphate radicle in it is objectionable, and it may generally be replaced by three-quarters of its weight of whiting or 'Paris white.' Plaster of Paris is the chief material of which 'moulds' are made. For this purpose its setting power, porosity, and hardness when set are the most essential characteristics. Poor plaster, being soft, wears away rapidly, and not being sufficiently porous, the clay goods must remain for a long time in the mould before they will leave it easily. 'Over-boiled' plaster will not mix into a smooth cream. The addition of various salts—especially sodium carbonate—is often recommended to increase the setting power of the plaster. They should not be used for this purpose, as the moulds thus made deteriorate more rapidly than those in which no salts are used.

Barium oxide (BaO) is valuable as a substitute for lead compounds. Like lead it has a high combining weight, and gives an added lustre to glazes of which it is a constituent. The connection between high combining weight and brilliancy of lustre produced by a material in a glaze has not been definitely proved, but such experiments as have been made for ascertaining this connection all point to its probability. Indeed, the lustre produced by barium compounds in leadless glazes is greater than that produced by any other ingredient.

Barium is usually introduced in the form of barium sulphate (sometimes sold as 'sulphate of barytes,' heavy spar or calk stone, all of which are more or less pure varieties of barium sulphate); but barium carbonate or witherite is frequently employed where it is desired to introduce barium without the simultaneous introduction of a sulphate. Wedgwood was the first to employ barium compounds successfully in pottery, and his famous 'Jasper ware' contains a large proportion of barytes.

Commercial barium compounds often contain iron, and are badly ground. Hence, inferior qualities stain the goods and do not produce a clear glaze.

Alumina (Al_2O_3) may be added in a variety of forms, as it occurs in all clays, in felspar, Cornish stone, bauxite, and in the alums. The manufacturer's choice must depend on the price and on the other constituents of the engobe or glaze, and of the aluminium compounds themselves. Thus, where it is desired to increase the alumina in a material already rich in fluxes, china clay would be used in preference to felspar or stone. If, on the other hand, the substitution of felspar enabled a glaze to be made without fritting, it would be used in preference to a soluble potash salt for the introduction of this constituent of the flux.

Felspar is often the chief constituent of leadless glazes used at high temperatures. Its fusion point is about 1300° C. (2370° F.), but varies according to the nature and purity of the material. The word 'felspar' represents a class of minerals rather than one particular substance, but the term is usually supposed to mean 'orthoclase,' a potassium felspar containing about 16 per cent. of potash, 18 per cent. of alumina, and 65 per cent. of silica. If used in excess it tends to cause the glaze to peel in drying. The commoner varieties are characterized by a high fusing point and, when made into slip and sieved, a large proportion of residue of a sandy nature is left. The slight pink colour of some felspars is due to a trace of iron which, as a rule, may be ignored, although the creamy varieties are to be preferred.

Cornish stone, sometimes known as china stone, pegmatite, and by a variety of other names, is less fusible than felspar, but more so than china clay, and possesses other characters intermediate between these two substances. It differs from felspar in containing only about 6 per cent. of potash. It is one of the most variable substances employed by the clayworker, and great care is required in its selection. The best qualities resemble felspar, but are not so liable to shell off from the goods during the drying. Cornish stone fused and kept at a little above its melting point may be used as a rough glaze, but to make it flow well requires the addition of a flux of the RO class. It is, however, seldom used alone as a flux, glazes containing it usually containing felspar as well, it being an advantage to have a substance present in all glazes which shall possess a relatively low fusing point, so that it may, on fusing, bring about a more intimate mixture and combination of the glaze materials than is otherwise possible.

Both felspar and Cornish stone are often used in engobes with a view to increasing the adhesive power of the latter to the goods during and after firing.

Soda (Na_2O) and *Potash* (K_2O), as already suggested, should be added in the form of insoluble compounds when possible, so that fritting may be avoided. For this purpose, a sodium or potassium felspar is used. When this cannot be done, the sodium is commonly introduced as sodium carbonate, or as borax, less frequently as salt or soda cake, and the potassium as nitre or saltpetre, each of these substances being fritted (p. 25).

Silica (SiO_2), like alumina, generally enters into the composition of several of the constituents of engobes and glazes. When required to be added, a leaner clay may often be substituted for a more plastic one, or a pure sand, ground quartz, or flint may be used.

Imported (French) flints are usually preferred to British ones; this is partly due to prejudice, and partly to the greater skill exercised in selecting and calcining French flints. The contention that British flints contain too much chalk and other impurities is not supported by analysis.

Boric acid (B_2O_3) is always added in the form of crystalline boric acid when required alone; as borate of lime, or as *borax* (borate of soda), when required in conjunction with alkalies. Boric acid possesses the property of lowering the melting point of a glaze in which it has been substituted for part of the silica without seriously altering the coefficient of expansion of the glaze. Thus, by replacing a portion of the silica in a glaze by boric acid, the melting point is lowered without the glaze crazing or running as badly as it would if the proportion of alkalies had been increased. At the same time, as most of the commercial compounds of boron are soluble in water, it is necessary to frit them with some of the other glaze materials before use.

Special materials are used for the preparation of coloured ware. Of these the oxides of *iron* (for brown), *copper* (for green or blue), *chromium* (for green or yellow or red), *cobalt* (for blue), *manganese* (for brown or violet), and *uranium* (for yellow) are the most important. The precious metals—*gold*, *silver*, and *platinum*—are also used to obtain lustre and metallic effects, the first-named being especially valuable also for conferring brilliant shades of red, although copper is sometimes used for this purpose.

Oxide of tin, either pure or mixed, in the form of *tin ash*, with lead oxide, is often used to produce opaque white glazes. Its use is, however, limited to moderately low temperatures; at high temperatures it acts as a flux. Tin compounds were formerly used extensively on the Continent, notably in the Delft ware of Holland ; their use is increasing in Great Britain.

Zirconia is sometimes a convenient substitute for tin oxide.

Zinc oxide is also used to render glazes opaque. It is particularly useful in the application of a colourless glaze to a body liable to slight discoloration At higher temperatures (if not in excess) it is a useful, although a somewhat expensive, flux.

Bone ash is used in the preparation of certain classes of china ware to impart translucency.

Fluorspar and *cryolite*, with other compounds of fluorine, find occasional employment as fluxes for highly siliceous materials. Other metallic oxides, such as bismuth oxide, antimony oxide, and arsenious acid, are added to glazes for special purposes, such as producing opacity at a relatively low temperature.

Preparation of Glazes and Engobes.—The preparation of engobes and glazes has hitherto been almost entirely confined to rule-of-thumb practice, with the result that many recipes refer to the use of materials the composition of which it is difficult to ascertain. Consequently it may happen that two almost identical mixtures may be thought to be quite different because one or more of their constituents are referred to under different names ; thus 'tincal' may appear in one recipe and borax in another without the clay-worker being aware that they are practically identical, tincal being simply crude borax. It is probable that the frequent use of plaster of Paris in the same glaze as whiting is due to a similar ignorance of the chemical composition of the materials employed and the reasons for adding them to the glaze or engobe. Glazes and engobes are prepared in at least two different ways, according as the materials used are 'raw' or 'fritted.' Engobes, in the limited sense of the word referred to on p. 17, are seldom or never fritted, except for special work, but the soluble portion of all glazes containing borax, soda, potash, or other soluble substances should be mixed with some or all of the remaining ingredients and fritted before use in order to render the whole of the glaze material insoluble.

For raw glazes and engobes, the materials in the form of sufficiently fine powders are weighed out, preferably in zinc scoops or in wooden boxes, according to the weight of glaze to be prepared, great care being taken to prevent mistakes in the quantities weighed out, as this would entirely spoil the glaze or engobe. It is, on this account, best to forbid the presence of any person other than those actually engaged in the weighing whilst this operation is going on. Sometimes the materials are only partially ground before being weighed, the final reduction to powder being carried out in an Alsing cylinder, a kind of barrel lined with glazed tiles and revolved either by hand or by machinery. When the materials are put into this barrel a number of balls of hard porcelain or flint pebbles are introduced at the same time. The balls are about three inches in diameter, and sufficient should be added to fill the cylinder to about a quarter of its capacity. Opinions differ as to the best sizes of balls and proportions of water to be added to the contents of the grinding cylinder ; as a general rule, about one gallon of water to every ten pounds of glaze or engobe material will be found convenient when the mill is rotated at a speed of twenty to thirty revolutions per minute.

Engobes and glazes containing clay are often difficult to grind owing to the clogging action of the clay preventing the grinding of the other materials. It is, therefore, best to buy the other materials ready ground, or only to add the clay towards the close of the grinding.

Some clayworkers add a little vinegar or acid to granulate the clay, but this requires great care, and is not to be generally recommended. For many classes of work it is sufficient to rub the materials between the hands with water until a cream is formed (but this is not practicable when more than about forty gallons are required per week), or a blunger may be used instead of a grinding mill.

The grinding must be continued until at least 95 per cent. of the material can be washed through the lawns or sieves, as otherwise the glaze will probably not have the desired uniformity or homogeneity of composition owing to some of the harder constituents not being sufficiently finely ground. The stones of the mills and the porcelain, or stoneware, linings of the cylinders need to be frequently examined, or the time required for the grinding will be materially lengthened.

When the materials have been ground so fine that on rubbing between the finger and thumb no trace of grit can be felt, the liquid may be passed through a sieve or lawn in order to separate the coarser particles. The fineness of the sieve will depend upon the nature of the glaze or engobe and upon that of the articles to be covered; thus, for ordinary sanitary ware, using commercial waterground materials of good quality, a sieve of 60 meshes per linear inch (No. 60) will be sufficiently fine, but in testing materials for high-class china a sieve with 200 meshes may be necessary. Colours generally require a finer sieve than the corresponding plain glazes, as, if the colouring materials are insufficiently ground, they will fall too readily to the bottom of the glazing tub and the goods will be too light in colour.

The fineness of the sieve through which the glaze slip should be passed is to some extent a matter of individual choice at the present time, as different workers vary considerably in the fineness which they consider necessary. Excessively fine grinding should be avoided as being unnecessarily costly, but the material must be so well ground and so intimately mixed that its composition is as uniform as possible. A sieve with 30 meshes per linear inch is only suitable for relatively rough work, but it is seldom necessary to use one with more than 150 meshes to the linear inch. Between these limits the particular size of mesh must depend on the nature of the materials used and the work to be done; sieves with 60, 80, 100, and 120 meshes per linear inch are in frequent use and are well adapted for most glazes.[1]

As the sieves used for straining out the coarser particles of glaze are very fine in most cases, it is necessary to have plenty of water mixed with the material in order that it may pass through the sieve rapidly, its passage being facilitated by gently rubbing the surface of the sieve with a soft brush—a hard one should on no account be used with a fine sieve, or the latter will be damaged. If too much water is used in sieving the glaze slip, it may easily be removed, provided that the slip contains no soluble constituents, by allowing it to stand and then decanting the supernatant water.

Although, at one time, sieves for glazes were almost exclusively made of silk or similar material, the use of phosphor-bronze is rapidly on the increase; it is harder than brass or copper, and is, therefore, not only more durable and less likely to contaminate the slip with particles of metal, but it is

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[1] Some particulars of the meshes and sizes are given on p. 85.

capable of being woven into sieves of ample fineness for most of the potter's needs.

The sieved material is received into blungers or tubs (p. 81), and may be passed through a trough containing magnets in order to remove any particles of iron in it; it is then run into the storage vat. It is always advisable to keep a stock of glaze and engobe, so that it may be tested before it is used and any error in its composition detected before any articles of value have been covered with it. Most glazes and engobes improve on prolonged storing, which increases their covering power.

Impurities, especially iron, are often introduced into the slips during the grinding, and must, when possible, be removed. The fine particles of iron may be withdrawn by allowing the glaze slip to flow past magnets or by agitating the slip with a frame to which magnets are attached as stirrers. These require to be cleaned at intervals.

It is becoming more and more common to purchase the raw materials for glazes for the simpler kinds of ware in a ground condition; where no fritting is needed this is a great convenience, particularly for the smaller works.

Frits.—As already stated, the main object of fritting is to render the water-soluble constituents of a glaze insoluble, and in this manner to facilitate the uniformity of composition of the material when it dries on the goods. It is seldom necessary or desirable to vitrify all the constituents of a glaze in the frit-kiln, as such a proceeding would be a waste of time and fuel. It is, therefore, usual to mix the soluble substances with so much of the flint or other siliceous material of the glaze as shall produce a mass fusible at a comparatively low temperature, and yet not soluble to any appreciable extent in water.

Substances which are much denser than the main constituents of the glaze or engobe may be mixed more completely if fritted with some relatively light constituents; this is especially important when a very small proportion of a very dense material is to be evenly distributed throughout the mass.

It is not always necessary actually to melt the materials together in order to render them insoluble; in many cases raising the temperature of the mixture to a dull red heat is sufficient. It is not necessary to have the materials to be fritted very finely powdered, but they must be as thoroughly mixed as possible, and the heating must be uniform throughout the mass. In the case of lead frits, care must be taken that the atmosphere is not reducing, or metallic lead may be formed. Although fritting is sufficient in most cases—indeed, overheating will often do more harm than good,—complete fusion of the material is necessary when a perfect mixture is required.

In the case of glazes rich in lead and used for domestic ware, another object of fritting is to render the glaze insoluble in the gastric juice and in weak acids; for this purpose the relative proportions of silica and base in the glaze are of great importance. In such cases, the greatest care must be taken to avoid a reducing atmosphere in the kiln, or lead will be volatilized and the ratio of this element to the silica upset. A further object in fritting is to render some poisonous lead compounds innocuous to the operatives.

As lead mono- and bi-silicates exercise a searching and corrosive action on brickwork, the time of fritting should be made as short as possible, and the joints of the furnace should not be wider than is absolutely necessary. Smooth firebricks are less rapidly attacked than rougher ones. Flint mixed with water is often used instead of fireclay mortar for building frit-kilns, as it has less contractibility. When once the necessary temperature has been obtained in a frit-kiln, it is best to continue it night and day until a sufficient quantity of frit to last for several months has been obtained, as the chief cost of the firing comes from the preliminary heating of the kiln.

The molten or semi-molten frit is run into a tank of water and the resulting rough powder is ground to impalpable fineness either between horizontal stones or in an Alsing cylinder; it is then sieved through a suitable lawn or sieve of at least 120 meshes per linear inch and dried or made up into a slip of definite density, usually 28 oz. per pint.

For use, the prepared frit is mixed with the other materials of the glaze, blunged up thoroughly and sieved repeatedly until quite free from coarse particles and thoroughly homogeneous.

The composition of frits varies so greatly according to the purposes for which the corresponding glazes are to be used that it is not possible to give recipes here. These may be found in the special works dealing with this subject, though most workers have their own recipes, which they have found to be suitable to their own particular class of clay and work.

Two points require special attention in fritting, viz.: (1) cleanliness, and (2) fineness.

It is so easy to allow dirt of all kinds to get into the frit in the various stages of its manufacture, as, for instance, when it does not run easily from the plug-hole in the side of the kiln and has to be helped out with iron pokers, with the almost certain result of contamination by iron compounds or by leaving it uncovered for all sorts of dirt and dust to blow into it, to say nothing of the dirt introduced by the use of mills and other apparatus which have not been properly cleaned.

The fineness of the frit also demands constant attention, as, if improperly ground, the coarser particles will be removed during the sieving and the proportion of frit and other materials in the glaze will be spoiled. The most suitable size of mesh depends on the class of work to be done; for coarser work a No. 120 sieve will do, but flannel is necessary for some work and the finest lawn for other goods. Under such circumstances each worker must ascertain the kind of sieve most suitable for his purpose, choosing one too fine rather than one too coarse. Yet the other extreme must not be reached, as an excessively fine frit may cause the glaze to run up from the edges of the goods as though they had been oiled.

The shape of the kiln in which the fritting is carried out depends largely on the amount of material to be fused; for moderate amounts, a large crucible with a hole in the bottom is mounted on bricks over a tank of water and heated by a furnace built round it in such a way that the material melts and runs into the tank, more being added to the crucible to replace that which has been melted until a sufficient quantity has been prepared. A commoner way is to place the material in a sagger in the kiln along with ordinary goods, and to remove it on discharging the kiln and to break away the sagger from the solid frit. This is but a crude method and wasteful of the frit, as the portions adhering to the sagger cannot be separated from the latter. Where larger quantities are needed, a proper frit-kiln with a hearth somewhat like a reverberatory furnace used for puddling iron must be used. When the frit has been sufficiently heated, a plug is removed from near the bottom of the hearth and the fluid frit is run into a pit or tank of water, the object being to granulate the frit by the sudden cooling.

Colours.—The methods of preparing the various colours are to a large extent regarded as 'trade secrets,' and though many recipes have been published from time to time, it will generally be found that either the proportions given are not quite correct, the method of preparation is insufficiently described, or some other point (often too subtle to be capable of being stated in black and white) as well as the lack of skill in manipulation, combine to prevent these recipes from being anything like as valuable as those having the sale of them would lead one to suppose.

When only moderate quantities of colour are required, it is generally best to purchase them from a reliable dealer in potters' materials rather than to attempt the difficult task of preparing them from the raw materials. The commercial oxides of copper, cobalt, iron, etc., which have not been specially prepared for clayworkers' use are seldom of value, as they require so much additional grinding and other treatment before they can be used in engobes or glazes. It is, therefore, very important to deal only with thoroughly reliable firms who are engaged in this special branch of the chemical trade (and even then not to buy the cheapest grades of colour) so as to obtain materials of a constant composition, as otherwise the clayworker will have the annoyance of finding that his colours vary so much in the different batches as to render it impossible for him to complete sets of decorated ware.

It is always desirable to try a small portion of the colour on some test-pieces of ware before the main quantity is mixed up for use, as the dealers limit their responsibility to replacing the colour by another sample in case of error, and refuse to take any share in the loss sustained by the clayworker if a batch of goods is found to be spoiled owing to any defect in their preparation of the colour.

It is also wise to buy as large a quantity as possible of any colour of importance and to mix it well before any is weighed out for use. In this way, variations which would result from buying small quantities from the dealer at different times will be avoided. This is particularly the case with some of the more expensive colours, such as gold and cobalt.

Faience *v.* Majolica.—There is, unfortunately, much looseness in the way in which these terms are used in describing coloured ware; and it is desirable to define them somewhat more clearly before describing the various methods of colouring glazed ware.

True Italian majolica is made of a crude body which does not burn white; it is covered with an enamel or opaque glaze,[1] often white, but frequently coloured. Sometimes this enamel is, again, covered with a soft, coloured glaze.

Faience does not admit of quite so clear a definition as majolica, as the early varieties of faience ware are identical with majolica of a similar date. It is, therefore, wise to follow the suggestion of S. G. Burt to the American Ceramic Society, and define faience as "pottery in which a clay body is covered with a transparent glaze."

Some goods may fall into either of these classes according to the custom of the manufacturer; thus a white-glazed brick may be either 'majolica' or

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[1] The term enamel has several meanings, which often lead to confusion. In the heavy branches of clayworking it is chiefly applied to opaque glazes, but in the earthenware and china branches it is applied to fusible overglaze colours (which are usually fired at relatively low temperatures); it is not a matter of colour, as both glazes and enamels may be of any colour as far as the name is concerned, though the application of certain colouring materials to a glaze may result in an opaque (*i.e.* a non-transparent) glaze being formed; this coloured glaze is then, strictly speaking, an enamel, and no longer a glaze. In those glazes which are partially transparent some exercise of discretion is necessary in deciding their nomenclature.

'faience' according as it is covered with a white enamel (majolica) or slipped with a white clay and then glazed with a transparent glaze (faience).

Faience may, therefore, stand for underglaze decoration when the ware is painted in order to decorate it, and for the main ground, if for the decorative effect a majolica overglaze colouring is employed.

Stained Glazes.—The simplest of all methods of producing coloured ware is the application of a glaze to which has been added a proportion of 'stain' or colouring matter, bought ready for use, the application being by 'dipping' or covering the desired portions of the article with the stained glaze by means of a brush. As the glaze melts in the kiln the colour flows more or less according to the particular shape of the article, and some portions are in this way coloured darker than others, a pretty effect being thus produced without the necessity of any skill on the worker's part. Coloured bricks and a large variety of vases, etc., are produced in this way. Once the correct composition of the stain and glaze have been ascertained (as already explained, the latter will depend on the composition of the clay, the method of firing, etc.), and the best method of placing the goods in the kiln so as to get the most decorative effects from the flowing colour, no further difficulties are met with, provided the materials used are of constant composition and the firing is properly carried out.

The stained glaze may be applied either to the green or to the fired clay (biscuit) with equal success, provided the goods are sufficiently strong to withstand the absorption of water from the glaze slip when they are dipped. For this reason, all thin-walled articles are best glazed after they have passed through the biscuit kiln, though some prettier effects are often obtained when the dipping is done previous to firing.

It is essential that the glaze slip be kept thoroughly well mixed during the dipping; if this is not done the colour will settle to the bottom of the vat and uneven colouring will result.

Stained glazes may be equally well used on articles which have been covered with a white or coloured engobe. In the case of many varieties of coloured bricks the natural colour of the body-clay is so strong as to spoil the purity of the colour of the glaze. In such cases, the bricks are first covered with a white engobe (p. 17) and are then glazed as usual.

When a glaze is 'stained' with tin oxide, or other materials which make it opaque, it becomes an enamel, the object of enamels being to hide the colour of the body of which the goods are made (p. 27, at foot).

Underglaze.—Underglaze decoration may be applied direct to the body or to an engobe. Underglaze colours are matt or dull after firing, and to render them glossy they must be covered with a transparent glaze. The colour may be applied either by a brush (painting), by dipping the articles into a stained engobe (*i.e.* an engobe slip to which a suitable proportion of colouring material has been added), by spraying or by printing.

Underglaze painting is the most expensive of the four methods mentioned, because the colours do not 'show' properly until after firing, so that considerable skill is required in their application, especially in flower or landscape work. For some classes of earthenware, however, hand-work is cheaper than printing, especially in what is known as 'sponge-work,' where pieces of very closegrained sponge, cut to a desired pattern, are used after the manner of india-rubber stamps for printing the pattern on the goods. Needless to say, this class of decoration is only applied to the cheapest articles—common basins, jugs, etc.

The colours used for underglaze work are practically the same, however they are applied, and their number is somewhat limited owing to the high temperature they must withstand when the glaze is fired over them. They must be very finely ground, usually with hard glass or porcelain mullers on glass or porcelain slabs framed in wood. The most usual medium is turpentine, but weak gelatin or gum-arabic solutions are sometimes used. Too much of these latter ingredients causes the glaze and colour to chip off when the goods have been stored a short time. Palette knives are used to remove the colour from the slabs. These are of bone, horn, or steel, though the latter are risky to use, as they are so liable to introduce iron (causing a brown stain) into the colours. The author has used a palette knife of xylonite for some time with considerable success; it is quite as strong and durable as horn and far more flexible.

Whilst underglaze decoration is far more durable than any other kind of painted pottery, there is so much difficulty in painting delicate shades accurately that this method is but seldom used, except for repetition work where the artistic skill required is not very great, and where, by means of printing, etc., the decorator can be given many helps not possible where the best class of artists are employed. Painting has, in fact, been largely replaced by chromo-lithographic printing.

Spraying consists in applying the colour in the form of a fine spray or 'mist' by means of an aerograph or other atomizing device and compressed air.

Printing underglaze is really a process of 'transferring,' the design being first printed by machinery on suitable tissue paper and then transferred to the article to be decorated. The printer's oil, or medium, with which the colours are mixed must be kept hot during the printing of the papers; this is accomplished by the use of tables heated by live steam. The printer's oil, itself, may be bought ready for use, but most printers prefer to use an oil made by themselves. Although much secrecy is maintained as to the composition of these oils, all those examined by the author have had a mixture of boiled linseed oil and tar as their basis.

A good recipe is the following (see also p. 43B):—

"Boil one gallon of linseed oil with one ounce of red lead for about two hours, taking off what scum may form either with a ladle or by burning it. Add one ounce of rosin and thirty ounces of Stockholm tar, and, after scumming twice more, allow to cool, stirring well all through the heating until the oil has become almost cold."

Properly prepared printer's oil should go 'tacky' almost immediately after it has been dropped on a piece of unglazed ware.

The colour is carefully ground into this oil in a proportion usually decided by the printer himself, depending, to a large extent, on the thickness with which he coats his plates and the relative strength of the colour he is using.

Copper plates are used to form the design. Iron ones cannot well be employed, for obvious reasons, and zinc plates are too soft to wear well. Great care is required in using the knives in spreading the colour on these plates, or they will soon be so damaged with cuts and marks as to be useless. The colour is spread evenly over the engraved plate with the knife; any excess is then cleaned off, first with the knife and then with a small corduroy cushion, which leaves the unengraved portions of the plate quite clean. Some printers use a small wooden muller to rub the colour well into the finer lines of the plate before cleaning.

Over the plate thus prepared is laid a sheet of strong tissue paper which has been previously 'sized' in a mixture of one pound of soft soap in a gallon of water. (If the water is very hard a little soda may be added to soften it and make the soap dissolve more completely.) The paper is used wet. The plate and paper are next placed in the printing press and the impression of the design thus transferred to the paper, which is then ready for use as a 'transfer.' Transfers are also sold ready for use.

'Transfers' are first cut roughly into shape so as to enable them to be handled more easily than when a considerable amount of unprinted paper surrounds the design. As the paper which is cut off at this stage is wasted, it is important that the printer be supplied with paper of the correct size in order to avoid a serious waste.

The designs are applied to the ware with the printed face to the clay, the paper side being gently rubbed with a small piece of flannel smeared with soft soap, so as to rub the colour well into all the flutes and cavities in the ware. Sometimes a stiff brush is also used for this purpose. At the close of the day, or first thing the next morning, the paper is washed off the ware with a sponge and cold water, both of which must be clean.

All articles decorated with underglaze colours must be heated in a kiln before any further treatment is possible, as it is necessary that the oil or medium should be removed before the article is glazed. The kilns used for this purpose (usually termed 'hardening-on kilns') are simply heated to a dull red tint, until all the greasy matter has been burned off the goods. These kilns require no particular skill in firing, but the setting of the goods, and particularly their removal, requires great care or the powdered colour will be rubbed off and the goods smudged. The smudges may to a large extent be removed with pumice-stone, but, with dark colours especially, it is exceedingly difficult to remove the last traces.

As considerable quantities of gases are produced by the combustion of the oils and by the evaporation of the water when gums are used, the hardening-on kiln should have plenty of vents.

If the heating in this kiln has been properly carried out, the colours will be dull and matt; if insufficiently heated, they will be glossy, and when they come out of the glost kiln these parts will be unglazed or blistered.

Overglaze.—When delicate shades are required, particularly certain reds, it is necessary to regulate very accurately the temperature at which they are fired. This temperature is in most cases far lower than that of a serviceable glaze, and consequently the goods are finished throughout before the decoration with these shades is attempted. Hence, they must be applied *over* the ordinary glaze, and the colours must have a sufficiently low melting point to form a kind of glass or glaze at an extremely low temperature. Overglaze work is also frequently used in patching defective underglaze ware.

The usual temperatures at which overglaze colours are fired are—

	Seger Cone.	°C.	°F.
Lustre ware, . .	022 to 015*a*	590 to 800	1094 to 1472
Soft-fired overglaze, .	014*a*	815	1500
Hard-fired overglaze, .	08*a*	940	1724

These figures are only approximate.

As the temperature at which overglazed ware is fired is so low, the colours used are of almost innumerable variety, but, of course, no aniline or coal-tar colours can be used, as they, like the vegetable dyes, are burnt out at this temperature.

Overglaze colours are mixed with a glaze of sufficiently low melting point to enable them to run to a smooth glass, these fluxes being of various compositions, according to the ingredients of which the colour is composed. They are, necessarily, almost always fritted, owing to the large proportion of borax they contain. One of the best known is the famous 'One-two-three frit,' composed of—

Flint,	1 part.
Borax,	2 parts.
Red lead,	3 parts.

These materials are mixed well, fritted, and ground extremely fine in a ball mill or on colour-pans. The proportion of colour to frit varies with the shade desired and the nature of the colour itself. If too much flux is used, it may be necessary to paint on so thickly that the colour will run unpleasantly. Conversely, if too little flux is used the colour will be matt and often too dark.

Overglaze printing is carried out similarly to that for underglaze, but up to the present it has hardly been so satisfactory, though some firms obtain excellent results.

Overglaze painting is also similar to that under the glaze, but the change in colour of the work in passing through the kiln is much less, and the possibility of obtaining a much larger variety of shades is so much greater, that for purely artistic work overglaze painting is preferred. It is not, however, so durable as underglaze work, and the decoration wears off in use.

In overglaze painting, the medium used is not ordinary turpentine itself, but an oil obtained by the evaporation of turpentine at low temperatures—known as 'fat oil.' It is more greasy and adhesive than turpentine, and is somewhat pleasanter to use.

Gilding.—Gilding may be effected in several ways, each of which has its own special recommendations. Some workers rub gold leaf up with medium (oil or gum-water) into a 'paint,' and apply it with a brush. They thus treat the gold leaf as an ordinary colour. After firing, the gold thus produced must be polished with an agate style; it is, therefore, somewhat expensive as a method of decoration, but lasts for an indefinitely long time.

The more modern practice is to use a 'liquid gold' which is glossy when it is drawn from the kiln, owing, probably, to the particles being in a much finer state of division. If it should be dull, it may be polished by gently rubbing with a non-gritty powder, such as levigated chalk or fine whiting; but the coating is not thick enough to allow of its being polished by rubbing with a stone.

'Liquid gold' is sold by the dealers in potters' chemicals at prices generally quite out of proportion to the amount of gold it contains; but the liquid is so troublesome to prepare that it is generally better to buy it than for the clayworker to prepare it for himself.

The composition of these liquids is not, of course, public knowledge, but a good liquid gold may be prepared by adding 11 grains of pure tin to 1 ounce of gold dissolved in half a pint of aqua regia. Twenty grains of butter of antimony should then be added and warmed until of 1·800 specific gravity. It is then diluted with water till of specific gravity 1·090, and 2 ounces of a 50 per cent. solution of sulphur in turpentine (technically known as 'Balsam of Sulphur') is then added, and the mixture heated, with continuous stirring, to 180° F. The thick liquid is allowed to cool completely, and is then mixed with five or six times its measure of hot water, so as to wash out the impurities somewhat; the mass is then dried on cloths as much as possible, mixed with twice its weight of turpentine, and warmed for several hours. After standing for a whole day and night, it is poured on to 2 ounces of powdered bismuth spread over the bottom of an empty photo dish, and kept at 212° F. for three hours, after which the liquid may be poured off and preserved as 'liquid gold.' The liquid should be tested, and if too dull when taken out of the kiln, the treatment with bismuth may be repeated.

When it is remembered that gold costs something over £3 per ounce, the cost of failure to make the 'liquid gold' successfully is very great, and the chance of the amateur, who has had no training in chemical manipulation, making the liquid correctly at the first attempt is extremely remote.

Gold is usually applied over glaze, but in some cases it is possible to use it under glaze provided that the gold is burnished, painted with ground-laying oil, and the powdered glaze dusted on and burned at a temperature rather lower than that used for gilding. A suitable glaze is made by fritting together 9 parts red lead, 6 parts fused borax, and 2 parts flint glass. To the cold frit 1 part of saltpetre is added and the mixture ground.

Water and Water-Supply.

The nature of the water-supply to most clayworks is a matter which has, up to the present, received but scant attention, with the result that much money is often wasted. This is especially the case where the town water-supply is used, as water may often be quite suitable for domestic use and general town purposes and yet quite undesirable from a clayworker's point of view. On the other hand, a water-supply liable to be slightly contaminated with sewage is quite unsuitable for domestic purposes, yet it may often be used in the clayworks without any deleterious results to the goods. A knowledge of the actual and probable impurities in the water-supply is, therefore, of great importance.

It is not in the water used directly in the manufacture of the goods that the absence of certain impurities is necessary, though in works on the banks of tidal rivers, or in the vicinity of salt and other soluble minerals, care must be taken that the water does not cause efflorescence, or scum, on the unglazed goods. The chief source of loss and waste is in connection with the boilers when unsuitable waters are used for steam raising.

In considering the results of an analysis of river- or brook water, it must be borne in mind that large variations in composition are possible—according to the amount of water flowing at the time the sample was taken, the season of the year, and other natural causes,—so that to secure the maximum of efficiency the water should be tested periodically. It is also necessary to remember that the impurities are almost always invisible owing to their being dissolved in the water, so that a change in composition cannot be detected by mere inspection.

Visible impurities in the water, such as mineral matter in the form of sand or detritus, should be removed by means of a strainer attached to the supply pipe, and this strainer should be examined frequently to see that it is not blocked up or broken. Small pieces of vegetable and other suspended organic matter may be removed by the same means, if present in sufficient quantities to interfere with the use of the water.

Oil of all kinds—either from the machinery or condensed steam—is very objectionable in water used for clayworking, as it spoils the clay with which it comes in contact, and in a boiler may cause overheating and explosion. Mineral oils are less harmful in a boiler than are vegetable oils, and in some boilers they prevent the formation of scale.

The **best water** for clayworking is rain-water which has been filtered. Moorland water is almost as good, but liable to be acid and to corrode boilers.

Chalybeate Waters (which contain iron), and those which yield a deposit on standing, should be allowed to remain in settling-tanks for some time before use; such waters are, however, best avoided, as the iron may not be completely removed by any practicable process of purification, and if left in it will inevitably spoil the appearance of high-class ware, and even with bricks it may cause an unpleasant discoloration.

Saline Waters should be avoided, as they cause the formation of an unpleasant scum on unglazed goods. If this is due to sulphate in the water, it may often be prevented by mixing the water, previous to use, with a solution of baryta or barium hydrate, which forms an insoluble sulphate. This may be allowed to settle and only the clear water added to the clay. Scum formed by soluble chlorides, such as common salt, cannot be removed, as there is no substance capable of forming an insoluble chloride which is cheap enough to use. Hence, sea-water or water containing a notable proportion of salts must not be used in clayworking, unless the temperature to which the goods are heated is sufficient to cause these salts to combine with silica and become insoluble.

Waters containing sulphate of soda or very light particles of finely precipitated lime and magnesia are apt to cause frothing and 'priming' in boilers. The sulphate may be removed before running the water into the boiler by the addition of baryta solution and by allowing the deposit to settle.

Finely precipitated carbonates may form a scum on the surface of the steam-bubbles and be projected by the latter as a froth, which can only be prevented by softening the water before it enters the boiler.

Hard Waters are those with which difficulty is experienced in forming a lather when using soap. This is due to the water containing carbonates of calcium and magnesium, or sulphates of these metals. Occasionally other difficultly-soluble carbonates and sulphates are present, but, in the main, hardness may be considered as due to the presence of chalk, gypsum, and magnesium compounds.

According as the hardness of the water is or is not removed by boiling, it is termed 'temporary' or 'permanent' hardness. Waters with only temporary hardness contain only the carbonates of magnesium and calcium (chalk), which are kept in solution by carbonic acid dissolved in the water; as this carbonic acid is removed on heating, the carbonates are precipitated. Any substance which, when added to the water, will combine with this carbonic acid will cause the precipitation of the carbonates. Such substances are usually alkalies—lime, caustic soda, and baryta being the most frequently used. Of these, lime, on account of its low price, is the most generally adopted, but for special waters combinations of the different alkalies are employed. The chemical is generally added in the form of a 'milk' made by mixing it with water and adding an appropriate quantity of this 'solution' to the water to be treated, stirring up thoroughly, and allowing the deposited carbonates to settle. In order to determine whether a sufficient quantity of the alkali has been added, the water, after settling, should be tested by holding a piece of filter paper previously soaked in phenolphthalein solution in it; if the reaction is complete, the paper will be coloured reddish pink.

Waters which are 'permanently hard' are those which contain the sulphates of calcium or magnesium and similar salts. These may generally be removed by the addition of a soluble carbonate, such as soda or pearl-ash, which forms an insoluble carbonate with calcium and magnesium, and a soluble sulphate of soda or potash. The insoluble matter is removed by means of settling-tanks, but the sulphates remain in the water and necessitate the water being removed from the boiler at frequent intervals. These sulphates tend to cause frothing and priming in the pipes, but they may be removed by substituting baryta for the soda or pearl-ash, as mentioned above. The baryta simultaneously forms an insoluble sulphate, and sets free an equivalent amount of free lime, which helps to remove any temporary hardness in the water, so that in practice the use of baryta does not prove so expensive as might appear at first sight. The water may be tested by filtering a little of it and adding a few drops of sulphuric acid, which will show a turbidity if a sufficiency of baryta has been added to precipitate the sulphates.

Many 'patent' materials for softening water have at one time or another been placed on the market. Some of these are claimed to work inside the boiler itself, but in regard to them it should always be remembered that the boiler is a water-heater and not a purifier, that all the heat put into the sludge or deposit, however produced, is lost as far as steam production is concerned, and that it is, therefore, far better to instal two settling-tanks, one to supply the boiler whilst the other is 'settling'; various patterns of these are on the market. If the amount of deposit is small, the water may be filtered through sand, but in the majority of cases where this is possible the water is scarcely worth softening. Some form of filter is, however, frequently used after the water has been allowed to settle the greater part of its deposit, as in this way smaller settling-tanks can be employed.

The majority of the patent 'purifiers' to be met with consist of caustic soda and waste vegetable matter, such as spent tan; they undoubtedly have their uses, but the prices at which most of them are offered are quite out of proportion to the cost of the materials of which they are composed. The author once analysed a highly recommended purifier of this class, and found it to consist of caustic soda to which a few grains of potassium permanganate had been added so as to colour the water to be purified; this interesting substance was offered at precisely ten times its market value as a mixture.

Some clayworkers are in the habit of using 'anti-crustators,' which are placed in the boiler once a month (or once a quarter) quite independently of the amount of variation in the quantity of water used or of its composition. Such treatment is analogous to patronizing the quack doctor who has one cure for all diseases, and to the case of a man who, taking a good meal at the beginning of the month, would not expect to eat again for four or five weeks! The specious argument that the water will only take up just as much of the purifier as it actually requires will be found, on careful examination, to be false both in theory and practice.

The characteristics of a good purifying plant are:—

1. Small cost of working.
2. Ease of handling and simplicity of construction.
3. Rapidity of action.
4. Purity of 'softened' water.

Particulars regarding the transmission of water by pumps, etc., and rates of flow through pipes, will be found in the Appendix.

Further information as to the removal of boiler-scale will be found under 'Boilers' (Chap. III.).

Fuel.[1]

The most important fuels for the clayworker are wood, coal, coke, oil, and gas. Of these, the second is by far the most commonly used. All these materials vary greatly in composition, so that if the maximum efficiency is to be obtained, continual watchfulness must be observed and frequent analyses of the fuel and of its combustion products made. The relative values in ordinary brick kilns are equal, if these fuels can be obtained at the following prices:—

Wood at 10s. 0d. per cord of 3250 lbs.
Coal „ 10s. 0d. „ ton.
Gas „ 5d. „ 1000 cubic feet.
Oil „ 1s. 3d. „ barrel.

Wood, at one time the principal fuel for the potter, is now only used in those cases where it is absolutely necessary to avoid any chance of the goods being spoiled by the sulphur which is always present in coal. Soft woods giving long flames, such as fir, pine, and larch, are preferred for biscuiting, whilst such woods as birch or beech are employed for the glazing, as they produce a more intense heat. Wood cannot well be used for intense heats, however, on account of the large proportion of water it contains. Although different varieties of wood burn in very different ways, the total calorific power of all is practically the same, viz. 6000 B.T.U. per pound of thoroughly air-dried wood. Oak, beech, hickory, and maple are usually more economical than coal when the same price is paid for a cord of wood (about 3250 lbs.) as for a ton of coal, but pine and other soft woods are seldom as cheap as coal.

Coal is of many varieties and of very varying composition. For use in pottery kilns a long-flaming coal which does not cake much is to be preferred; the denser coals can, as a rule, only be used when the fuel is close to the goods to be fired.

In choosing coal for kiln-firing it is not only important to select a fuel with a large heating power, because of the saving in carriage as compared with a dirty coal, but to avoid the use of fuels with a high percentage of impurities which sometimes introduce difficulties that even the cleverest fireman cannot overcome. Wet coal is particularly objectionable on account of the heat expended in vaporizing the water and of the effect of such vapour on the goods.

Coals with a high percentage of sulphur compounds yield a strong odour of burning sulphur, produced chiefly from the pyrites in the coal, which, on a moderate heating, parts with a portion of its sulphur. This ignites, and forms the very objectionable, overpowering gas so characteristic of burning sulphur.

Another disadvantage possessed by coals rich in sulphur compounds is their readiness to catch fire spontaneously. It not infrequently happens that the temperature set up in a damp coal by long storage is sufficient to start spontaneous combustion, if the percentage of sulphur is sufficiently great.

The discoloration of the goods and the unwanted opacifying of glazes may also be due to the presence of sulphur in the fuel.

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[1] The composition of various fuels is given in the Appendix.

The greatest difficulty occurs in the 'smoking' or early fire, when the gases from the smouldering fuel are warming up the goods gently. If the coal used for this purpose contains much sulphur, the sulphurous and sulphuric acids produced will rapidly act on the clay, and cause, in presence of any moisture from the goods or condensed from the gases of the fuel, a scum, the colour of which may be so intense as to entirely disguise the true colour of the clay. Thus, whitish-grey bricks may be produced instead of red, or, where buff bricks are expected, reddish-brown ones may be obtained. If the coloration were evenly distributed over the surface this would matter less, but, as only the exposed parts are so discoloured, the bricks are often rendered almost unsaleable.

The amount of scum so formed will be very small if the firing be alternately oxidizing and reducing; but if it be due to sulphates occurring in the clay itself, the latter may be treated with baryta, or the firing temperature must be sufficient for them to combine with the clay and so become invisible. In any case, an alternately oxidizing and reducing fire is desirable.

Under these conditions it is possible to use fuel containing a high proportion of sulphur and yet obtain good results; but the increased cost of so constantly changing the firing, and the actual loss of fuel through the smoky fires used in reducing, will in most cases be greater than that of using a better-class fuel.

Coal should not be stored longer than necessary, as even when kept under cover it loses 3 to 10 per cent. of its heating value, whilst if it is exposed it tends to form too much small slack and dust.

The precautions that should be taken against the overheating of stored coal are simple. It should never be heaped if thoroughly wet, and should be kept in iron or concrete bunkers in a cool place not adjacent to boilers or flues. The pile should never exceed 10 feet in depth, and should be arranged with efficient ventilating spaces round the sides and at the bottom. Iron pipes 3 inches to 4 inches diameter should be inserted vertically to different depths, one pipe being fixed for each 300 square feet, or so, of surface area. The temperature of the coal at various depths should be measured frequently by lowering a thermometer into each of the pipes in succession. In the event of combustion or overheating occurring, water may be poured down the iron pipes, but the best plan is to turn the coal over thoroughly; pouring water on the top of the heap is of little use, as it may only penetrate sufficiently to make matters worse. If turning over is impossible, and the heart of the pile is suspected to be alight, an effective method is to ram in a good-sized pipe drilled at the end with several holes. When this has penetrated the surrounding coked fuel, a stream of water should be turned into it, which will speadily result in extinction of the fire.

The use of *pulverized coal* offers advantages both in kilns and boilers, but can only be produced economically on a much larger scale than is possible for most clayworkers. It is prepared by grinding dry small coal in a centrifugal mill and blowing the resultant powder into the boiler or kiln. This form of fuel is easy to use and control, and the combustion is so much more efficient that there is a considerable saving (25 to 60 per cent.) in the amount of fuel used and it is said to create less smoke than any other kind of fuel.

Peat Blocks are used in some parts of Ireland for burning common bricks, but they are more successfully used in boilers if the latter are designed with large fire-boxes to accommodate the bulky fuel. If the peat is used in a gas producer fitted with a suitable condenser to remove the excess of water from the gas, a satisfactory fuel for gas-fired kilns is produced, but unless this water is removed the heating power of the gas will be insufficient for burning hard bricks. The great drawback to peat as a fuel for the clayworking industries is the large amount of water evolved when it is burnt or gasified; this water absorbs so large a proportion of the heat evolved from the peat, as to leave little surplus heat available. Air-dried peat is much better than freshly dug peat in this respect, and in the absence of a better fuel it can be used with moderate success.

Coke is of little use in the kilns, as it produces too short a flame; it is, however, sometimes mixed with coal, and is also used during the smoking stage of burning where a very gentle heat is required. Coke is excellent for stoves and dryers where a long flame is not necessary. It is also more economical than coal, as combustion is more complete and little or no smoke is produced. A mixture of fine coal and coke may be used satisfactorily in a boiler if a suitable blast is introduced; with care a saving of 16 per cent. on the coal may be effected by its use.

Blended Fuel.—Mixtures of coal and coke are very useful for kiln burning where coke is readily obtainable; they sometimes have a higher heating power than the coal alone, so that a rather lower-grade coal may be used. For boilers, the coal and coke may be supplied in two layers, one above another, but for kiln firing the fuels should be mixed thoroughly before use if the best results are to be obtained. Insufficient mixing is very unsatisfactory.

Oil is being increasingly used abroad as a fuel in connection with engines and kilns. It is not used to a large extent in this country as, at present, it has to be imported, and so is more expensive than coal or producer gas. When sufficiently cheap it is much more efficient and gives a more complete combustion than solid fuels, and in accuracy of control and simplicity of manipulation it is, in some respects, superior to gas, especially for large kilns where a very long and luminous flame is required. If a native oil can be obtained at a sufficiently low price in this country, it will be worth using for most kind of kilns. Apart from the cost of the air compression and burners, the conversion of a coal-fired into an oil-fired kiln is not expensive. Oil firing has been used with great success in burning many kinds of clay wares in the United States, though little has yet been done in this direction in the British Isles except for small testing furnaces.

Gas as a fuel has scarcely met with the popularity it deserves in connection with clayworking. This is due to some extent to the number of patents of but little value which have been taken out for its use. Clayworkers are, therefore, somewhat prejudiced against it. Its cleanliness, ease of manipulation, and, under proper conditions, its low cost, will probably make it an important fuel in the near future. The gas used is, of course, 'producer-gas' made from coal burning in a current of steam and air, or air alone. The combustible gases present are chiefly carbon monoxide and hydrogen, with a varying proportion of hydrocarbons and other products of the partial distillation of coal. The total percentage of combustible gases seldom exceeds 40, about half this being carbon monoxide. The cost of producer-gas varies with that of the fuel consumed, but, as a rough figure, 3d. to 5d. per 1000 cubic feet may be taken as a fair basis for calculation.

'Mond' gas at one time appeared to possess special advantages for kiln-heating, although it has not yet been very extensively used for this purpose. It is a kind of producer-gas, but by using bituminous coal and a large proportion of steam the working temperature is lower than in other producers, and permits of the recovery of ammonia, the sale of which by-product greatly reduces the cost of the gas. It has been found, however, that it yields too short a flame, which is deficient in carrying power. The same objection applies to all gases from which the tarry matters have been removed by any process of condensation or scrubbing.

In order to obtain the maximum effect from a fuel it is necessary to burn it in such a way as to secure its complete combination with the oxygen of the air and the application of the heat produced to those places where it is required. Thus, with coal, a considerable volume of combustible gas is produced somewhat suddenly as soon as the fuel becomes sufficiently heated. This gas will pass into the flues in an unburnt condition if there is not a sufficiency of air to combine with it. Hence the supply of air to coal must not only be through the grate-bars to burn the solid fuel, but a further supply of air must be introduced above the bars in order to combine with the gas produced. At the same time, care must be taken to avoid an excess of air, or the heat used in warming it up will cause a waste of fuel. (See Chapter IX. on 'Burning.') With gaseous fuel, the air regulation can be effected with great exactitude, but the variations in the composition of the gas, together with insufficient knowledge of its working peculiarities, have so far prevented its being used to any large extent in clayworks in this country.

The Value of a Fuel is determined chiefly from a comparison of its heat-giving power (calorific power) with its price, but consideration must also be given to the length of flame, to the amount of clinker, and last, but by no means least, to the fireman's opinion of the fuel, for these men are, as a class, so totally opposed to changes, that it is a bold manager who will attempt to use a fuel against his fireman's wishes, no matter how good the fuel may be. If a change is to be made, it is best to do it gradually, so that the fireman may not have an opportunity of blaming the new fuel for his own carelessness or wrong-doing.

By the calorific power of a fuel is understood the number of heat units evolved by unit weight of the fuel. In England the heat unit is the amount of heat required to raise one pound of water one degree Fahrenheit, and is termed a British Thermal Unit (B.T.U.). For scientific purposes and on the Continent the metric unit of heat is employed. It is the amount of heat required to raise the temperature of a kilogramme of water from 0° to 1° C., and is termed the major calorie. For very exact scientific work a smaller unit of only one-thousandth of the value is employed, but for ordinary purposes the term calorie is understood to mean the larger unit. The unit weight of fuel is the pound and kilogramme respectively. As many English writers employ the calorie, it is well to remember that the number of calories multiplied by $\frac{9}{5}$ gives the corresponding number of B.T.U.

The following calorific powers are given by Favre and Silbermann and other authorities as standard values:—

Fuel.		British Units.	Calories.
Hydrogen, ...		62,032	34,462
Carbon, ...		14,544	8,080
Carbonic oxide, ...		4,741	2,634
Methane (Marsh gas), ...		23,513	13,063
Good steam coal, . .	(about)	13,000	7,000
Coal gas (per cubic foot),	„	700	400
Producer-gas „	„	300	170

The calorific power of a fuel may be determined experimentally in a calorimeter (see Chapter XIII.), or it may be calculated approximately from the results of an analysis of the fuel. This method, although not strictly accurate, enables one to rapidly sort out fuels when their composition is known, so that the actual tests may be confined to the most likely fuels. According to Dulong, and confirmed by Bunte, who experimented on samples weighing about ½ cwt. each, the calorific power of a fuel in calories is

$$\frac{1}{100} \text{ of } \left\{ 8080C + 28800\left(H - \frac{O}{8}\right) + 2500S - 600N \right\}$$

where H = the percentage of hydrogen, O = the percentage of oxygen, S = that of sulphur, and N = that of nitrogen in the fuel. Thus, if a coal showed on analysis the following composition:—

Carbon,	82·05
Hydrogen,	4·93
Sulphur,	1·06
Oxygen,	8·99
Nitrogen,	2·97

calorific power would be approximately—

$$\frac{1}{100} \text{ of } \left\{ (8080 \times 82{\cdot}05) + 28800\left(4{\cdot}93 - \frac{8{\cdot}99}{8}\right) + (2500 \times 1{\cdot}06) - (600 \times 2{\cdot}97) \right\}$$

$$= \frac{(662964 + 109728 + 2650 - 1782)}{100}$$

$$= 7735 \text{ calories, or } \left(\times \frac{9}{5}\right) = 13{,}923 \text{ B.T.U.}$$

As 1 lb. of water at 60° F. requires 1119 B.T.U. to convert it into steam, the calorific power of a fuel divided by this number will give the number of lbs. of water which at this temperature will be converted into steam at 212° F. by 1 lb. of fuel. The calorific power divided by 967 will give the number of lbs. of water at 212° F. which will be converted into steam *at the same temperature* by 1 lb. of fuel.

The amount of air in lbs. required to burn 1 lb. of coal is $\frac{1}{8}C + \frac{1}{3}(H - \frac{1}{8}O)$, where C = percentage of carbon, H = that of hydrogen, and O = that of the oxygen in the coal. About 12 lbs. of air are usually required.

Ash.—A knowledge of the composition of the ash of a fuel is important, because not only is the ash useless as a heat-producer, but it also causes trouble when in large proportions by clinkering and causing difficulty in cleaning the fire-bars. Unfortunately, the coals that are in all other respects suitable for kiln use are often very defective in this particular. There is no general remedy, although a careful analysis of the ash and a knowledge of its melting point will occasionally suggest one, especially where mixed coals are used. Thus, a sandy coal will, under some circumstances, mix with a coal which clinkers badly, and form a 'clinker' which is infusible under existing conditions.

The addition of brick dust or clay to a coal with a troublesome ash has occasionally proved beneficial by raising the melting point of the ash.

Oils and Lubricants.

Lubrication has for its object the reduction of friction between moving surfaces. In the case of two solid bodies the amount of friction depends on the character of their surfaces, and is proportional to the force which presses them together, except in those cases where the adhesion due to the use of a lubricant has a greater influence than the actual pressure of contact of the two solids. The friction exerted between two fluids, on the other hand, varies with the area and velocity of the surfaces and with the density and viscosity of the fluids. In most machines, the friction at the lubricated surface is made up of the friction of the solid metal and the liquid lubricant in varying proportions; with slow-moving, heavy machinery it is chiefly due to the friction of solids, but in some cases the moving part can be floated in the lubricant so that fluid friction is chiefly concerned.

The 'body' or viscosity of a lubricant is of the greatest importance, as the more viscous it is the greater will be the pressure which it can sustain without being squeezed out from between the lubricated surfaces, but care must be taken not to use a lubricant unnecessarily viscous, or the increase in fluid friction will neutralize the beneficial effects of the lubricant. The *best* lubricant is that which can just keep the moving surfaces apart under the greatest pressure likely to be obtained at the point of contact. For heavy machinery, where the viscosity of the lubricant must be exceedingly great, soft solids are frequently employed instead of oil, the hardness of the material increasing with the pressure on the bearings and ranging from grease through graphite, mica, steatite, sulphur, to various soft metals. Thus, for greasing the axles of tubs, clay waggons, etc., a mixture of palm oil with one and a half times its weight of tallow and five times its weight of a ten per cent. solution of caustic soda in water is often used, the proportion of tallow being increased, if necessary, in hot weather. Rosin-grease is a mixture of similar consistency.

It must always be borne in mind that the thicker the oil the greater the power which will be necessary to drive the machine, so that the lubricant should be as fluid as the weight of machinery and the speed of rotation will permit.

The following characters should be taken into consideration in forming an opinion as to the suitability of a lubricant for a particular class of work :—

1. The **viscosity** or 'body' of the lubricant at the temperature at which it is to be used. This property is a fixed one in the natural animal and vegetable oils and greases, but in the case of mineral lubricating oils the viscosity can be increased or diminished to almost any desired extent by suitable treatment and admixture. The viscosity is determined by noting the time required for a certain quantity of the lubricant to flow through a small orifice of accurately measured size, the time required for a similar quantity of rape oil to flow through the same orifice being taken as unity. A rough standard of comparison is thus obtained which is independent of the size of the orifice and the quantity of lubricant. Although the *accurate* determination of viscosity, especially at high temperature, requires considerable experience and manipulative skill, a sufficiently accurate determination can be made for clayworks purposes with the apparatus originally devised by Allen, which consists of a 25 c.c. pipette enclosed in a wide glass or metal cylinder, which acts as a water-jacket and maintains the lubricant at the desired temperature. The lubricant (previously heated if necessary) is drawn

up the pipette to a definite mark, allowed to remain there until of the required temperature, and the time it takes to run out of the pipette is carefully noted. The chief points requiring attention are the temperatures of the water-jacket, the position of the lubricant in the pipette, and the measurement of the time with sufficient accuracy. It will be obvious that this apparatus is only suitable for oils or the less viscous greases; other appliances, which need not be described here, must be employed for testing lubricants used for the heaviest classes of machinery.

Numerous other instruments for measuring viscosity, such as those of Redwood, Engler, and Doolittle, are intended for the use of experts, and so do not come within the scope of the present work.

2. The **solidifying point** or melting point of the lubricant is of considerable importance, though less so than the viscosity. Suffice it to say that, as a general rule, a lubricating oil is required to remain liquid at the temperatures at which it is used, but a grease or solid lubricant, having to withstand greater pressures, will generally be expected to remain solid.

3. The **flash-point** or temperature at which the lubricant gives off inflammable vapour should be so high that under no circumstances can the lubricant catch fire in use. In the case of oils for engine cylinders, the flash-point should never be under 400° F., and the higher it is the better, as not only is there less risk of fire, but the packing of the engine is less liable to be attacked.

4. The **volatility** of the lubricant should not exceed 4 per cent. after heating for eight hours at a temperature similar to that at which it is used in practice.

5. The '**gumming**' which is characteristic of certain fish oils and of many vegetable oils renders them unsuitable for use as lubricants. The drying oils, of which linseed oil is a type, are quite unsuitable for lubricants on this account. With non-drying vegetable oils the addition of a small proportion of mineral oil notably lessens the tendency to thicken, while their adulteration with rosin increases it greatly.

6. The **acidity** of lubricants is of great importance, as the free acid often present attacks the metal bearings and forms soaps which gum and clog the machinery. Although an oil or grease, when freshly made, may be quite free from acid, it often sours on keeping or on exposure to heat. On this account, fatty oils are, as a rule, not suitable for use in engine cylinders unless mixed with mineral oil; and whenever possible mineral oil should be exclusively used for this purpose.

7. The **specific gravity** of a lubricant is in itself of little importance. At one time it was thought that the specific gravity and viscosity of oils and greases were closely related to each other, but it is now generally recognized that these two characters are not connected in any way.

Lubricating Materials.—Most lubricating greases are made by treating an oil, grease, or fat with lime or soda, and then adding a large proportion of the original fat to the composition to obtain a sufficiently stiff and greasy mass. Many commercial greases are adulterated with 'filling' materials, such as chalk or heavy spar, which give a spurious stiffness to them. The following are the chief oils and fats used for lubricating:—

Palm oil, used for the best greases. The more acrid qualities are in most demand, as they combine with a larger proportion of alkali.

Tallow of very low grade is frequently used.

Foot oils of all kinds are in great demand.

With high-pressure steam, animal oils and fats should not be used, as they are decomposed into stearic and other acids and so attack the iron of the cylinders. Mineral-oil preparations should, therefore, be alone used with high-pressure steam.

Lard oil, Rape oil, Castor oil, and *Mineral oils* are extensively used for heavy machinery. Mineral oils are less liable to oxidation and chemical action and so are usually to be preferred, but for engine cylinders and some other purposes a mineral oil to which has been added 5–10 per cent. of animal or vegetable oil is often the most satisfactory.

Rosin is one of the commonest materials. It is chiefly used in conjunction with one-third of its weight of lime. Being very repellent to water, this material is particularly suitable for outside or exposed bearings.

Anthracene oil—a coal-tar product—when mixed with lime, forms a thick but oily grease. It is one of the cheapest materials for lubricating heavy machinery.

Yorkshire grease is a stiffish grease made from the soap-liquors resulting from wool-scouring.

Grease is by no means so effective a substitute for oil as is often supposed, as it is difficult to ensure it reaching the requisite part of the bearings, though it may frequently be used with advantage for the heavier machines and especially for footstep bearings in edge-runner mills and the like and in the bearings in heavy crushing rollers. Grease is most advantageously applied through a short pipe about $\frac{3}{8}$-inch internal diameter, one end of which enters the bearing, whilst the other is fitted with a screw-down box or cap, the rotation of which forces the grease down the pipe.

Mineral oils and greases are of very variable composition, ranging from comparatively thin oils (summer dark) to thick, tarry cylinder oils and greases of a 'vaseline' nature. Fairly thin mineral oils are very useful for lubricating the working parts of presses, though the dies and plungers should be smeared with paraffin. Thick or viscous oils should be avoided when thinner ones can be used satisfactorily, as there is always considerable difficulty in getting them into the place where their lubricating action is required. Vaseline or petroleum residue is an excellent mineral grease, though it is too expensive to be used for other than special purposes.

Graphite, when suitably prepared, is an excellent lubricant, either alone or when mixed with oil or grease, but it should not usually be employed in ball-bearings as it tends to clog them.

The Table on page 43 indicates the analysis and properties of a good quality cup-grease and oil respectively for ball-bearings and general engineering purposes.

Of the various '*fillings*' used, gypsum has no lubricating value. French chalk is slightly useful, and plumbago (graphite) has a high lubricating power, especially for wood. The addition of a small proportion of colloidal graphite and oil ('oildag') to a lubricating oil is very advantageous for lubricating heavy machinery where a solid grease is unsuitable. Care should be taken to purchase a suitable quality of graphite, as some inferior ones contain hard particles which rapidly wear away the metal in the bearings. In some cases, a finely ground, refined flake graphite mixed with a good mineral lubricating oil is quite satisfactory.

Four fallacies are very common in regard to the use of lubricants, viz. :—

1. That the same lubricant may be used everywhere, and equally well in summer and winter.

2. That a cheap oil will do as well as a more expensive one, so long as it is used freely. As cheap oils are frequently 'loaded' as well as poorer in quality, the saving in the oil bill is soon neutralized by the increased cost of repairs.

3. That oil may be collected, filtered, and used over and over again indefinitely. This is a particularly dangerous error, as oil which has turned rancid or 'gummy' will rapidly do damage. Every care should be taken to use the oil as long as it will do its work properly, but to use it after this is, in the highest degree, foolish. The life of an oil varies with its composition and work, but careful observation of any changes in its behaviour will repay the time and trouble expended.

Analysis and Properties of a Good Quality Cup-Grease and Oil.

	Grease (up to 3000 r.p.m.).	Oil (3000 to 5000 r.p.m.).
Free mineral acid, ...	Nil	Nil
Free alkali, ...	0·1 per cent.	trace
Sulphur, ...	0·3 ,,	0·3 per cent.
Resin, ...	Nil	Nil
Salt, ...	Nil	Nil
Neutral saponifiable oil, . . .	1·00 per cent.	...
Ash, ...	1·8 ,,	trace
Moisture, ...	2·0 ,,	...
Abrasive particles (sand, etc.), . .	Nil	Nil
Melting point, ...	194° F., 90° C.	
Flash point, ...	...	300° F., 150° C.
Heat test, ...	...	Does not gum
Viscosity (Redwood secs.), . . .	...	200 at 100° F.

4. That an excess of lubricant is an advantage. Provided that the two metallic surfaces of the bearing are kept continuously apart by the lubricant, the smaller the amount used, the better. Lubricant applied to any other part of the machinery is wholly wasted!

The most important property of an oil or grease is that it shall remain in position in the bearing even when the latter rises in temperature. This property is usually ascribed to the specific gravity or viscosity, but it is not solely due thereto.

Conditions differ so greatly in different works that no figures relating to lubricating oil are widely applicable, but the following are useful as a guide:—

Oil for	Specific Gravity at 60° F.	Evaporating Point, °F.	Flash Point, °F.
Engine cylinders, - . .	0·893	550	680
Heavy machinery, . . .	0·880	440	520
Light bearings, . . .	0·871	420	500

RECOMMENDED LOADS FOR BEARINGS AND LUBRICANTS (z Viscosity, c Clearance).

Class of Bearing.	Lubricant.	p lb./in^2.	N r.p m.	z.	$z\ N/p$.	c/Dia.
Automobile Crank Shaft	Medium machine oil	300–700	900–1400	7–8	15–25	<0·0010
Stationary Gas-engine Main Bearing	,, ,, ,,	500–700	250–800	30	25	0·0010
,, ,, Crank Pin	,, ,, ,,	1500–1800	250–800	50	15	<0·0010
,, ,, Crosshead	,, ,, ,,	1500–2000	250–800	40	10	<0·0010
Diesel-engine Main Bearings	Heavy engine oil	250–600	60–160	30	15	0·0010
,, Crank Pins	,, ,, ,,	1500–4000	60–160	40	2–5	0·0010
Stationary slow-speed Main Bearing	,, machine oil	80–400	40–80	70	20	0·0010
,, ,, Crank Pin	,, ,, ,,	800–1300	40–80	80	6–8	<0·0010
,, ,, Crosshead	,, ,, ,,	1000–1500	40–80	70	5	<0·0010
,, high-speed Main Bearing	Engine oil.	80–250	360	15	25	<0·0010
,, ,, Crank Pin	Machine oil	400-1500	360	30	6-15	<0·0010
,, ,, Crosshead	,, ,,	1500–1800	360	25	5	<0·0010
Locomotive Drive Wheel	Heavy machine oil	550	250	100	30–50	<0·0010
,, Crank Pin	,, ,, ,,	1500–2000	250	100	5-8	<0·0010
,, Crosshead	,, ,, ,,	3000–4000	250	130	6–8	0·0010
Stationary Steam Turbine	Machine oil	400–950	2000	20	100–200	0·0010
De Laval 7-h.p. Steam Turbine	Light machine oil	7–15	30000	1	1500–3000	0·0020
,, 300-h.p. Steam Turbine	,, ,, ,,	20–25	10500	2	1000	0·0020
Railway Truck Axle	Heavy machine oil	300–450	300	100	50–100	...
Generator and Motor	Engine oil.	30–80	160–500	25	200	0·0010
Brick Works Main Shaft	Hot neck grease	1800–2500	60	...	<1	...

The Table on p. 43A indicates the loads which are satisfactory at the bearing surfaces of the various kinds of bearings shown. The figures are necessarily of a general character and are intended solely for use as a guide, as local conditions may call for a different kind of lubricant or for a much smaller load, to ensure the best results.

Special Oils.

Printer's Oil.—Colour applied to goods by means of printed transfers necessitates the use of a tacky, oleaginous medium as a vehicle for the colour, and one that will neither be affected by, nor cause any injury to, the glaze. Almost every pottery printer makes or uses a composition which he considers superior to all others, but the majority of these 'oils' resemble one or other of the following recipes (see also p. 29):—

1. To 1 gallon of linseed oil, which has been boiled for three hours and then scummed, add 30 oz. Stockholm tar, 1 oz. red lead, 1½ oz. rosin, and boil well, skimming carefully.

2. Boil a mixture of 2 quarts linseed oil, 1 pint rape oil, and 1 oz red lead for two hours. Allow the mixture to cool somewhat and add 2 oz. of sulphur and rather more that half a pint of common tar, stirring well together.

Printer's oil of good quality rapidly becomes tacky if a drop of it is placed on a piece of unglazed (biscuit) ware.

Fat Oil (see p. 31) and other vehicles for painters' and decorators' materials are best purchased under a quality guarantee.

Cat Oil, largely used in the lubrication of clay in brickmaking, is a mixture of mineral and other oils of very varying composition, its constituents being to some extent adjusted to suit the clay (see pp. 90, 92, and 93). *Cresote oil*, cheap *emulsions*, and oily waste products are largely used for this purpose on account of their cheapness. It would be much better and less costly in most cases to use an oil or emulsion of superior lubricating power and to control its application so as to prevent wastage. This may be done by a device such as the Middleton 'Fulflo' oil economizer, which easily effects a saving of 70 per cent. of oil in many brickworks.

CHAPTER II.

PREPARATION OF THE CLAY.

Mining and Quarrying.

In order to facilitate the action of the weather on the clay, it is well to dig in such a way as to expose as large a surface as possible; by this means the clay is more easily obtained.

Clay is usually obtained by digging with spades and picks; these should be of correct design and weight, as an unsuitable spade may decrease a man's output to a much greater extent than is usually supposed. Careful tests have shown that, for constant work at an efficient rate, a spade should be of such a size that an average of 26 lbs. of material is moved at a time. Larger quantities tire the men unduly and so reduce their output over a long period.

Shales and hard clays require a preliminary blasting to loosen the material. Where *blasting* is necessary, it should be wholly under the charge of a man who thoroughly understands the work, or serious accidents may occur. The explosives used in clayworking are generally :—(1) Nitroglycerine absorbed in kieselguhr, forming dynamite. (2) Blasting gelatine, a compound of nitroglycerine and gun cotton which is more powerful than ordinary dynamite and has the additional advantage of being little affected by dampness. Gelignite and carbonite consist of a mixture of blasting gelatine, nitre, and wood meal. Various other well-known explosives are made by adding ammonium oxalate to gelignite. (3) Safety explosives frequently consist chiefly of ammonium nitrate with about 5 per cent. of a hydrocarbon such as benzene. They are not suitable for hard rocks, but excellent for shales and hard clays. (4) Gunpowder is not such a powerful explosive as those previously mentioned, but has the advantage of breaking the material into lumps instead of shattering into inconveniently small pieces as when a more rapid explosive is used.

The use of explosives is regulated by the Explosives in Coal Mines Order for 1899 and the Explosives Act of 1875, with subsequent modifications, including Order in Council No. 16 of 1913, which should be studied before explosives are used.[1]

A detonator, consisting chiefly of fulminate of mercury, is required for most modern explosives. They are sold ready for use, and require careful treatment as they are highly explosive. The detonator is applied to the top of the charge of explosive and is ignited either by a fuse or preferably by an electric-sparking apparatus which ignites the fulminate, and the latter explodes the charge. The holes for taking the explosive are about 1½-inch diameter. They are made by augers or by long chisels driven in to the rock

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[1] A summary of these regulations, with a list of permitted explosives, will be found in the author's *Ceramic Industries' Pocket-Book* (Sir Isaac Pitman & Sons, Ltd.).

by hammering or by a pneumatic drill. They are usually 6–12 feet deep, about the same distance apart, the distance of the holes from the clay face being not more than half the distance the holes are apart from each other.

The charges should be fired whilst the men are not working, *i.e.* in the early morning and at the mid-day meal-time or in the evening, so as to ensure no one being in the vicinity of the explosion. In the event of a misfire, special precautions should be taken in approaching the blast-hole, especially where a fuse is used. When the charges are fired by electricity, misfires are much less dangerous, but suitable precautions should nevertheless be taken. The explosives should be kept under lock and key in a safe place, in compliance with the Government regulations.

Where large quantities of material can be excavated without any veins of unsuitable material needing to be avoided, a steam navvy or grab may be used with advantage.

Excavators consist of a bucket attached to a crane and provided with claws to dig into the workings and so remove large quantities at a time. This 'bucket'—usually of about a cubic yard capacity—is dragged by force up the side, or face, of the working, the steel claws breaking up the ground and scooping it into the bucket. This is then raised clear, swung over a cart, or truck, and emptied by means of a chain which releases a catch and allows the bottom of the bucket to open. With such an appliance, working under favourable conditions, it is easily possible to cut up a face of clay and load it into waggons at a cost of about fourpence per cubic yard.

For soft clays, a series of buckets on an endless band may replace the single bucket just described. Where a heavy excavator is used, sufficiently heavy rails on a foundation of ample size should be employed, or difficulty may be experienced in moving it, especially when working on a slope. A properly trained man should be employed to work the excavator, so as to save the wastage and to reduce the risk of serious accident.

Steam grabs are frequently used by contractors for loose material such as produced by blasting, but are seldom used in clayworking, as the conditions for which they are then suitable are uncommon. Steam grabs require the material to be loose, and of such a nature that no sorting is necessary. They are, therefore, chiefly confined to moving weathered clay or materials which have been brought from some other locality and deposited in a heap near the works.

Neither excavators nor grabs are suitable where only a part of the clay deposit can be used.

Hydraulic stripping is employed in some cases, especially for china clays where the clay is soft and only constitutes a small part of the whole mass. It consists in applying a powerful jet of water on to the material to carry off the clay in suspension, the residual matter being then removed by hand labour or mechanical means. Hydraulic stripping is very cheap where the conditions are suitable and a sufficient supply of water at the requisite pressure is available at a reasonable cost.

In this chapter no attempt is made to describe in detail the various methods employed in mining and quarrying, as the clayworker may be assumed to be acquainted with these; otherwise he must consult special books on the subject. The following brief suggestions deal with matters that are frequently overlooked to the disadvantage of all concerned.

The waggons for carrying away the clay should be taken as near as they can be to the place from which the clay is dug, so as to keep the cost of carriage as low as possible. Tipping-waggons made of metal are superior to barrows where they can be used, and there are now on the market a number of different patterns of rails which can be fixed by unskilled men, so that the cost of laying is very small and the greater output soon redeems the initial outlay. For distances of less than 100 yards, an endless belt is sometimes used with advantage. For large distances, especially where the ground is irregular and where the output is large, an overhead or aerial ropeway is an advantage, as it conveys material very cheaply, and is not in any way hampered by the nature of the ground or by the weather. A single overhead rope carrying a bucket which is moved to and fro is sometimes cheaper than a waggon hauled along a track, as the rope may be in a straight line and pass over buildings, pits, etc., whilst a waggon would have to take a circuitous route.

Unusable materials, such as stones, pieces of wood, roots, etc., should be thrown aside at once into a box, kept for the purpose, near every miner. This is not, of course, possible when the clay is obtained from coal-mines where it is too dark for the preliminary sorting to be accomplished satisfactorily.

In surface working it is an advantage to provide some means of shelter at the clay face, so that the men may work in wet weather and that the clay may not be too wet for the machines.

It is important that the wrenches, hammers, nails, bolts, and other tools should be kept in a box when not in actual use, as in this way far less iron will get into the machines than when the workmen are allowed to lay the tools down anywhere and to throw waste nails, etc., about.

If the mining is to proceed without interruption, some means must be adopted for removing any water which may accumulate. Channels, which need not be deep if sufficiently numerous, should be cut so as to drain the water away from the face of the clay. These channels should be connected to a deep draining pit which can be emptied when necessary by means of a siphon or pump. Where the water can be run direct into a drainage system or river it is naturally cheaper. A plunger or diaphragm-pump is the best for clean water, but for dirty water a pulsometer or centrifugal pump, well cased in straw to prevent the water in it freezing in winter, is to be preferred. The water should not be used in the works boiler unless it has been properly tested, as it may be harmful.

The exhausted parts of the pit, or quarry, must be so fenced that no damage can occur to the workmen. The angle or slope of the walls or sides must not be greater than 37 degrees from the horizontal if the material is likely to slip. Where clays or allied materials (such as ganister) occur immediately above or below a coal-seam, the methods used for working the coal are employed for the clay. The methods employed in underground mining should only be employed for valuable clays, as the cost is greater than that of open quarrying. Many excellent fireclays cannot be used, because the cost of delivering them on to the surface is more than their commercial value.

Clay Sorting.—Either before or after the clay has been weathered, it must, in most cases, be carefully examined and as much of the foreign matter picked out as possible; the men who do this are better paid at the rate of so many pence per ton, as this encourages a good and rapid workman to do his best; some care must, however, be taken that the men do not scamp their work by only sorting out a portion of the impurities.

Iron sulphide is a particularly common and objectionable impurity in fireclays and clays used for sanitary ware, and should be removed as completely as possible, or it will form patches of black slag on the surface of the goods. If the lumps of clay are broken by sharp blows from a hammer, the nodules of pyrites may readily be removed. Other stones and pebbles are removed in a similar manner. An electromagnetic separator may be used for separating these minerals from the ground clay, but, as they are only feebly magnetic, this method is not completely satisfactory, and most manufacturers prefer to have the nodules picked out by skilled sorters.

If different varieties of clay are found in the same bed, they must be kept quite separate from each other, as they may probably require quite different treatment to render them fit for use. When common bricks are being made it is often convenient to mix the various materials together, but if this is done some attempt should be made to ensure the proportions of each being as constant as possible; otherwise serious irregularities in the bricks may occur.

In order to ascertain the best use to be made of the various clays in a given site, an expert should be consulted, especially for the manufacture of high-class goods.

Weathering.—It is seldom that a clay can be used without some kind of a treatment which shall enable it to mix easily with water, and to be easily worked. The natural agencies of wind, rain, and frost may well be made use of in this connection, supplemented, if necessary, by washing, grinding, and pugging.

The object of exposing the clay to the action of the weather, especially in the winter months, is to bring about its disintegration.

The chief agents concerned in the weathering of clay are water, air, and frost; the water soaks into the pores of the clay, and at a sufficiently low temperature is converted into ice. In passing from the liquid to the solid state, water increases in volume, and in expanding reduces the clay more or less completely into powder. The clay should, therefore, be kept sufficiently moist by watering, and should be spread out in such a way that as large a surface as possible should be readily and completely exposed to frosts. In the absence of a water-supply under sufficient pressure to enable a hose-pipe to be used for watering the clay, metal tipping-waggons may be employed to convey the water, though they are far less satisfactory.

Many clays disintegrate on simple exposure to the air, forty-eight hours being quite sufficient in some cases. Others require the physical action of water or frost as well as the chemical action of air.

As in weathering, the action takes place from 'inside' the clay, it is necessarily more effective than the application of pressure from the outside by means of machinery, and it is probably on this account that well-weathered clay is so much more mellow and pleasant to work, the disintegration being much more complete.

Although, at the present time, machinery has attained such a high pitch of excellence, no treatment yet devised has proved so efficient as the action of weather. The clayworker should, therefore, never grudge the money spent in exposing the clay, especially if it is not uniform in composition, but composed of a number of different varieties, some of which may have been added to the original with a view to improving its quality. In this case, the mixture, if milled at once, without weathering, will usually be found to be so imperfectly ground and mixed that some of the clays will pass through the mill more easily than others. If the clay be all of one kind it may often be ground without previous weathering, but it is doubtful if this effects any real economy, as it is less easy to manipulate, and more than one clayworker has found that he has been able to turn out half as many more bricks when using weathered clay than when machinery alone has been employed for the disintegration. The characteristic red colour of red bricks and terra-cotta is usually enhanced by weathering the clay. Excessive weathering should be avoided, or the clay particles may be washed away by rain, leaving a non-plastic residue behind.

The length of time of exposure of the clay to the weather must vary with the particular class of clay, but, as a general rule, a layer of clay not more than 4 inches thick should receive the benefit of at least one night's exposure to frost before it is covered by a second layer, but the longer the exposure the better for any clays affected by weathering.

It is, therefore, important, if the clayworker requires his material to be acted on by frost, he should estimate in the early autumn what will be his daily requirement of clay during the ensuing year, and to arrange for spreading it out to weather.

In some works, fireclays and pipeclays are exposed for several years, but it is questionable whether so long a time is really necessary. It is, however, generally understood that such clays are more satisfactory than those which have only been weathered for a single season.

Besides weathering lean clays in order to increase their plasticity, highly plastic clay pastes are sometimes exposed to the atmosphere in order to secure more uniform distribution of the moisture in them. An exposure of a few days is usually sufficient to complete this action. Care must be taken to avoid the formation of a crust of dry clay on the surface of the material, or if such a crust is formed it should be cut off and returned to the crushing machine for re-conversion into paste. In addition to its physical disintegrating action on clay, the weather oxidizes some of the impurities in the clay, and if oxidized products are soluble they may be washed away in the drainage water, whilst some of the insoluble impurities are rendered more conspicuous and very easily picked out. Some organic compounds present in clay are also decomposed during the weathering, the products of the decomposition helping to increase the plasticity of the clay. Various other obscure actions also occur, including an increase in the amount of some of the colloidal substances in the clay; this also causes an increase in the plasticity.

Instead of weathering, it is sometimes better to pass steam through the piles of raw clay. This, although more expensive and less effective with some clays, is a valuable means of breaking down some hard materials which are not appreciably affected by ordinary weathering.

There are a number of varieties of clay in which weathering must be dispensed with; clays rich in pyrites, for instance, often yield soluble sulphate of iron which, if not washed out by the rain, will tend to scum the goods. At the same time there is a great tendency on the part of some clayworkers to imagine that machinery can work as effectively and faster than nature, which is seldom the case in clayworking. It is true that almost all clays can be reduced to powder by sufficiently heavy machinery, but the articles made with them will not possess the strength of others made from the same clay after exposure. Weathering is sometimes avoided, as it is thought to be expensive, but the reduced wear and tear on the machinery, and the greater output under proper management, rapidly compensate for what, at first sight, appears to be the more costly procedure.

After weathering, the clay may require purifying; if not, it may be sent direct to the crushing or tempering mill, or it may be thrown into pits and covered with water in order to further ripen and mellow it (see p. 53).

The last method is frequently adopted where a strong clay is mixed with sand or other non-plastic material before use.

Cleaning Clay.—If the clays used are mixed to any considerable extent with gravel, small stones, or other foreign matter which cannot be picked out by hand, they must be washed or screened according to the nature of the impurities to be removed. Some clayworkers urge that washing the clay is more economical than pugging and screening, as less power is required, and the product is superior; but the relative efficiency of the two methods must necessarily depend upon the kind of clay and the purposes for which it is to be used. A description of washing and screening appliances suitable for this purpose will be found in the author's *Modern Brickmaking.* (See Appendix.)

It is sufficient here to state that in a *clay-cleaner* the material is first mixed into a paste with water and then pressed against a plate perforated with numerous holes about $\frac{1}{16}$ inch in diameter. The clay and finer particles pass through the screen, but the stones are retained. Such an appliance is very useful when boulder clays are used, but it must be specially designed and constructed if it is to work economically, most home-made clay-cleaners being wasteful of power. (See p. 75.)

In a *wash mill* (which consists of an octagonal or circular tank provided with a stirrer or mixer) the clay is saturated with water and is made into a slip or slurry of the consistency of cream.

The stones and other heavier particles fall to the bottom of the tank and are removed, whilst the lighter particles are carried away by the water, a screen being used to prevent any wood, leaves, etc., from entering the pits. Care should be taken to avoid an excessive accumulation of coarse material in the bottom of the wash mill or the harrows may be damaged. It is generally sufficient to clean out the wash mill about once a week, though for very impure clays it may be necessary to clean it daily or even more frequently. Coarse washing can sometimes be effected by mixing the clay into a slurry and passing it through a screen, the coarser particles being retained whilst the clay passes through with the water. This method is not, however, very satisfactory for separating stones less than $\frac{1}{50}$ inch diameter, as there is a liability for the sieve to clog so that the output is low and the method of treatment is then unduly costly. China clay is preferably washed in a long trough (through the length of which a stirrer revolves horizontally) followed by a series of other troughs. The cost of washing in such continuous troughs varies from 3d. to 2s. per ton according to the proportion of impurities in the clay and the cost of supplying the water to the clay. It is advisable to weather the clay before washing, as a more rapid separation is obtained and the cost of washing is thereby reduced.

It frequently happens that great difficulty is experienced in breaking up ('dissolving') a rich or 'fat' clay, as it remains in lumps, and causes unnecessary loss of driving power in the machine. In such a case, the clay may be dried, either artificially or by being placed in a roomy shed and frequently turned over, or the clay may be added to the washing water in very small quantities at a time, allowing each quantity of clay to be disintegrated before the next is added. Alternatively, the clay may be crushed, cut into small pieces or made into a soft paste by passing it through a pug mill before washing it. The use of *warm* water has been found to be of great value by some clayworkers. Complete drying of the clay is, however, the best remedy for difficult washing, although care must be taken that the clay is not heated much above 100° C. Recently, Bleininger has shown that some clays may be advantageously heated to 200° C. before being tempered.

The success of the washing operation necessarily depends on the speed of the flow as well as on the volume of the water. These must be so regulated that whilst as little of the clay as possible shall sink to the bottom of the tank, owing to an insufficient supply of water, there shall, on the other hand, be a minimum quantity of foreign matter carried off with the clay, which would not be the case if too rapid a current of water were employed. It is not practicable to state exactly any speed of flow which is suitable for all cases, as so much depends on the nature of the foreign matter present. Seger gives the following velocities and dimensions of grains, and these definitions are generally accepted as standards:—

Clay.—All grains with a diameter of less than 0·01 mm. washed out by a stream of 0·18 mm. velocity per second.

Silt.—All grains between 0·01 mm. and 0·025 mm. diameter washed out by a stream of 0·7 mm. per second.

Dust Sand.—All grains between 0·025 mm. and 0·04 mm. diameter washed out by a stream of 1·5 mm. velocity per second.

Fine Sand.—All grains between 0·04 mm. and 0·33 mm. diameter.

Coarse Sand.—All grains over 0·33 mm. diameter.

For the washing of many kinds of clay on a large scale, however, the water usually has a much greater velocity, although it should not much exceed 4 feet per minute (20 mm. per second). The addition of a little alkali to the wash water effects a great improvement in the purity of the clay suspension on account of the colloidal properties of the clay, but care must be taken not to use too small a proportion of water, or the coarser particles will remain suspended in the viscous fluid instead of settling out, as desired. Feldenheimer has patented the addition of 1·5 per cent. of soda to a 5 per cent. suspension of the clay, and precipitates the clay in a second tank by the addition of 1·5 per cent. solution of aluminium sulphate.

It is often economical to tip the clay, previous to its being washed, on to a fairly steep slope about 10 yards long, and to wash it down this into the mill with a sufficiently strong stream of water; many small stones are thus kept out of the mill itself, which consequently does not so often require cleaning. The Freygang washing apparatus consists of an inclined pipe containing a screw conveyor driven from the lower end by gearing. The pipe has three openings, one at the bottom which serves as an inlet for the raw materials and water, one near the middle fitted to a vertical pipe which acts as an elutriator through which the clay and water pass, and one at the top through which the sand and other coarse materials escape. The apparatus is so arranged that the solid material and water are thoroughly mixed, and as they travel up the tube with the water, the fine particles remain in suspension and are carried off through the middle exit. The sand and small stones being relatively heavier, cannot rise through the vertical pipe connected to the opening but settle down into the screw conveyor and are carried by it to the upper opening and discharged. A very ingenious clay-washer patented by W. Gee consists of a rotary-inclined cylinder the interior of which is fitted with a series of projections forming a screw thread. The crude clay is suspended in water and passed into the upper end of the cylinder, and a current of water enters the lower end of the cylinder and passes through it. As the cylinder rotates the coarse materials fall and are carried by the screw thread to the lower end of the cylinder, where they are discharged, whilst the fine material remains in suspension and is carried off with the water.

For white-burning clays it is necessary to remove all particles of metallic iron which may be present. This is usually accomplished by passing the washed clay, in the form of slurry, through boxes containing magnets, or, better still, by attaching magnets to the revolving arms of the wash mill or blunger.

Separating Water from Clay Slips.—The clay suspended in water, as received from various clay-cleaning processes, may be run into settling pits from which, after some time, the supernatant water may be run off and the pasty clay dug out and dried.

Care should be taken that the pits which receive the washed clay are emptied regularly and cleaned out well before being refilled. The best results, as regards speed of settling and drying, will be obtained if the pits are not filled to a greater depth than 2 feet of solid clay.

When not too large, the pits may be heated by the gases from a small stove passing underneath and around the sides, so as to facilitate the evaporation of the water from the clay; but, for brickmaking, basins are built by throwing up banks of earth, so that the slurry, when placed in these basins, gradually deposits the clay. The bulk of the water may be run off. The soft paste then dries slowly by evaporation of its contained moisture. The old-fashioned dry-pan, consisting of a shallow tank occupying a considerable area and heated by flues beneath, is capable of drying any clay slip satisfactorily, but to ensure good results these pans require a considerable amount of attention or the clay will be overheated and spoiled.

As washed clay takes a considerable time to dry, care must be taken in opening new yards not to begin using the clay until an ample supply is in stock.

The somewhat crude method of drying by evaporation is often replaced by the use of filter-presses in which the water is removed by subjecting the slurry, contained in cloths folded to form bags, to considerable pressure.

The presses must be made of a material which will not stain the clay. Iron standards with wooden frames for the cloths are largely used, but enamelled or rustless metal frames are stronger. Filter-presses are costly, and do not produce a sufficiently stiff cake with some clays, nor is pressed clay so plastic as that which has been 'boiled' on a dry-pan.

These filter-cloths are particularly liable to a kind of mouldy growth which destroys them, but this may, to a large extent, be prevented by treating them with a dilute solution of carbolic acid or other suitable disinfectant. The breaking of cloths is usually caused either by excessive pressure or by using a worn-out cloth. When a 'burst' occurs the supply of slip to that compartment of the press should be shut off and a new cloth inserted in place of the defective one. All filter-cloths should be numbered, and an account kept of the dates when they were put into use, repaired, or discarded, as carelessness and waste can thus be minimized. The cloths need (1) careful folding, (2) frequent washing, and (3) wetting before folding.

The water from the filter-presses should be run into settling-tanks, from which the sediment can be cleaned out periodically and returned to the scrap-blunger. A pail or two should also be kept ready in the event of a cloth bursting.

More recently, clays have been separated by the use of centrifugal devices with a peripheral speed of over 9500 feet per minute and by electro-osmosis.

Small quantities of clay slip may be converted into paste by pouring it on to a slab or into a tank made of plaster of Paris which absorbs the water, leaving the clay behind.

Absolute cleanliness is essential in all operations connected with the washing of the clay for the production of white ware.

Grinding.

In working certain clays, especially those containing limestone and other hard minerals and the shales and clay rocks, it is necessary to crush them so that they will the more readily mix with water and so become plastic. In order to make the output of the grinding machinery as effective as possible, it is customary to remove all pebbles and similar useless material which can be picked out by hand before sending the clay to the mill, although the facilities offered by the use of rollers for working up all sorts of material with the clay induce some clayworkers to pay but little regard to the suitability of the materials thus introduced. The removal of limestones from clay is very important, and special precautions should be taken to secure it (see p. 2). Edge-runners and rollers are the chief types of grinding machines used for clay, but they are supplemented in some cases by disintegrators, stone-breakers, and ball mills. All these are described in the author's *Modern Brickmaking* and in Bourry's *Treatise on Ceramic Industries.* (See also pp. 75 to 81.)

For brickmaking, edge-runner mills and crushing rolls both have their special advantages depending on the nature of the clay. It will usually be found that edge-runners are most suitable for shales and dry clays which can be crushed to powder, whilst rolls are more satisfactory for 'fat' and pasty clays; but if a clay is very stiff and sticky, however, an edge-runner mill may be used to break down large lumps and force the clay through slots in the bottom of the pan and on to crushing rolls. By this means, clays which cannot be crushed by plain rolls may be reduced to a condition in which rolls can deal with them satisfactorily.

When crushing rolls are used the space between them should be that best suited for the particular clay being treated. If two or more pairs of rolls are used, the upper ones should be further apart than the lower ones. If the rolls are too close together the output is unnecessarily limited and power is wasted, whilst if the material is insufficiently crushed, the finished goods will lack durability or the clay will be difficult to mix with water. Both rolls and edge-runners should be kept in a proper state of repair, the grinding surface not being allowed to wear unduly hollow before being reground or supplied with a fresh roll or rim, otherwise the clay cannot be ground to any particular size.

In the United States disintegrators (p. 76) are employed for dry clays and shales, but the material discharged from these machines should be still further ground in an edge-runner mill. Jaw crushers are preferred in this country, as they can deal with larger pieces of clay or rock. Disintegrators are not suitable for clays in a plastic state.

In edge-runner mills, opinions differ as to the advantages of the revolving and stationary pans (Chap. III.), and the pan may be either perforated (to allow the ground material to pass away) or not, according to the nature of the material.

Some clayworkers claim that excessive grinding makes the clay 'short' and of less binding power, but this is more probably due to the fact that very finely ground clay requires much more water to render it as plastic as coarser material. In any case, excessive grinding should be avoided.

Glaze materials and similar products are most conveniently ground in a small pan mill or in a ball or pebble mill. In most cases it is cheaper to buy them ready ground. For further suggestions on grinding, see p. 79.

Blending Clays.

It is frequently desirable to mix several clays together so that the product may possess properties not possessed by any one clay; this is known as blending. Some clays do not mix readily with others on account of the colloidal matter present. It is also unwise, when making stoneware or other vitrified ware, to include a clay which vitrifies at a low temperature and to burn at a much higher temperature than the more fusible clay will stand when burned alone. Surface pimpling, bleb structure, and weak strength are the usual defects caused by such a practice. They may be avoided by drying the clays, grinding them to a fine powder, mixing them in this state as thoroughly as possible, and then adding water and pugging the mixture.

Mixing or Tempering, Pugging.

In order to bring the clay into a plastic condition it must be mixed with water, unless it has been previously washed or made into slip. Washed or 'slipped' clay must have the excess of water removed by (1) drying (either naturally or artificially), (2) by means of a filter-press or centrifuge, or (3) by electro-osmosis, though this latter is too costly for clay for most purposes.

In drying clay artificially before it is used for the manufacture of goods, it is very important that its temperature shall never exceed that of boiling water (212° F. or 100° C.); it should, in fact, seldom approach this temperature, or it will lose some plasticity and cohesion (p. 50). If cost or the limited size of the works necessitates the employment of artificial means of removing the excess of water, a current of warm air should be used in preference to any other method of drying.

As time is required for the water to be absorbed by unwashed clay, it is often placed in pits, or sumps, and covered with water and left for some time If sand, or other materials, are to be added to the clay, such additions may be most conveniently made at this stage. Clay which has been treated in pits in this way usually makes better ware than that which has simply been mixed with water in a pug mill. Hence, when the clay is to be made into vessels with very thin sides, or walls, it is sometimes stored or 'matured' in air-tight boxes, where it cannot lose much of its moisture, for several months or even years. Under these conditions putrefaction of the organic matter in the clay takes place, the colloidal content of the clay is increased by the action of the water present and is then coagulated by the acids derived from the decomposition of the organic matter, and in this way the clay becomes more 'mellow' and workable. Different clays vary greatly in the extent to which they are improved by this treatment. Of recent years this prolonged storage has been to a large extent abandoned and the clay worked more in the mixing machines.

In order that the clay may absorb the water readily, it must be reduced to powder or be passed between rollers; it is then carried to the pits, where it receives its necessary quantity of water, baryta, etc. In order to ensure that the clay is not removed too soon, it is advisable to arrange the pits in the form of an oblong or ellipse, so that they may be filled and emptied in regular order. Many clayworkers omit the pits and pass the clay direct from the crushing plant into a pug mill (p. 86). With some clays, the water must be added in very small quantities at a time, and with others warm water is advantageous (see p. 49). The control of the amount of water added to the clay in pugging is very important, as, unless the correct quantity of water is added, a proper consistency cannot be attained. Where a large proportion of non-plastic material is used, more water may be required than with the highly plastic clay.

Every care must be taken in order to ensure that the clay, when ready for use, shall be of the same composition throughout—that is, the mixing of the solid materials and water should be as perfect as possible especially if flint or other materials have been added to the original clay, as irregularity in composition causes unequal contraction of the clay on drying, and the goods are apt to 'fly.'

The further mixing of the pasty clay in the pits may be effected by turning it over repeatedly with wooden spades and treading it, or in smaller quantities by 'wedging' or cutting off pieces with a wire and dashing them down with considerable force on another piece placed on a plaster slab, and repeating the operation until it is supposed that the mass is quite homogeneous. When large quantities of clay are required, however, this operation is usually carried out by means of a pug mill, which is in many respects very like a large sausage-machine (p. 86).

Some clayworkers contend that hand-wedged clay is superior to pugged clay, but this is doubtful, as the clay may be put more than once through the pug mill when necessary, and in this way may be mixed to almost any degree of completion, whilst there is far less chance of the operator performing his work carelessly when a machine is used, and air-bubbles are quite as efficiently removed from the clay by slow and careful pugging as by wedging in the old-fashioned way. When it is specially necessary to avoid air-bubbles in the clay, the paste should be treated in an edge-runner mill instead of a pug mill.

The clay, when pugged, should be of such a consistency that a small piece of it when kneaded in the hand will retain the impression of the lines of the skin quite distinctly, and yet it must not be so wet as to cling to the skin. If time does not permit of the clay being dried when it is too wet, ground sagger or 'grog,' or even dry clay dust, may be added and the mixture again pugged, but this procedure cannot be regarded as satisfactory and should only be employed in exceptional circumstances. If it regularly happens that the clay is too wet when put into the pug mill, and less water cannot be used, the best plan is to provide more drying accommodation, so that, although the clay may have a longer time to dry, the daily output need not be diminished.

Should more clay be prepared than can be used at once, it must be prevented from drying by being covered with sacks or bags, which must be kept wet, although the bags must not be watered just before the clay is to be used.

It is not wise to add anything to the clay in the pug mill if it can possibly be added before, as in the latter case it is much more likely to be properly incorporated. Baryta and other scum-preventers should be added to the clay at the same time as the water.

As dry materials in the plastic clay will interfere with its being properly worked up into goods, clay which has become dry on the outside should be treated with sufficient water to make it plastic, and be again put through the mill. Some partially dried clays give better results if they are allowed to dry completely and are then mixed with the new clay and passed through the whole crushing and mixing process. Ball clays which have been pugged and then crusted with dry clay should always be treated in this manner, as they tend to crack if the pieces of crusted paste are placed direct in the mixer or pug mill.

Further suggestions on the preparation of clay will be found on p. 86 *et seq.*

CHAPTER III.

MACHINERY.

Boilers.

THE types of boilers used for steam production in clayworks vary greatly according to the purpose for which they are used, from the simple vertical boiler to the most completely fitted water-tube boiler made. An ideal boiler is one which can supply the maximum of steam required at the lowest possible cost. In view of possible extensions of the works, however, it is never wise to put in a new boiler without ensuring that it has ample power for producing more steam than is ever likely to be required. Too large a boiler, on the other hand, by having unnecessarily large radiating surfaces, will waste heat. As in most clayworks the steam is required almost as much for heating (drying) as for power, there is no advantage to be gained by using a boiler making very dry steam, and, although in engine driving dry steam is to be preferred, where the boiler is used for heating as well as for driving moderately dry steam is best. Where coal is cheap, great refinements in 'economical' steam production may actually result in financial loss. The following matters should be taken into consideration: (*a*) the amount of steam required; (*b*) the length of the pipe circuit; (*c*) the type of engine to be used; (*d*) the means of utilizing the waste heat; (*e*) the quality of the feed water; (*f*) the means to prevent or choke the draught; (*g*) the advantages and disadvantages of mechanical or natural draught; (*h*) the general arrangement of the plant; (*i*) the means to be taken to secure adequate or maximum efficiency; (*j*) the means used to prevent the occurrence of leaks and waste. A proper consideration of these matters prior to the installation of a boiler will save a great deal of money, trouble, and annoyance which would otherwise be incurred after it had been placed in position.

At the same time, it should be remembered that exhaust steam from the engines possesses but little less total heat than live steam from the boiler, so that it is better engineering to use the exhaust steam rather than live steam for heating purposes.

Great care must be exercised in preventing any back pressure being put upon the engine when exhaust steam is used, as a comparatively small back pressure may cause a serious loss of power.

The efficiency of a boiler is dependent on the ratio of water evaporated to fuel consumed, the number of heat units produced by the fuel being compared with the number of heat units required to evaporate the water. It is generally considered that an efficiency of 75 per cent. is good; with a coal the calorific power of which is 14,000 B.T.U., this would mean the evaporation of 10·87 lbs. of water at 212° F. per lb. of coal.

The *power* of a boiler is a somewhat indefinite quantity, but is nominally the power necessary to produce one horse-power in the engine. It therefore depends on the engine used and on the steam consumption. A boiler horse-power has also been defined as that required to convert 34½ lbs. of water at 212° F. into steam at the same temperature, or as the equivalent of the transfer of 33,300 B.T.U. per hour. At the same time, one engine horse-power if converted into heat and used in a boiler will only develop 2545 ÷ 33,300, or one-thirteenth of a boiler horse-power. From this it will be seen that calculations of the power of boilers are complex and may easily lead to confusion.

The rate of combustion of fuel in a boiler varies, with natural or chimney draught from 16 to 20 lbs. of fuel per square foot of grate per hour, and with forced draught from 25 to 80 lbs. of fuel per square foot of grate area per hour according to the draught, the lower figure corresponding to rather less than ½ an inch of draught (w.g.), and the higher figure to 4 ins. w.g. The highest efficiencies are obtained with low rates of combustion.

The average steam consumption per I.H.P. may be taken as about—

40 lbs. per I.H.P. per hour for non-condensing engines.
30 „ „ „ „ condensing engines.
22 „ „ „ „ compound engines.

Better results than these have frequently been obtained.

The *coal consumption* per H.P. depends on the boiler as well as on the engine. Thus 3 lbs. per H.P. hour for a non-condensing and 2 lbs. for a condensing engine is good practice.

The average coal consumption may be taken at the following rates, on the assumption that each lb. of fuel evaporates 8 lbs. of water:—

For non-condensing engines,	3 to 6 lbs.	per I.H.P.	per hour.
„ condensing engines,	2 to 4	„	„
„ compound non-condensing engines,	2·5 to 3	„	„
„ „ condensing engines,	1·5 to 2·75	„	„
„ triple condensing engines,	1·2 to 1·75	„	„

Where the cost of fuel is considerable, it is wise to make occasional tests of the 'commercial efficiency' of the boiler, *i.e.* the cost of evaporating 1 lb. of water. In this way it is not infrequently found that a saving may be effected by using a slightly more expensive fuel! In choosing coal for boilers the following points should receive consideration, as different boilers require different kinds of coal: (1) the size of coal most suitable for the particular boiler or conditions of use; (2) the most satisfactory percentages of fixed carbon and volatile constituents in the coal; (3) the nature and amount of the coke produced from the coal; (4) the amount of ash left by the coal and its melting point and clinkering properties; (5) the amount of moisture in the coal and its origin (a considerable saving may be effected by using dry coal and by storing it under cover); (6) the type of boiler furnace and its relation to the coal available: some furnaces are much more suitable than others for a given fuel; (7) the design of fire-bars used in the furnace: this should be arranged to suit the coal: the grate should not be too large, as a small one is much more economical; (8) the arrangement and size of the flues and the manner in which they are constructed; (9) the dimensions of the chimney; (10) as a check on the conditions in the boiler furnace, the gases passing out of the chimney should be (periodically) examined, as the completeness of the combustion and the amount of air used in excess of that actually needed can best be ascertained by an analysis of the flue gases. Some firms find that a continuous assay of the flue gases is advantageous.

Where a battery of boilers is employed, mechanical stokers will be useful, but they are of a doubtful economy where only one boiler is used. In conveying fine fuel to the stokers by means of conveyors, it must not be allowed to fall far, or the air in its neighbourhood will become dust-laden and explosive.

Mechanical stokers burn rather less fuel than hand-fired ones for the same amount of steam, but have the disadvantage of being limited to small coal. The cost of upkeep of mechanical stokers is much greater than is usually imagined, and much stress is frequently laid on the small amount of labour required.

It must always be remembered, however, that even 'automatic' stokers require skilled attention if good results are to be obtained, and whilst a regular mechanical feed gives a more uniform temperature with better combustion and less cleaning is required, especially with very poor or small coal, it will be found in most cases that with coal of fair quality a really skilled man is superior to the best mechanical appliance. As clayworkers are more or less trained to recognize the necessity for skilled firemen at the kilns, they are more ready to employ similarly skilled men at the boilers, though there is a great tendency in some works to think that "anyone who can handle a shovel can fire a boiler," although such a neophyte would never be entrusted with a kiln.

The composition of the *water* used in boilers is frequently of importance (see p. 32).

The proportion of solid matter left on evaporation should be as small as possible, but the composition of this matter is usually of more importance than its amount when the latter is large.

Rain or moorland water is the most suitable for boilers, providing that it is not acid. Where such waters are not available, the ordinary water-supply should be analysed and a suitable method of treating it should be applied. If containing temporary hardness it may easily be removed by lime (p. 33), or permanent hardness less easily by sodium carbonate or baryta; but if the water contains a large proportion (say over 30 grains per gallon) of sodium or potassium sulphates or chlorides it is seldom fit to use. Water containing more than 10 grains per gallon of magnesia (MgO) is apt to cause corrosion at the water-line if the water also contains chlorides.

Where the water-supply is not too hard the feed-water may be heated by means of 'economizers'—systems of pipes heated by the waste gases from the boiler or kiln flues passing over them before they enter the chimney. Where these economizers are fixed it is important to arrange a by-pass, so that the waste gases can be sent direct to the chimney when desired. With hard water, the incrustation in the pipes is apt to be more troublesome than the scale in a boiler. Some means of removing the accumulations of soot from the pipes of the economizer must also be provided, or overheating will ensue. As the waste gases from many types of kilns are passed into the chimney at a very high temperature, several attempts have been made to utilize this heat for heating the feed-water; the use of economizers diminishes the draught, however, and so often renders the use of a fan essential.

In addition to the use of feed-water heaters, the condensed steam from the engines and heating chambers should, when possible, be returned to the boiler, but care must be taken that this water is quite free from oil, or trouble will ensue. If a filter is used to remove dirt and oil from the condensed steam, it should be kept in good working condition or it may be worse than useless; it also should have a by-pass (with a key kept in the manager's possession) for use when the filter is out of order or undergoing cleaning. If the by-pass is under the control of the boiler attendant he may surreptitiously pass the water through *it*, and not through the filter, in order to avoid the trouble of cleaning the latter.

By careful attention to the supply of warmed water to the boiler a saving in fuel equal to 10 or even 20 per cent. may be effected. Other losses of heat may also be prevented by attention to the proper housing of the boiler, and to the proper covering of all pipes used for conveying steam and not for heating purposes. These points are almost universally neglected in clayworks, yet many factories, especially brickyards, are largely dependent on the cost of power and steam as to whether a profit is made or not!

The temperature of the feed-water on entering the boiler varies greatly in different works. In many engineering establishments it is heated by economizers to a temperature of 180–350° F. The water is fed into the boiler either by means of a pump or an injector; if pumps are used a pump-governor is often advisable to maintain a practically constant speed of working even under considerable variations of pressure tending to make the pump race.

Some boilers are fed by gravity, but this implies the existence of water under a considerable pressure.

The injector is an appliance by which the energy of a jet of steam is imparted to a column of water so as to force it, partly by suction and partly by pressure, into the boiler. A detailed description will be found in most works on the steam engine, and so need not be given here. There are several types in use, the best for ordinary purposes being those which both lift and feed the water into the boiler, thus doing away with the necessity of any head of water in the supply. It is also more convenient to have a self-starting injector than one with a positive action only. Injectors use as much steam as a pump, but as this steam is returned to the boiler with but little loss, and the instrument is so simply made that it is seldom in need of repairs, the use of injectors has become very extended. The chief difficulties experienced in the use of injectors are: (1) the steam pressure is too low; (2) the feed-water is too hot (most injectors cannot deal with water at a temperature above 100° F.); (3) air gains admission to the suction pipe; (4) dirt or other material causes a stoppage in the suction pipe; (5) the tubes and cones of the injector are neglected, become dirty, and the injector then ceases to deliver the requisite amount of water; (6) the injector is too hot; (7) water is not delivered properly, because the injector has to lift it to too great a height. If a suitable injector is chosen in the first place, and care is taken to keep it in good condition, these difficulties can, in most cases, be avoided.

The most usual form of pump for boiler feeding is direct-acting, and either single or duplex, which has several advantages over other types (such as the absence of dead-centres, which enables it to be self-starting), and delivery accurately regulated by throttling the discharge, with consequent ease in adjusting rate of supply. Power pumps run by belting from the shaft are also often employed, but as they cannot run when the engine is out of operation they are subject to great disadvantages.

It is desirable to have two independent means of feeding the boiler, so that if one is out of action the other may be employed. When this is the case the pump is commonly employed for daily use and the injector as an auxiliary.

The feed-water should be allowed to enter the boiler near the coolest portion of the water-space, so as not to impinge on hot plates; it should also be diffused through a perforated pipe, and not be delivered in a direct stream.

In order to facilitate the cleaning of the injector, or pump, a cock should be placed between the boiler and the feeding mechanism, and the latter should be examined at intervals and cleaned if necessary.

The question of *superheating* the steam after it leaves the boiler and before it enters the engine is gaining in importance and interest. As already mentioned, in most clayworks a considerable proportion of the steam is commonly used for heating, so that dry steam is not so essential as where the steam is entirely used for power purposes. Briefly the advantages of superheating are: —

1. The production of dry steam and its delivery in a dry state at a much greater distance than is otherwise possible.
2. Increase in volume of the steam due to higher temperature.
3. Better use of the steam in the cylinder, less loss by condensation—hence greater efficiency of the whole plant.
4. Lessened strains on the boiler.
5. Saving of upwards of 10 per cent. in fuel consumption.
6. Smaller total heating surface per H.P. Where superheated steam is employed the pipes for conveying it should be of cast iron or steel (brass and similar metals being deteriorated by the superheated steam), and special lubricants are required on account of the high temperature. The little extra cost involved is soon repaid by the advantages gained.

Superheating the steam supplied to the dryers is even more important, as it affords a simple means of ensuring the dryness of the steam at the place where it is used.

Before starting a boiler, it should be thoroughly examined to see that it is in perfect working condition, so as to avoid loss by leakage, etc. The pipes should be particularly examined, cleared if necessary, and any grease on the inside of the boiler should be removed. The boiler should then be filled with water to the bottom of the water-gauge, but not so high as when in regular use, so as to allow for the expansion of the water when heated. It is also advisable to open the safety valve when starting up, so as to avoid accidents. Other important precautions in starting a boiler are: (*a*) not to heat a closed boiler, as the air would expand but could not escape and might cause serious damage; (*b*) not to connect the boiler to the steam main to which other boilers are connected until pressure in the newly started boiler is at least equal to that in the main, or a 'backwork of steam' may result; (*c*) not to heat the boiler too rapidly at first, as the metal-work requires time to 'seat itself properly.'

In *firing* a boiler, the general conditions to be observed are such as will secure perfect combustion of the fuel. For this to be accomplished it is essential that the fuel should not be too thick on the bars to prevent its allowing air to rise through them, while at the same time no part of the grate area must remain uncovered. In order that the gas produced from the coal may be properly consumed, it is best to stoke in small quantities at a time, and on alternate sides of the grate, the fresh coal always being put on near the front and gradually pushed forward as it becomes coked. The stoking should always be done when the fire is burning well, not when the chimney is smoking. The furnace doors should be kept shut as much as possible so as to prevent cold air getting to the boilers. When about to clean out the scar or clinker, one side of the fire should be well charged and the other allowed to die almost out; the clinker may then be taken from this side with comparatively little loss of combustible matter along with the ash, otherwise an examination of the ashes will show that they contain a large proportion of only partly burnt coal. It is also wise to keep a self-registering record of the draught or temperature of the boiler flues, as well as a strict watch on the amount of coal burnt per hour. The draught near the (open) damper should be fully equal to a pressure of $\frac{3}{8}$ or $\frac{1}{2}$ an inch of water (= 10 mm.), but in some cases 1 inch of water may be the correct pressure. A deficient draught may be due to too narrow or too wide a chimney, to stoppage in the flues, to leaks in the brickwork or in the damper, or to the boiler door being left open. Further suggestions for firing will be found in Chapter IX.

Boiler Troubles (*Corrosion and Scale*).—By corrosion is generally to be understood the action of water or of some of its impurities on the plates of a boiler. It is usually due to acid in the water, or in the 'scale-preventers,' or to galvanic action set up by pieces of metals other than iron which may find their way into the boilers. Sometimes oil from the engines undergoes hydrolysis and produces a corrosive acid. When acidity is the cause, the water should be made slightly alkaline by the addition of a little lime water, as in softening (p. 33). To prevent galvanic corrosion, sheets of zinc are usually suspended inside the boiler, so that they are partly immersed in the water, and by their electrolytic action become attacked themselves instead of the boiler plate.

Scale is formed by a variety of substances. Most of these have the power to make water 'hard,' and their removal has been discussed on p. 33. The removal of scale from the boiler itself must usually be accomplished by means of a hammer and chisel. Petroleum is sometimes employed to loosen the scale, but its use is accompanied by considerable risk on account of its great inflammability. One of the best ways of using it is to allow the water in the boiler to cool completely, to pour in the petroleum, and allow the water to run slowly out of the boiler. When completely emptied it is refilled with clean water, heated as usual for a few days, and then again emptied and the scale scraped or chipped off. With very hard scale, however, it is best to have the scale itself analysed by an expert, who will then be able to suggest a chemical which will soften it and so avoid the risks attending the use of a chisel. Various other scale-removers may be used. Like some anti-crustators, some of them depend chiefly on forming a colloidal coating around the grains of scale, so preventing the latter from hardening, or softening it after it has hardened. Other scale removers—such as soda—are intended to decompose the scale without corroding the boiler. In one English brickworks the addition of 15 lbs. of china clay to the water in a 30-foot Lancashire boiler was found, after three months, to have completely loosened a hard gypsum scale which had formed in the boiler. The reason for this action of the clay is not clear. Some engineers prefer to leave a scale of about one-eighth of an inch thick in the boiler, especially at the water-line, to prevent corrosion. This is particularly the case with water containing magnesium chloride, which is converted in presence of steam into magnesia and hydrochloric acid—the latter corroding the boilers.

Overheating and *collapse* of the plates are usually caused by faulty circulation in the boiler, due either to faulty construction or to a deposit of non-conducting matter. Fatty acids or the corresponding lime soaps often combine with the boiler deposit to form a very adhesive non-conducting coating. Mineral oils cannot do this, but occasionally they attach themselves to particles of scale and produce a similar result in a rather different way. Other causes of the collapse of boilers are:—(1) the boiler plates may be worn out; (2) the boiler may be subjected to an excessive pressure, especially if old and worn or corroded; (3) the flues may be displaced through faulty foundations or may collapse from some other cause; (4) the flame from the furnace may have impinged continuously on one part of the boiler and may have burnt it away; (5) the neglect of inspection and of repairs is a frequent cause of overheating and collapse; (6) irregular stoking, by causing an unequal expansion of the steel casing, may cause the latter to buckle or crack; (7) general mismanagement, due to either ignorance or carelessness.

The simplest method of preventing overheating is to employ a good fireman and to use a well-designed boiler, taking every care that no oil or boiler-scale gets into the boiler. The oil may be kept out by an efficient filter, the scale by using only softened water. The design of boilers lies outside the scope of this work, but as the scale is usually most abundant where there is least circulation of water, a careful study of the distribution of the scale will often give valuable information as to the circulatory system, and this, if defective, should be remedied.

Priming, frothing, or the throwing of water violently into the pipes from the boiler is usually due to oil or to soluble salts in the water. Priming is also a frequent result of using waters, containing gypsum, which have been softened with soda. The substitution of baryta for soda will often prove to be the best remedy, this substance now being on the market at a sufficiently low price for its use in this connection. Oil is also a frequent cause of priming when exhaust steam from the engine is allowed to enter the boiler.

Engines and other Sources of Power.

The most natural source of power in all works where drying is effected by steam is a steam engine, usually of the non-condensing type. There is, in fact, little if any advantage to be gained by the use of compound engines, as the heating power of exhaust steam differs so little from that of live steam direct from the boiler. Single, non-condensing steam engines are, therefore, the most generally suitable for clayworking.

It is generally advisable to use a cheaper if more wasteful engine, as the difference in cost between it and a more complicated though more economical engine will be more than counterbalanced by the larger amount of exhaust steam available for heating. Of course this argument must not be pushed to an extreme; but where considerable quantities of steam are required for heating and less for power, it may be considered that the power is obtained for next to nothing, as the steam loses so little of its total heat in passing through the engine. Hence, in such cases, the cheapest engine that will do the work without serious cost in repairs is the best to use.

Where the amount of steam for drying purposes is small, and where machinery is inconveniently distant from the boiler, other sources of power available are gas or oil engines and electric motors. When considering whether a gas or oil engine or an electric motor would be preferable to steam in a clayworks it is necessary to take into account (1) whether extensive drying of the goods by artificial heat is required; (2) the distance of the works from the coalfields; (3) the distribution of the machinery—a pump or other machine at some distance from the rest may best be provided with a separate source of power; (4) whether—if a steam engine is used—all the exhaust steam can be utilized; (5) the cost of labour and loss of time due to boiler cleaning; (6) the nature and amount of the water-supply and its cost. If the above conditions are unfavourable, it may be desirable to use a gas engine or motor in preference to steam. The relative cost of the various sources of power differs greatly in different localities according to the greater facility with which one particular source of power can be obtained. Where coal is cheap and electricity dear, it is obviously advisable to use steam, or in works where little steam is used for drying purposes it may be advisable to use gas or oil engines. Where the power is only required for short intervals an electric motor is preferable to either gas, oil, or steam engines, if the current can be obtained cheaply. In some works it is desirable to use two or more different sources of power, one for driving the main machinery and the other for outlying plant such as pumps or haulage. In such a case a steam engine will probably be best for the former, and an oil or gas engine for the pumps. Haulage engines are a problem still awaiting solution, but if an endless rope or chain is used, a gas or oil engine is quite satisfactory, though not so suitable for a single rope or main-tail haulage. For outlying machinery an oil engine avoids the wastage and trouble of steam carried over a long distance, and it requires very little attention; electricity, if available, is even less trouble, but may be more costly.

Under special circumstances (such as those just mentioned) the use of a *gas engine* will often prove more economical than that of one driven by steam. This is particularly the case with gas engines having a suction-producer attached. Until recently, the gas used for engines has been chiefly that supplied for illuminating purposes by the local gas company. This in several respects is not the most suitable as fuel, it being almost entirely manufactured for use as an illuminant. With engines of moderate size, on the other hand, a gas-producer of the ordinary type which supplies the gas under pressure usually entails an unduly large expenditure on the producer. If, however, the engine is so arranged as to draw the gas into itself by suction, a much smaller and less expensive producer is possible, with the result that gas engines may play an important part in the machinery of the clayworks of the future. They have numerous advantages over steam engines in regard to economy of fuel, and need but little attention, while no steam boiler or boiler attendant is required.

There are several forms of gas engines and producers on the market which are quite suitable for use in clayworks. Readers who are interested should consult some of the many books published on this subject. The increasing use of dryers, etc., heated by kiln or producer gases is decreasing the use of steam and causing an increase in the use of gas engines in clayworks, especially in the United States. The recent development of gas engines with portable producers for use on motor cars should produce an excellent type of engine for pumping purposes in clayworking and quarries.

Starting a Gas Engine.—Each morning, before starting, the engine should be thoroughly examined to ensure everything being in good order. The valves and ignition apparatus should be carefully inspected and the necessary parts of the engine properly lubricated. The following require careful attention whilst the engine is running:—(1) Correct adjustment of mixture; (2) correct compression; (3) correct timing of valves and ignition; (4) effective governing; (5) good circulation in the water jackets; (6) good, but not excessive, lubrication. When stopping the engine, the load should be taken off before the supply of fuel is cut off. This avoids straining the engine when it is slowing down and also facilitates restarting it when required.

Average Fuel Consumption per B.H.P. hour (full load).

Gas engine (coal gas)	22 cub. ft.
,, (producer gas)	1 lb. anthracite.
Oil engine (paraffin)	0·8 lb.
,, (semi-Diesel)	0·55 lb.
,, (Diesel)	0·4 lb.
Petrol engine (tuned)	0·6 lb.

Mechanical Efficiencies (constant speed).

Fraction of load	¼	½	¾	Full.
Mechanical efficiency	0·5	0·67	0·75	0·8

Oil engines are being increasingly used in clayworks where steam is not employed for drying the goods; in other cases it is cheaper to use a steam engine and to employ the exhaust steam for drying. Oil engines may also be used with advantage in isolated parts of a plant, such as pumps, and to provide power in addition to that available from a steam engine. Engines using refined oil or petrol are seldom practicable in clayworks on account of the high cost of oil. Where crude oil can be obtained fairly cheaply, oil engines are very useful. They have the advantage of being compact and clean, and require little attention if kept in good condition, but they require more skilled care than a steam engine and are often costly to instal and maintain.

Electric motors have only been used to a limited extent in the clayworks of this country, because so many of those works are too remote from a public supply of electricity. This disadvantage is likely to be much less in the future, and electricity will then be a suitable source of power in clayworks in which the goods are not dried by steam; otherwise it is cheaper to use a steam engine, and to pass the exhaust steam into the dryers.

The unit of electric power is the *Watt*, and is the work done by a current of 1 ampere against a resistance of 1 ohm. 746 watts equal 1 mechanical horse-power. Generators are rated in kilowatts; 1 kw. = 1000 watts. The *Kilowatt Hour*, or number of kilowatts used divided by the time of use, is also known as the Board of Trade Unit (B.T.U.); it is the quantity unit upon which payment is made for power. Another way of stating the watt unit is: 1 watt = 1 volt × 1 ampere.

The expression $\frac{\text{power (watts)}}{\text{volts} \times \text{amps.}}$ is termed the *power factor*.

Power (watts) in single phase A.C. circuit = volts × amps. × power factor = volts × amps. × cosine of angle of phase difference.

In a three-phase A.C. circuit—

$$\text{Power (watts)} = \sqrt{3} \times \text{volts} \times \text{amps.} \times \text{power factor,}$$
$$= 1{\cdot}732 \times \text{volts} \times \text{amps.} \times \text{power factor.}$$

In three-phase work, windings may be connected in *star* or in *mesh* (*delta*)—

Star windings—Line voltage = 1·732 × phase voltage.
Line current = phase current.

Mesh windings—Line voltage = phase voltage.
Line current = 1·732 × phase current.

Thus, if in a *star*-connected system, in which the voltage between a pair of mains is V, apparatus (say lamps) is connected between one main and a line run from the neutral point, the voltage between the terminals of the lamps will be $\frac{V}{1\cdot732}$. By this means, different voltages may be obtained for power and lighting from the same circuit.

The theoretical efficiency of a series motor is $\frac{I_a E_b}{IE} = \frac{E_b}{E}$;

The commercial efficiency of a series motor is $\frac{I_a E_b - W}{IE}$.

The theoretical efficiency of a shunt motor is $\frac{I_a E_b}{IE} = \frac{I_a E_b}{(I_a + I_{sh})E}$;

The commercial efficiency of a shunt motor is $\frac{I_a E_b - W}{(I_a + I_{sh})E}$,

where E = applied voltage, E_b = induced voltage, I = line current, I_a = armature current, I_{sh} = shunt current, W = loss (in watts) due to eddy currents, friction, etc.

Like gas engines, motors are not nearly so elastic as steam engines, and the liability to serious damage by overloading requires far greater consideration. With reasonable care and the installation of sufficiently powerful motors and good fuses the risks of damage are greatly reduced, and are probably no greater than those connected with steam engines or boilers. The facilities offered by a public supply of electricity for increasing the amount of power used in a works are important, and the absence of breakdowns and irregularities in the supply of power—such as occurs with steam or gas engines in a clayworks—tends to greater efficiency and to an increased output. If care is taken to switch off the power when it is not required, and to distribute it wisely by using a separate motor for each machine, or by only connecting a few machines to one motor, the greater efficiency attained often effects a considerable reduction in the cost of power, as the losses occasioned by belting, etc., are often far greater than is commonly realized. As compared with gas, oil, or steam engines, the chief advantages of electricity are:—(1) freedom from vibration and noisy exhaust; (2) small floor-space required and low first cost; (3) no expensive foundations are needed; (4) the motor may be coupled directly to the machine it drives, thus eliminating belt losses; (5) a minimum amount of attendance is required and a maximum efficiency is obtained; (6) the cost of lubricating the motor is low; (7) there are no delays in starting any machine; (8) the simplicity of electricity as a source of power is very noticeable; (9) the cost of electricity is strictly proportional to the power used, and no useless running of idle machinery occurs when electricity is employed. Against these notable advantages must be set (*a*) the greater cost of electricity per horse-power; (*b*) the difficulty of obtaining a supply in some localities; (*c*) the necessity of providing steam for drying purposes in most clayworks; (*d*) the lack of elasticity in electric power, especially when used to drive grinding and crushing plant, so that unnecessarily large motors have to be employed for these machines and are consequently working inefficiently, because most of the time they are not developing their normal power.

Before installing either a gas engine or electric motor, the fact that when steam is used for drying the cost of power in a steam engine is practically *nil* should not be overlooked. Where the drying is conducted by means of fires or air-heaters, electric motors may prove the most economical form of prime-mover, especially as, when not in use, any machine can be 'switched off.'

The design and construction of motors and engines for use in clayworks is beyond the scope of the present volume, so that the following paragraphs are confined to suggestions which most clayworkers will do well to follow, quite independently of the type of engine in use at the works in which they are interested.

Precautions.—It is very important to provide strong foundations of ample size for the engine, as a loose foundation with defective bolting is a prominent cause of breakdown and of many minor but costly troubles. The design and construction of a good foundation requires a considerable amount of skill and should not be entrusted to an amateur.

If success is to attend the employment of the many varieties of engines (prime-movers) employed in clayworks, the utmost cleanliness should be observed, although this is admittedly difficult in the presence of the large quantities of dust which accumulate in most clayworks. It must, however, be remembered that such dust, by getting into the bearings, tends to wear away machinery far too rapidly and greatly shortens the life of any engine, while it is, at the same time, a source of continual loss of power by the unnecessary friction it causes. Hence, one of the first points to be aimed at is to secure a clean engine and a clean engine-house.

Another matter which requires continual attention is that of tidiness. If things are allowed to lie about 'just anyhow' in the engine-house, an accident will sooner or later occur through some tool or other article getting access to the machinery. There is no reason why the engine-house of a clayworks should not be as clean and tidy as any room or office in the works, and failure to secure absolute cleanliness and order in this department will not only result in loss of economy in working and a shorter life of the plant, but will, in addition, prove a source of continual danger to the workmen engaged in it. It is therefore imperative that there should be a place for every tool and appliance used by the man having control of the engine and plant, and care must be taken that they are kept in their places when not in actual use.

It need hardly be pointed out that all repairs should be attended to at once—for a stitch in time saves nine; also that loafers and others having no direct interest in the engines should not be allowed in the engine-house.

Lubrication should be undertaken regularly and systematically, and all used oil should be carefully collected and placed in a 'saver,' so that it may be used again instead of being wasted. A little attention in this respect greatly facilitates the work of keeping the engine clean. Where high-pressure engines are employed, it is especially necessary to avoid the use of animal fats and oils as lubricants, as these are apt to decompose (particularly in the presence of steam) into stearic and other acids which corrode the metal-work and may in this way cause a direct loss of power. For gas and oil engines the lubricant should have a very high flash-point (above 400° F.), so as to avoid undue decomposition of the oil. It is especially important to use an oil which does not leave a deposit of carbon in the cylinder, as this reduces the efficiency of the engine and causes poor ignition. The oil should also have a low freezing point, so that it will not solidify in very cold weather. It is sometimes necessary to use one kind of oil in hot weather and another in cold.

The bearings should be felt from time to time whilst the machinery is in motion, and if any are found to be getting hot, more lubricant must be applied; or if this does not succeed, a mixture of graphite (blacklead) and oil may be applied to the heated part. Should this also fail, the machinery must be at once stopped and the cause of the heating ascertained and remedied. Local heating of this kind is sometimes due to the stoppage of the oil-hole of the bearing; hence, it is advisable to clean these holes out from time to time. As it is only the oil that is actually in moving contact that is of value as a lubricant, the flooding of any part with oil is generally only a waste of good material and serves no useful purpose (see also p. 40). A device which prevents the waste of oil common with sight-feed and bottle lubricators, and has further advantages of automatically cutting off the supply when the engine or other machine is not in action, consists of a rotating wheel driven from the machine and partly immersed in a bath of oil. A steel scraper removes the oil from the wheel and carries it in measured doses into a funnel and pipe connected to the bearings.

The bearings must not be run with loose caps, and the brasses must be sufficiently tightly screwed to make a good bush (a liner being inserted if necessary).

Heated bearings are also an indication of several defects: (1) new and therefore rough bearings; (2) bearings too tightly screwed down; (3) an imperfect fit between the axle and the bearing brass; (4) badly turned brasses; (5) warped or bent brasses; (6) cracked or broken brasses; (7) deficient lubrication; (8) too thin an oil; (9) oil feed in the wrong position; (10) dirty oil.

Lack of alignment in shafting will cause heated bearings in some cases, though it is usually shown in an undue tendency of the belt to run off the pulleys.

It is poor economy not to have *spare parts* of machinery in stock, as the time spent in waiting for a new part to be ordered will often cost more than the interest on the capital locked up in stocking the spare piece. When such a spare piece is used and the one it replaces cannot be repaired or used again, another spare piece should be ordered at once. It seldom or never pays to put off such orders. It is also advisable, when the new part arrives, to see that it is correct in every particular, so that when it is required in a hurry no unnecessary alterations and fitting have to be done.

Keeping the *packing* of the engine in good condition requires some small amount of skill and fairly frequent attention, but it is well worth the labour bestowed on it, and the cost will be easily compensated for by the saving of power effected. A similar amount of attention should be paid to the fitting of the piston rings in the cylinder, as any leakage between these means a direct loss of power, which may often go on for a long time unsuspected if the inspection of the interior of the cylinder is not systematically carried out. The essentials of a good packing are that it shall not be affected by water or oil, that it shall be flexible and heat-resisting, and that nothing in its composition shall injure the moving parts either by abrasion or corrosion.

The primitive form of packing was hemp-yarn saturated with tallow, but for high-pressure steam asbestos is usually substituted on account of its heat-resisting properties. With very high piston speeds white metal is frequently added to the asbestos, either as a central core or woven in. Care should be taken that the diameter of the packing used is sufficiently large: if anything it should be slightly larger than the space it is intended to fill, and the length such that the ends just butt, leaving no space or overlap. Where soft metal packing is used its flexibility and contact with the rod are ensured by the use of springs assisted by the steam pressure. Though somewhat greater in initial cost, it will be found more economical to use metallic packing on all rods over 1 inch diameter. The choice of the metal for packing is very important. Very soft cast iron is usually the most satisfactory, as it is strong, withstands heat, and is not readily corroded. Copper alloys are easily corroded, and white metal is very brittle and easily affected by heat. The most satisfactory form of packing is rectangular in section. It should be surrounded by a solid L-shaped ring which is made to fit accurately into the packing box, eight or ten of these rings being usually required. White metal V rings may also be used at the end furthest from the heat. The rings must be properly lubricated, or excessive wear will result. Provision should also be made for draining away the condensed steam.

In the case of steam engines it is very important not to allow the temperature of the engine-house to fall below the freezing point of water (32° F.), or the condensed steam may freeze in the cylinders, valves, and pipes, and so cause damage. This is not so vital a matter in this country as on the Continent, but the author has come across more than one case in Britain where an engine was damaged through neglect of this simple precaution.

The *power* of an engine is the rate at which it is capable of doing work. The term is one suggested by James Watt, who found by experiment that an average heavy horse raising bales from the ground to the upper floor of a warehouse can elevate about twenty-two thousand pounds one foot in one minute. Allowing 50 per cent. as an ample margin of safety in favour of the horse, Watt adopted as his 'horse-power' the rate of 33,000 foot-pounds of work per minute, or 1,980,000 foot-pounds per hour. This figure has now been universally recognized as the standard unit of mechanical power in spite of its arbitrary nature.

Several terms are used to denote the power of engines; thus, the ***nominal power*** is based entirely on the dimensions of the engine cylinder. This is no longer satisfactory and should be avoided, as it eliminates all consideration of the steam pressure and the number of strokes of the piston. There is a tendency to reintroduce this term in connection with motor engines; this should be discouraged.

The *indicated horse-power* of an engine is that calculated from an indicator-diagram as described under 'Power' in Chap. XIII.

It is convenient to attach a pressure gauge to each end of each cylinder of a steam engine in such a manner that the pressure can be read after turning a small cock. If the speed of the engine is constant, the pressure will be directly proportional to the indicated horse-power.

The horse-power of an electric motor may be calculated by multiplying the number of ampères used in one hour by the voltage of the current, and then multiplying the product by 1·34. As one electrical unit per hour is equivalent to 1·34 horse-power, the power of an electric motor may also be found by multiplying the number of units used per hour by that figure.

The *brake horse-power* of an engine is the power developed in a brake applied to the fly-wheel. It represents the ***net power*** available for actual work.

The *testing* of the horse-power of engines, whether by indicators or brake tests, is somewhat beyond the province of the ordinary clayworker. It should not, however, be neglected on this account, as such tests serve to point out when and where the engine needs adjustment and attention, and if carried out with sufficient frequency will often save serious loss of power, and even prevent serious breakdowns of the plant.

It is, indeed, very unfortunate that in so few works 'indicator-diagrams' of the engines employed are taken at frequent and regular intervals. The cost of doing so is small, and the indications obtained are of great value in pointing out the defects of the engine and their increase by wear and tear, and in securing more economical working (see 'Power' in Chap. XIII.).

In cases where the *output* cannot be directly weighed or measured, it is often wise to attach a 'counter' to the engine and other machines, and in this way an approximate idea of the work done may be ascertained. Thus, if the engine be driven slowly so as to lessen the work of the men at the machinery (mills, etc.), or if stoppages are numerous, the number of revolutions of the counter will be below the normal, and an inquiry may then be made as to the cause. It is, however, important to ensure that the counter is not tampered with. A continuous recorder is often better than a simple counter, as it shows the times when the output was produced and those when the machines were idle.

It must, however, be observed that different works are provided with very different facilities for economical working, and it does not by any means follow that what one works can do is equally applicable to all. Thus, in many works, the latest milling and making machinery has been put down with but little regard to the location of the engine-house and the description of engine. It suffices most managers to know that the engine can supply the necessary power—the cost of so doing is comparatively seldom considered,—so that, even with the best machinery, the engine may be located in some out-of-the-way corner, clogged up with dirt and water from leaky valves and condensed steam, and be in a general state of dust, mess, and slop, with steam blowing to waste at several places. If the proprietor of such a works can summon enough courage to have the matter properly investigated, and to try the effect of following the advice of a competent engineer, he will be surprised at the economy which will result.

Even when the engine and engine-house are kept in a thoroughly clean condition, much of the difference between economical and wasteful working may be due to the way in which the various operations of running the plant are performed, and to the promptitude with which repairs are attended to. A small jet of steam may not have a very imposing appearance, but the clayworker who studies his coal-bill will seize the first opportunity of having the leak made good. An even more insidious waste often occurs at the steam trap, which should be frequently inspected to see that it only opens to discharge water, as almost all these valves get out of order in course of time, and so waste steam instead of saving it, unless they are carefully watched. This is partly due to the use of steam traps which are too small to be efficient. The makers' statements as to suitable sizes are generally unsatisfactory for clayworkers. Double the capacity specified in the makers' lists will usually be found more economical.

Quite apart from any repairs which it may be necessary to make, the question of *cleaning* is one which calls for attention; the engine must be kept as clean as possible, and yet no unnecessary amount must be spent on cleaning it. Thus, in the matter of cotton-waste two methods may be adopted: the first is to decide exactly what can be afforded for the waste per day, or week, and not to give a scrap more until the man in charge is tired of asking for it, and so does not keep the engine clean; whilst the other method is to allow the man as much cotton-waste as he wants, to make him account for all he receives, to keep a sharp look-out on the condition of the 'used-up' stuff, and to insist on the engine being kept clean. If the latter plan is adopted, it will usually be found to be the cheapest in the end, particularly if the waste be used systematically in such a way that the oldest is used for the dirtiest work, the next for cleaning-up generally, and the newest waste for the fine work. Even when too dirty for the engine-house it can still be used for the roughest machinery, or the boiler, and finally, when thoroughly soaked with oil, it may be used as fuel. White waste is a luxury only to be found in Corporation works, but care must be taken not to go to the other extreme and buy waste with much grit or sand in it, or the machinery will soon suffer; and there is a further possibility that, if pins and other sharp objects are present, the cleaner may have a poisoned hand. The use of 'meat-cloths' (cloths which have been used as wrappers for frozen meat) instead of waste is often recommended. The usual claim is that they may be washed and so used over again, but this is not the case when mineral lubricants are employed, as the cost of cleaning then becomes prohibitive. Cloths have the advantage of not leaving loose strands about the machinery, but this is not of such importance with clayworking machinery as it is with more delicate engines, such as are used for electrical work.

Much labour and cost may often be saved by cutting down the amount of polished work on an engine as much as possible by covering all parts that it is not absolutely essential to keep bright with lacquer, Brunswick black, or paint.

Transmission of Power.

The chief means of transmitting power at the present time are electricity, gas, steam, compressed air, belts, chains, and ropes. Of these, the first four have been dealt with under the heading of 'Sources of Power'; the remainder are not in any sense sources, but only transmitters, of power.

Belts, ropes, and chains, though differing in some respects, may be classed together for convenience. Belts and ropes are more commonly used in clayworks on account of their freedom from metal, but, if the wheels to which chains are attached are suitable, they have several advantages—notably that of durability and freedom from stretch—in the use of chain-belts for driving.

Belts for use in clayworks should be made so as to resist the combined action of damp and dust; hence, the material of which they are composed should be dense, waterproof, and not apt to stretch. Leather belts—although excellent in every way—are now considered too expensive for long drives, and are being rapidly displaced by those made of composition consisting largely of rubber, canvas, and similar materials. 'Balata,' 'Teon,' and 'Camel' brands are three of the best known of this type of belt. They have the further advantage of being waterproof, and can be used in the presence of water and steam. A really good belt of this type does not deteriorate so rapidly as leather; it has much less contraction or expansion when subjected to a change of temperature, and will not stretch so much under normal conditions.

Oak-tanned leather is the most suitable for leather belts, leather tanned with extracts not being good, although chrome tannages are rapidly increasing in favour. Considerable care and skill are required in choosing leather for belting, those made from the portion of the hide immediately over the kidneys being the strongest.

The power of a belt depends on its contact with the pulleys, and may, to some extent, be increased by (1) the use of wider belts and pulleys, (2) by adjusting the distance of the pulleys from each other, (3) by tightening or slackening the belt, and (with high speeds) (4) by perforating the rim of the pulleys so as to allow the air between them and the belt to escape more rapidly.

As belts transmit the power entirely through the frictional contact they make with the pulleys on which they move, the size of the belt is a matter of some importance. As this contact only extends over one portion of the pulleys at once, the arc of contact should be made as large as possible. This may often be most efficiently done by making the lower side of the belt the driving side. Large pulleys transmit more power than smaller ones bearing the same ratio of diameters to each other, but wide belts are less effective per inch of width than narrow ones. Short belts should be avoided when long ones can be used, but this must not be understood to mean that very slack belts are desirable.

Power is often wasted by the belt slipping on the pulley. This can largely be avoided by a careful study of the conditions,[1] avoiding the use of too narrow a belt, too short a distance between the pulleys, or by having one pulley too vertical above the other. It may also be reduced by using a wooden pulley which is covered with a leather band nailed on whilst wet so as to shrink in drying and grip the wheel. The use of a good belt-dressing also reduces slipping, but preparations containing resin should not be used for this purpose, as they damage the belt.

To find the length of a belt when the pulleys are already fixed in position, add the diameters of the two pulleys together, multiply by 1·57, and add twice the distance between the shaft of the pulleys to the result. Thus, if one pulley is 12 inches diameter and the other 18, and the distance between the shafts of the two is 20 feet, to find the length of belt necessary add 12 and 18 (= 30 inches), which multiplied by 1·57 = 47 inches. On adding to this twice the distance between the pulley-shafts (= 40 feet) it will be found that a belt 44 feet long will be needed, but a somewhat greater length than this should be ordered to allow for the overlap if an overlapping joint is made.

If one pulley is fixed on the shafting, to find what size of pulley will be required to afford a given number of revolutions per minute, it is simply necessary to multiply the diameter of the first pulley by the number of revolutions per minute it makes, and to divide the result by the number of revolutions per minute which it is desired to give to the second pulley. Thus, to make one pulley with a diameter of 18 inches and making 50 revolutions per minute cause a second pulley to turn 80 times per minute, it will be necessary for this second pulley to have a diameter of $11\frac{1}{4}$ inches, for $\frac{18 \times 50}{80} = 11\frac{1}{4}$. Similarly, to calculate the number of revolutions per minute which a particular pulley will make—the diameter of this and the driving pulley and the revolutions per minute of the driving pulley being

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[1] A mistake which is occasionally made is to drive from a large pulley on to a small one, and then, from a second small pulley on the same countershaft, to a large pulley on the brick machine. The use of these small pulleys causes a serious loss of power which would be avoided if large ones were used.

known—the product of the last two, divided by the first, will give the required result. Thus, a pulley of $11\frac{1}{4}$ inches diameter driven from one of 18 inches and making 50 revolutions per minute will make 80 revolutions per minute, because $\frac{18 \times 50}{11\frac{1}{4}} = 80$ revolutions.

The thickness of a belt should depend somewhat on its composition. For the best leather it is usually taken at one-hundredth of the diameter of the driving pulley.

The width of a single leather belt may be taken as equal to 1000 × H.P., and divided by the velocity of the belt in feet per minute where there is not any great inequality in the diameter of the pulleys, but with belts of specially high working tension (say 150 lbs. per inch of width), half the width given by the above calculation will be sufficient.

The width of a pulley should be somewhat greater than that of the belt; 1 : 1·2 is a very suitable ratio, so that a 5-inch belt will be carried on 6-inch pulleys, though some engineers would prefer $6\frac{1}{2}$-inch.

Many tables have been published from time to time on the proportions of belts, but the assumption of R. Berry that a single leather belt of good quality transmits one watt, or 1/746 H.P., per foot velocity per minute per inch of width is sufficiently accurate for most clayworkers' purposes. This may be expressed as follows:

If W = width of belt in inches,
V = velocity of belt in feet per minute, and
H.P. = horse power.[1]

Then $$\text{H.P.} = \frac{W \times V}{746} \quad \text{and} \quad W = \frac{746\ \text{H.P.}}{V}.$$

Thus, a belt $7\frac{1}{2}$ inches wide and travelling at 1000 feet per minute will transmit $\frac{1000 \times 7\frac{1}{2}}{746} = 10$ H.P., or conversely, a belt travelling 1000 feet per minute to transmit 10 H.P. must be

$$\frac{746 \times 10}{1000} = 7\tfrac{1}{2} \text{ inches wide.}$$

The correct distance between the pulleys depends on the ratio of their diameters, thus:—

If the ratio of diameters of pulleys is 2 : 1, the distance between them should be at least 8 feet; if 3 : 1, 10 feet; if 4 : 1, 12 feet; if 5 : 1, 15 feet.

The speed of belts should not usually exceed 3000 feet per minute for main shafting or 2000 feet for lighter work.

Smoothness of running of all belting is essential to all economical working. It may be secured (1) by careful adjustment of the belts to the proper tightness, (2) by the use of fasteners (or couplers) which do not noticeably project on the side of the belt in contact with the pulleys, and (3) by correctly running pulleys. Jumping, or rocking, of the belts is not only dangerous to those who may be near when the belt comes off the pulleys, but is also a serious source of loss of power. The use of too narrow pulleys or of too thick belts improperly stretched is the cause of much loss of power. It is better in every way to have a broad, single belt than a double one of twice the thickness.

It is very unwise to use a very light belt for heavy work, as this only

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[1] For belts more than 10 inches wide the result should be *doubled*, to allow for the additional power transmitted by the thicker belt—wide belts being usually thicker than narrow ones.

subjects the belt to strains which are beyond its capacity. The result is that the belt is stretched and delays are occasioned in tightening it. Moreover, the use of a belt which has been unduly stretched reduces its durability and hastens the time when a breakage will occur.

Few clayworkers realize how seriously they overload the belts on their machinery, and how much they would save in fuel and repairs if the belts were replaced by others which are more capable of transmitting the required power.

Driving belts should be kept in good condition, and when their surface shows signs of undue glazing, they should be cleaned and treated with a suitable belt-dressing.

All belting should be washed occasionally with soap and tepid water, and afterwards oiled with castor, or neatsfoot, oil. Rosin, colophony, and similar adhesives should not be used. An excellent dressing for rubber belts is made by melting 20 lbs. of beef tallow, allowing it to cool to about 50° C., adding 10 lbs. of cod liver oil, and then stirring until the mixture is cool. When the works are closed for the winter months it is especially necessary to grease the belting well and to put it away in a dry place. Dubbing is the best grease for this purpose, but the belt should be carefully cleaned from all dirt before it is applied. When well saturated with the grease the belt should be rolled up and kept in this form until it is again required.

Steel driving-belts are used in some engineering works, and are stated to have very little slip and to be more durable than those made of other materials. Steel belts do not stretch in use and, being much stronger, they seldom break. A steel band 1 inch wide transmits more power than a leather one 6 inches wide, so that narrower pulleys may be used. Steel belts are not affected by oil, though it is necessary to preserve them from rust.

Rope-driving has already been referred to as giving a smoother drive than belts, a matter of great importance in connection with machinery used in making ware.

For this reason, it is largely used in place of belting for transmitting power from the engine to the shafting, particularly in brickworks and potteries. The contact between the rope and pulleys is much greater than that between a belt and pulleys, owing to the wedging action of the rope in the grooves of the pulley, so that rope driving is more positive than that of belts. Ropes have also a much greater freedom from breakdown, as they seldom give way without warning, and in the multiple-rope system the snapping of a single rope need not stop the machinery, as the remaining ropes will suffice until the broken one has been repaired. Rope-driving is also satisfactory for long distances if proper care is taken with regard to the diameter and shape of the grooves in the pulleys and to the proper selection and construction of the ropes.

Rope-pulleys should be large (not less than thirty times the diameter of the rope), as the internal compression caused by the rope bending round too small a pulley quickly causes it to break. The grooves in the pulleys should have an angle of about 45° and be rounded at the bottom to prevent the rope wearing out of shape. The actual diameter of the groove must be almost exactly that of the rope, as all ropes become somewhat thinner in use, and if too small for the groove will not have sufficient gripping power and will, therefore, slip. On the other hand, excessive gripping will rapidly wear aware the rope and so unduly shorten its life.

The unnecessary use of carrying pulleys also forms a common cause of short-lived ropes; no more carriers should be used than is absolutely necessary.

The thickness of the ropes used varies from 1 inch to $1\frac{3}{4}$ inch, according to the amount of power required and the diameter of the pulleys which can be employed. As explained, the rope must fit the sides of the groove and not touch the bottom.

In ordering new ropes a template of the grooves on the pulley should be furnished to the rope-maker.

The life of the rope will depend chiefly on the points above mentioned, and under good conditions, when well looked after, a rope should last several years. In some cotton mills where cotton ropes are used for driving the machinery the ropes have lasted twelve years and more, but the dust from the clay in a clayworks prevents most ropes from lasting more than eight to ten years. Manilla and hemp ropes are frequently employed, but they are neither so durable nor so good as cotton ones.

Ropes for driving purposes are usually driven at a speed of 4000 to 4800 feet per minute, or about 3000 feet per minute for small loads on small pulleys; above this speed centrifugal action begins to interfere seriously with efficiency.

The power transmitted by ropes is highest (taking into effect centrifugal tension) at a speed of 4800 feet per minute. At this speed, Pickworth found the following data to be accurate:—

Diam. in in.	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
Horse-power,	8·7	12	15	20	24·2	29·2	34·7	40·8	47·3	61·7

A table showing the power transmitted at other speeds is given in the Appendix.

Ropes are usually run with much more slack than belts, the under-side being the driving side, so that the slack on the top of the pulley may give the rope a better contact. If, however, there is a great tendency for the rope to bounce, or surge, it is better to let the upper side drive, so that the slack falls away in one long sweep. Tightening the ropes will minimize surging, but the real cure is to keep the load more uniform.

Although cotton ropes have a far smaller tendency to stretch than hemp or Manilla ropes, yet all ropes stretch more or less in use. When this is the case they should be taken up properly, and not, as is sometimes the case, shrunk by drenching them with water. This remedy is worse than the disease, for the drenched rope becomes slacker than ever on drying.

For a similar reason cotton or hemp ropes, unless waterproofed, should not be used in exposed positions.

Driving chains are particularly useful for slowly moving machinery where the conditions are not suitable for belts. Such chains have a very high efficiency (over 99 per cent.), are very strong, require little attention, and are very durable. They are free from slipping, and avoid the difficulties associated with tight belts.

General Machinery.

There are so many varieties of machinery employed at the present time in connection with different branches of working clay that it is not possible to give a detailed description of each. The machinery essential to one branch is often quite useless to another, so that for details of this nature the larger special works (*Modern Brickmaking*, and others, in the Appendix) or the catalogues of makers of such machinery must be consulted. There are, however, several points which should be kept in mind by all those having the control of machinery, some of the more important of which may here be mentioned.

1. All machine-parts liable to breakage should be kept in duplicate, and as soon as the duplicate is taken into use the original part should either be repaired immediately or a fresh part ordered without delay. The comparatively small amount of capital locked up in spare parts on stock is more than counterbalanced by the saving when a breakage occurs, providing, of course, that such spare parts are kept in good condition and accessible.

2. The installation of a definite and easily worked system of signals (preferably bells), which will at once cause the engineman to stop the machinery near to the place when signalled, and to arrange that this signal shall always be used for stopping the machinery and shall be promptly attended to; in this way serious accidents may often be avoided.

3. All machines should be kept well lubricated, but this is not to be understood as implying a general bath of oil; any oil or grease where it is not wanted is not only so much waste of material, but is also liable to cause damage to the goods being made, especially with certain classes of clay.

The protection of workmen from liability to accident from the machinery is probably sufficiently provided for under the Factory Acts, and so needs no further reference here.

The general machinery in a clayworks may usually be classed under three heads:—

(*a*) Machinery for preparing the clay.

(*b*) Machinery for making articles.

(*c*) Machinery for conveying clay, etc., from one part of the works to another.

Other machinery for maintenance, repairs, etc., should be available, but cannot, in a sense, be regarded as clayworking machinery. Under the latter term are included such appliances as lathes, drilling machines, and similar plant employed in the engineer's or smith's shops.

Machinery for Grinding.[1]

Clay Grinding.—Grinding is a term used to express two distinct processes, viz. the crushing of clay and the formation of a paste. It is an operation which requires more care than it often receives, if the material is to be brought into its proper state of fineness at a sufficiently low cost. The exact amount of grinding required will depend on the clay itself and on the articles into which it is to be manufactured.

It is, in almost every case, of the greatest importance that the clay should be sufficiently weathered (p. 47) before it is sent to the grinding plant, as in this way considerable wear and tear on the machinery may be avoided and a far better product result. In fact, it may be stated as true for the majority of clays, that unless the clay is well weathered before use, some inconvenience is bound to be experienced either in the lack of durability of

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[1] Illustrations of clay machinery have been purposely omitted, as the present volume is intended chiefly for clayworkers, who are assumed to have a general knowledge of these machines. Detailed descriptions may be found in some of the larger treatises, such as the author's *Modern Brickmaking* (see in Appendix).

the goods or in the additional expense of working the clay. There is no agent known which is so perfect a disintegrator as the action of the weather for making the particles far finer than can be obtained by grinding alone, and in consequence giving a greater plasticity and ease of manipulation.

From a clay-grinder's point of view there are two classes of clay—(1) those which have impurities in them which must be removed and not ground up with the rest of the clay; and (2) those in which the impurities, if there are any present, are of such a nature that they require no separation during the process of grinding. The latter class may be still further divided into clays which are relatively 'soft' and those which are 'hard.'

Cleaning Clays.—In the first class of clays are those containing a notable proportion of stones, and if these are to be removed some form of sieve must be employed. The usual method is to feed the clay on to a pair of conical stones or rollers in which the clay is flattened and passes between the rolls, but the stones remain behind and are taken away by a supplementary roll provided with points, though in many cases this is not necessary. Such machines are not very efficient, as the rolls crush some of the stones and send them through with the clay.

A more recent, and in many cases a more efficient, method consists in passing the wet clay into a pug mill with perforated sides. The clay is converted into a paste and escapes through the perforations, the stones being retained inside the mill and removed at intervals. Various modifications of this arrangement are to be seen in the Bohn, Elapidator, and Diesener clay-cleaners. These machines have now replaced the older form, in which the clay and stones were passed in at the open end of a vertical, perforated cylinder until the latter was full, and a piston was then forced into the cylinder so as to squeeze the clay through the perforations, the stones remaining inside the cylinder. When no more clay could be squeezed out the piston was withdrawn, the stones removed, and the operation commenced afresh. Two cylinders should be arranged so that whilst one is being acted on by the piston the other may be filled with the stony clay. Unfortunately, a considerable proportion of clay adheres to the stones and is wasted, moreover, the wear and tear of these grids is excessive and the machines are expensive to construct and use and if the proportion of stones in the clay is more than 10 per cent. they have a low output.

For these methods to be effective, it is essential that the clay shall be sufficiently soft and 'open'—a hard shale cannot be treated in this manner.

When clay is admixed with sand and similar materials which it is necessary to remove, it may be roughly ground and then washed, when the sand will settle out before the clay, and may, in this way, be separated (see p. 50). As, however, the washing of clay is very costly, it is only undertaken in the case of those classes of goods where a specially fine clay is needed.

For certain purposes, it is usual first to pass the clay through rolls set 2 inches apart, and to crush the stones somewhat while allowing of the greater portion being separated or 'cleaned' as just described. As some of the stone gets crushed sufficiently fine to pass through the holes, the separation is by no means so perfect as by washing; but it is far less costly, and is sufficiently effectual for many purposes. Sufficient water must be added to the clay to convert it into a very soft paste, or this treatment will not be satisfactory. Unfortunately, so soft a paste is usually too wet for manufacturing purposes.

Crushing Clays.—When the whole of the clay, as delivered to the mill.

requires to be crushed, it is desirable, if it is at all hard and in sufficiently large pieces, to use some form of *Stonebreaker* or *Disintegrator.* This is especially the case with rock clays worked in large quantities; smaller amounts may be broken into small pieces by crushing rolls or by means of a hammer. For grinding burned material (pitchers, saggers, broken bricks), it is also advisable to use a preliminary breaker of this kind.

In stonebreakers, the material is crushed between two plates, one of which is fixed and the other movable, so that a very powerful crushing action is exerted. All stonebreakers of the jaw-crusher type should be of very solid construction and well lubricated. The surface of the crushing blocks should be specially hardened, and plates should be so fitted as to be easily replaced when worn. Stonebreakers are made with outputs varying from 2 to 12 tons per hour, and for grinding hard clays and admixed stones to pass through ½-inch ring require about 2 to 3 H.P. per ton.

In a modern type of disintegrator, an axle carrying radial beaters dashes the material against a serrated outer casing; a portion of the circumference of which is fitted with gratings to separate the powdered material will be found most convenient. A speed of about 3000 revolutions per minute will usually be found the most economical, and provided that pieces of metal are kept out of the material the machine will run for a long time without needing repairs. In any case, it is very important to only use a disintegrator in which the beaters may be easily and rapidly replaced (as is the case in all the best makes), and if this precaution is observed the damage done by breakage is rarely serious. In order to avoid 'vibration,' it is necessary that machines running at such high speeds should be carefully balanced; this is best accomplished by taking out the spindle and allowing it to roll on two carefully levelled knife-edges, and filing or chipping the heavier parts until it will remain indifferently in any position. A disintegrator of the 'bar' type will crush three times as much stone as a jaw-crusher of equal size, and yet it requires rather less than 1 H.P. per ton of crushed material, though, where very large pieces of rock are to be crushed, a jaw-crusher is preferable.

As all disintegrators produce a great volume of dust owing to the rapid motion of the air blown through them (after the manner of a ventilating fan), it is necessary to discharge them into a chamber, one wall (or the roof) of which is made of canvas or similar material, through which the air, but not the ground material, may pass. This canvas will require beating at intervals to remove the adhering dust, and must be at some distance from the discharging outlet of the machine, or the force with which the material is delivered will rapidly cut it to pieces.

Stonebreakers and disintegrators are rapid workers, but are not very economical of power when used to grind to great fineness; they should, therefore, be used to crush the clay to pieces not less than half an inch in diameter. They are most suitable for dry clays and shales, but are not well adapted for very fat plastic clays; but, fortunately, the latter can be readily dealt with in rolls. A 'smeary' material of this nature is, however, always a source of trouble when it has to be crushed.

When the clay is required to be rather coarse, as in the manufacture of common bricks, the grinding is chiefly carried out by means of *crushing rolls*, which may be either toothed, fluted, or plain, according to the kind of clay. When a single pair of rolls is insufficient, a second, and in some cases a third, pair may be used, the additional rolls being usually placed at a lower level, so that the clay may fall from one to another by its own weight. The diameter of these rolls may vary within considerable limits, but it is not advisable for them to be of less than 18 inches, or they will not grip the clay sufficiently to yield a good output, although when the clay has been previously reduced to small pieces the rolls may be much smaller than this. The distance between the rolls is also of great importance: if too far apart the clay is not sufficiently crushed, whilst if the rolls are too close together a great loss of power will ensue. The coarsest rolls should be placed two-fifths to three-fifths of an inch apart, the next somewhat less than one-quarter of an inch, and the finest rolls as close together as possible without touching. It is necessary to see that the correct distances between the rolls are strictly maintained; they should be examined each time the mill is used. For many kinds of clay, scrapers about one-eighth of an inch above the surface of the rolls are necessary to ensure the most effective working. They should on no account be allowed to actually touch the metal.

The final pair of crushing rolls in a series must be kept true and in good condition, or it will be impossible to reduce the material to the required fineness. It is quite customary to remove each roll in order to turn it true, but a grinding attachment is sometimes fitted on the frame carrying the crushing rolls and saves the time otherwise required to remove and replace the rolls. This attachment cannot be used satisfactorily where any turnings falling through the rolls would damage the clay.

Flaky clay, particularly when rather moist and adhesive, is difficult to work with rolls, but much help is often derived from driving one of the rolls rather faster than the other so as to *press* rather than to crush the clay between them.

When the clay contains any notable proportion of limestone, it is necessary to grind it very fine (see p. 2).

Limey clays—and others in which the grinding must be carried out so as to produce a fine clay—are most suitably treated in *edge-runners*, *pan mills*, or *pug mills*, and the clay may be ground either in the wet or in the dry state, according to its composition and the manner of its subsequent treatment. Hard clays should be passed through a stonebreaker or disintegrator, as already suggested, as this preliminary treatment saves much wear and tear on the pan mill. The construction of the edge-runner or pan mill is well known; and although machines by different makers vary considerably in matters of detail, the general principle is the same in all—a pair of rollers on a horizontal axle, crushing the clay on a metal bed, this bed being sometimes perforated and sometimes solid. The bed or pan may be fixed, but revolving pans are now largely used and possess several advantages. As the output of such a mill depends on the area of the crushing surface actually in use at any one time, it is usual to employ two or more rolls or 'runners' on the same bed, the width of 'tread' and the diameter of the runner being regulated to suit the particular clay. The power may be supplied to the runners direct—in which case the pan or bed is fixed—or to the pan, in which case the runners are made to revolve by the pressure they exert on the clay in the moving pan. The fixed pan is often considered to be the stronger mill of the two, as it enables a more solid foundation to be laid down, and there is less liability to damage the pan when the heavy rollers are raised several inches above the bed by a piece of stone which has got into the mill, and then drop suddenly down when the stone is passed. Where the clay will permit, however, there are several advantages to be gained by the use of revolving pans, and these are rapidly increasing in favour, although the fixed pans still hold their own in the case of clays requiring very heavy rollers to crush them. Edge-runner mills may be under- or over-driven as desired, the latter being in most cases preferable, as it keeps the gearing more out of the way of dust from the machine, facilitates access, inspection, and repair; it also allows more space underneath the pan for the collection of the ground material.

It is very important in grinding with edge-runners that the clay which has been crushed to a sufficient fineness should be immediately removed from the mill; its continued presence amongst the coarser clays only prevents the latter from being properly ground, and so lowers the output of the machine. It would appear at first sight as though this would be best accomplished by making the bottom of the pan into a sieve by perforating it with innumerable holes over its entire surface, but in practice it is found that this weakens it too much, and it is, therefore, the custom to allow the runners to roll on a solid plate and to remove the clay from this to the outer, perforated portions of the plate by means of scrapers attached to the main axle in the case of a fixed pan, or to the framework of the mill when a revolving pan is employed. The centrifugal motion imparted to the clay, in the latter case, is of great assistance in rapidly separating the fine clay, and this may be increased very considerably by perforating the sides of the pan as well as part of its base, and collecting the fine clay thus separated by means of an outer casing. There are, however, many different arrangements of the perforations or slots, according to the kind of clay to be treated.

The size of the perforations in the pan will vary with the different purposes for which the clay is to be used; for ordinary bricks $\frac{1}{4}$- or $\frac{1}{2}$-inch holes or slots may be used, but for glazed bricks, sanitary goods, and finer ware, the holes should be circular, and not more than $\frac{3}{16}$ inch in diameter, whilst for some purposes it is necessary to employ even finer perforations. Although the holes tend to wear most at the top, it is advisable to let them taper outwards (*i.e.* become larger in diameter as the bottom of the plate is approached), so that they will not clog up in use. From the point of view of durability the best pan mill is the one which has the greatest output for the smallest pan-area; consequently, the scrapers must be kept in proper relation to the bed if efficient work is to be obtained. For pans with small circular perforations, the scrapers should be close down on the bed, and both bed and scrapers must be true to each other; with slotted beds it is better to allow some clearance, as the clay is not so finely ground.

The output of a pan mill depends on the number of revolutions of the pan or of the rollers about the main axle, on the type of perforations used, on the size of the runners and on their number, and on the efficiency with which the powdered clay is removed from the mill. The quality of the product, on the other hand, depends on the breadth of the runners, the form of the pan (which regulates the number of times the material is passed under the runners before it is removed), and the time taken in the grinding. The last consideration is especially important in the case of wet grinding ('panning' or 'tempering') of the clay after it has received a preliminary crushing, has been mixed with water, and has been put into the pan for tempering and mixing. When this is the case, a solid (non-perforated) pan must be used and the material treated for a definite time with the mill running at a definite speed in order to secure uniformity of product. The time required naturally depends on the kind of clay, but usually it varies from fifteen to thirty-five minutes, the clay being removed by a kind of shovel with a handle working in a joint so as to secure leverage without much risk. It is, however, important that the plates composing the bottom of the pan should be kept exceedingly level, or the shovel may catch in one of the joints of the plates and cause a serious accident to the man at the mill. It is, in fact, wise to insist that the plate shall be cast in one piece when this method of operation is practised.

Continuous delivery mills are quite practicable as far as grinding dry clay is concerned, but for wet grinding they have not, up to the present, proved very successful, although a continuous mill of this description, which is simple in construction and capable of giving a product of uniform fineness and plasticity, is greatly needed. For some lean clays and siliceous materials continuous wet mills have proved quite satisfactory.

In grinding or preparing a clay mixture composed of several widely differing ingredients, it is advisable to consider the order in which they can most efficiently be ground. Thus, many highly plastic clays, which will cause difficulty if ground alone, may be easily treated when mixed with non-plastic materials before being put into the mill, it being a matter of experiment as to the proportions of each needed, and the desirability or otherwise of first grinding the less plastic constituents before mixing. As a general rule it may be taken that the earlier the different ingredients are mixed, the more complete will be their admixture in the final product.

Edge-runner mills with partly perforated pans possess great advantages over crushing rolls for clays containing such hard substances as pyrites, as the latter tend to remain on the pan uncrushed, and can, to a large extent, be eliminated from the clay by cleaning the pan each night. It is also much more difficult for the clay from a mill of this class to be contaminated with iron (nails, bolts, nuts, etc.), as such foreign substances are held back by the grate.

Much of the dust caused by rotating pans is due to the fan-like action of the scrapers underneath, and may be avoided by building a funnel-shaped well under the mill and dispensing with the scrapers altogether—the ground clay falling straight into the well or 'open base,' and being drawn out, in the usual way, by an elevator.

To secure the greatest output, edge-runners must not be overloaded, and must be fed regularly. A useful attachment indicates when a grinding pan is being overloaded, and consists of a bell-crank, one end of which is placed above the runners so that when the runner is raised too high above the bed it will move the crank and ring a bell.

A still better method is to replace the ordinary system of hand feeding by an *automatic feeding appliance*. These feeders are of several patterns, the three most generally used consisting of (*a*) a worm conveyor on which the clay is tipped direct from the waggon and is carried in a steady stream to the mill, (*b*) an open cyclinder with a rotating base plate which carries the material out of the cylinder and into the mill, and (*c*) a belt conveyor, with or without scrapers, and (*d*) a rotary scoop to deliver small quantities of clay in rapid succession. Each of these arrangements has its special advantages and limitations, for the details of which a larger treatise must be consulted. 'Automatic feeding' is, in almost every case, preferable to hand-labour, producing a maximum output for a minimum expenditure of power.

Grinding Non-plastic Materials.—The grinding of non-plastic materials for glazes, etc., whether in the raw or fritted state, is usually carried out by means of (1) edge-runners, (2) horizontal grind-stones similar to those in a flour mill, and which give a much larger proportion of flour than do edge-runners, (3) in a gyratory mill, (4) block mill, or (5) Alsing cylinder, or (6) a ball or tube mill.

Edge-runner mills have been described on pp. 77–79.

Mills similar to those used for flour are now seldom used in the clay-working industries.

Gyratory mills are of two types—those in which a cone rotates inside a cylindrical casing, and the various pendulum mills.

The *Pendulum Mill*, much used in the United States, has a crushing roller rigidly attached to the lower end of a vertical shaft suspended by a universal joint in such a way as to force the roll centrifugally against a ring or die. To the under side of the roll ploughs or stirrers are attached, and a fan above it raises the finer particles and throws them against the screen placed above the die. A dust-cover is arranged over the pan so as to prevent dust being blown into the air of the workshop. The pulley speed of the machine is 200 revolutions per minute, and a die of 30 inches in diameter is said to give an average output of 30 to 40 cwt. per hour at 25-30 H.P. of material passing a No. 50 sieve. This mill has the great advantage of suffering little damage from pieces of metal which may obtain access to it by accident, and the arrangement of the screen is such that its life is considerably longer than that of an ordinary screen over which the material flows. It is chiefly used for grinding fine materials of a dry nature, as flint, spar, chalk, etc., and is particularly valuable in the manufacture of Portland cement and clay dust for preventing explosions in coal pits.

Block mills are used for grinding flint. They consist of a circular pan with a paved bottom above which rotates a frame carrying flint boulders which press on to, and grind, the contents of the mill to a very fine powder and simultaneously mix it very thoroughly. Water is added to assist the grinding and to prevent the escape of the fine dust.

A *cylinder mill* consists of a cylindrical vessel lined with vitrified tiles and partially filled with flint pebbles or porcelain balls. The vessel is rotated until the material (which has been previously mixed with a suitable amount of water) is sufficiently finely ground. The door of the cylinder is then replaced by a fine grating and the contents are allowed to run out. The amount of water, the length of time, and the fineness of the grating will depend on the nature of the materials to be ground.

A *ball mill* also consists of a rotating cylinder containing balls, but the cylinder is perforated or provided with a grating and surrounded by a fixed casing, so that the ground material escapes into the latter and the action of the mill is continuous.

Overloading a ball or cylinder mill will result in the time of grinding being disproportionately lengthened. When large quantities of material are being ground the output of a ball mill is greatly increased by providing it with a screen which delivers the material to an air-separator in which the fine product is removed and the coarser returned to the mill, the grinding and separating being continuous.

A *tube mill* is another form of ball mill with a very long cylinder. The material passes longitudinally through this mill, and escapes at the further end. The product is so fine that no sieve or grating is needed except to prevent the escape of the balls. Even when used for grinding materials to an extremely fine powder, tube mills are capable of grinding from 1 to 4 tons of material per hour.

In the Lehigh and similar mills a far smaller number of balls is used, and these are carried on a frame which rotates around a vertical axle.

Where ball mills are used a proper allowance must be made for the quantity of porcelain or flint which will be worn from the pebbles or balls used for the grinding. The amount is, in any case, small, but the correction is too important, except in very rough working, to be neglected. Not only so, but as the mills are constructed to work with a definite weight of pebbles or balls, this weight should be kept as constant as possible by cleaning and drying the balls once a month and re-weighing them.

The note on an earlier page as to the need for care in grinding mixtures of plastic and non-plastic materials is especially noteworthy in the case of glazes; if they contain plastic clay it should not be added until near the end of the grinding, and then it should be in the form of a thin slip, otherwise it will adhere too strongly to the balls and unground particles, and so will seriously impede the grinding. The use of water in grinding is now almost universal with non-plastic materials which have to be very finely ground for glazes and bodies. Not only is it more healthy for the workmen, but the amount of material which is lost as dust in dry grinding is, to a large extent, saved when the materials are ground in a thoroughly wet state or in the form of slip. Grinding mills for glaze materials are not usually fitted with arrangements for removing the ground material as in the case of clay mills, but the materials are kept in the grinders until it is considered that they are sufficiently finely ground—when they are passed through a sieve of moderate fineness (say 80 meshes per linear inch), and then through one of greater fineness (*e.g.* Nos. 100, 120, or 150). In order that this may be done effectively and without undue loss of time, it is necessary to have plenty of water present, *i.e.* the slip must be very thin, weighing—according to the material and the fineness of the sieve—not more than 26 or 28 oz. per pint.

Blunging.—Where the same constituents are used in a number of different glazes in different proportions, it is generally most convenient to grind them separately into slips and to keep them in this state and mix as required. It is also very desirable that glazes and bodies (engobes) should be kept at least a week before use. For mixing these slips, 'blungers' are used. There are numerous types of blunging arks, but the best for most purposes consists of a vertical vat or cylinder provided with a well-fitting cover and a vertical shaft bearing horizontal arms arranged as screw-blades, which continually raise the material from the bottom of the vat and thoroughly incorporate it with water. The blunger should be about three-parts full when at work. When dry-ground materials are to be mixed with water, a suitable quantity is placed in the blunger, the requisite volume of water added, the cover put on the machine, and the latter started. The use of a cover prevents loss when working at high speeds, and so facilitates a high output. Some materials, especially flint, have a troublesome habit of forming a hard cement-like mass on the bottom of the tank, and so rendering it difficult to start the blunger without some risk of damage. Such materials should not be left in the blunger all night, but should be cleaned out immediately after use. In any case, the blungers should be started with care, some minutes elapsing before they are allowed to run at their full speed, so that the water and the material may have become, to some extent, mixed before full speed is attained. Blungers should be fixed at as low a level as possible on account of the material being carried to them, though when a separate blunger is used for each material the latter may be led to the blunger by means of a shoot or elevator. Some simple troughs, open and easily cleaned, should be arranged to convey the blunged slip to the tanks and sieves. Blungers may either be round or polygonal, but the circular form has a tendency to slow working, owing to the material being carried round and round. If an octagonal blunger is used, the eddies caused by the corners prevent the rotation of the material and so secure a more satisfactory mixing.

When only small quantities of glaze, or engobe, are required, hand-blunging may replace that of the machine. The materials are first broken up moderately fine (especially ball clay), and are then well mixed by means of a wooden mixer or beater, perforated with a number of ½-inch holes.

The proportions of water and material to be fed into the blunger differ with the different substances—ball clay slip usually weighs 24 oz. per pint; china clay slip, 26 oz.; flint, Cornish stone, and felspar slips, 32 oz.; and most other materials are blunged with their own weight of water, thus giving a slip weighing 25 to 28 oz. per pint.

Sieves and Sifting.

Sieves are used in connection with the grinding of clay, so that the fine material may be separated as soon as possible from the coarse, and so render superfluous grinding impossible.

For rapid sifting, the clay must be fairly dry, and must not contain too large a proportion of fine matter. If the clay is sufficiently moist to be plastic, the particles will adhere to each other and will not pass through the sieve and so prevent further separation of the particles. If, however, the clay is made up into a sufficiently thin slip, the water with which it is mixed acts as a vehicle and carries it through the sieve. Except in the cases of clays used for engobes and bodies of fine quality, or clays which are washed before use, it is not usual to work the clay into a slip before passing it through a sieve. Such a process is too costly for most kinds of clay, so that dry sieving is generally employed.

If a riddle is working perfectly, the material which remains on it, or which is shot off in the form of 'tailings,' will contain no material which, on passing over the riddle a second time, will pass through it. In practice it is seldom that so perfect a separation is obtained, for various reasons. For instance, even if the clay put on to the riddle is in such a fine state that it is capable of wholly passing through, it will be found that there is a certain proportion of 'tailings,' the exact amount of which will depend on the kind of riddle used, its length, and the time the material takes in passing over it. On this account, the efficiency of the riddle as a separator will be highest when there is not too much fine material in the clay.

There is no definite line of division between riddles and sieves, though it is usual to apply the latter term to the finer form of riddle. Very fine sieves are sometimes known as 'lawns.'

Riddles or sieves for dry clay are of two main types—fixed and moving—this latter class including the revolving riddles as well as those to which a vibratory motion is given.

The material of which riddles for clay dust are constructed are iron, steel, brass or bronze, and, less frequently, copper. Silk is used for sifting slips, but not, to any notable extent, for dry materials. The screening surfaces may be made (*a*) of woven wire or gauze, (*b*) of wires arranged side by side, as in the well-known piano-wire riddle, or (*c*) of perforated sheets. Each form has its special advantages and advocates, and what will best suit one clay will not necessarily be equally suitable for another.

Fixed riddles are usually sloping planes down which the clay slides, the fine material passing through into a receptacle placed beneath and the coarse passing from the end of the riddle into a trough and thence to the mill. If such riddles are made of gauze, it will usually be necessary to beat them at intervals in order to clear them of adhering clay, or the frame may be struck frequently with a rapper driven by a small belt; gauze is not, however, very suitable material for such riddles, and it is preferably replaced by perforated steel or by parallel wires.

Perforated steel riddles have met with severe criticism from time to time, chiefly because their output cannot be calculated in just the same manner as that of a gauze riddle. Their surfaces are so smooth that the clay travels over them with great rapidity, and in consequence of this the sifted material is much finer than would be expected from the size of the perforations of the riddle. From a large number of tests made by the author on riddles of various sizes and with various perforations, it would seem, however, that for a particular angle of inclination and a definite speed of travel, the size of particles which pass through is constant for each clay. The data must be adjusted to suit local conditions, but it will generally be found advisable to give the riddle an angle of 45° and to ensure that it is at least 6 feet long. For some clays, there is an advantage is using two riddles—one about 4 feet long, and the other placed at right angles to it, and about 3 feet long. This arrangement prevents the clay from gaining too high a speed in its journey, and so brings about a more efficient separation of the fine material.

Piano riddles, in which the wires are arranged in parallel, are excellent for granular clays, but in some cases they have proved unsatisfactory owing to thin, flat particles of material lodging between the wires, and so altering the amount of open space between them. In an improved piano-wire riddle the wires, instead of being arranged parallel to the length of the riddle, are placed crosswise. This arrangement greatly reduces the liability of two wires being permanently parted by a flake of hard material being wedged between them, and it also prevents the particles of clay from moving rapidly over the surface and rapping is usually necessary.

Revolving riddles are usually made of gauze. They may be circular or polygonal in shape—a six-sided sieve being usually most efficient. Circular cylinders are expensive to repair, both as regards time and material. With the hexagonal form each side may be made independently, the gauze fitting into frames attached by bolts to the framework of the riddle, and easily replaced by another frame when one side is in need of repair. By adopting this simple plan, the machinery is only stopped for a few moments whilst a new frame is being attached. Revolving riddles are usually beaten automatically to prevent clogging. With circular riddles the beating effect is not so intense as in the hexagonal form, so that the efficiency is not so great for riddles of the same diameter.

Reciprocating Riddles.—Some firms prefer rectangular riddles which are moved backwards and forwards by means of a small arm attached to an eccentric, and hit a stop at each end of their travel. Though excellent for slips where the proportion of coarse material is very small, they have a much lower output than either the inclined plane or the hexagonal revolving riddle when dry clay is being sifted, and so have not met with very extended use for this purpose. They still hold their own, however, in the case of potter's slips.

In *vibrating riddles* the screening surface is given a vibratory movement by means of an electro-magnet or other device, so that the particles of clay, etc., are caused to 'dance' on the screen. This arrangement produces very effective screening.

Mesh of Sieves.—Sieves and riddles, when made of metal, are usually named according to the number of holes in a linear inch of the material—thus, a sieve with 60 holes per linear inch is designated as '60-mesh' or 'No. 60.' In France and Germany sieves and lawns are frequently quoted by figures denoting the number of meshes per square inch or per square centimetre; but as this is liable to cause confusion, it is to be deprecated. To convert a sieve measured on the latter system into the English linear one, take the square root of the foreign number, multiply this by 10, and divide by 4. Thus, a German sieve No. 900 has 900 meshes per square centimetre. The square root of 900 is 30, which, multiplied by 10, gives 300. This divided by 4 gives 75 as the corresponding number for an English sieve.

The number or mesh of a sieve may thus be expressed in four different ways:

No.	Meshes per linear inch.	Meshes per square inch.	Meshes per cm.	Meshes per square cm.
30	38	900	12	144
60	60	3,600	24	576
90	90	8,100	36	1,296
100	100	10,000	40	1,600
120	120	14,400	48	2,304
150	150	22,500	60	3,600
200	200	40,000	80	6,400

It is obvious that the number of holes per linear inch is no real criterion of the size of the particles a sieve will pass. This depends upon the number of holes and the thickness of the wires. Standard tables have been prepared, giving the size of the means and of the maximum particles passed by sieves of varying meshes.

Lawns are numbered arbitrarily; those most frequently used are Nos. 14 and 16, No. 18 being too fine for ordinary use. In connection with lawns, it must be remembered that they 'give' a little, and so will pass somewhat larger particles than a wire sieve of the same mesh. Lawns are commonly arranged in tiers one over the other, the finest below; they are drawn backwards and forwards by a small eccentric over glass slides (to reduce friction).

Owing to the great irregularities in ordinary wire gauze, the Institute of Mining and Metallurgy has drawn up a specification for standard screens and has made arrangements with N. Greening & Son, Warrington, for their manufacture. These standard screens have the characteristics shown in the following table, which also contains some additional data by J. W. Mellor.

The I.M.M. Standard Sieves.

Mesh, *i.e.* apertures per linear inch.	Diameter of wires.		Diameter of apertures.		Screening area per cent. holes.	Mesh, *i.e.* apertures per linear inch.	Diameter of wires.		Diameter of apertures.		Screening area per cent. holes.
	inch.	mm.	inch.	mm.			inch.	mm.	inch.	mm.	
5	0·1	2·540	0·1	2·540	25·00	70	0·0071	0·180	0·0071	0·180	25·00
8	0·063	1·600	0·062	1·574	24·60	80	0·0063	0·160	0·0062	0·157	24·60
10	0·05	1·270	0·05	1·270	25·00	90	0·0055	0·139	0·0055	0·139	24·50
12	0·0417	1·059	0·0416	1·056	24·92	100	0·005	0·127	0·005	0·127	25·00
16	0·0313	0·795	0·0312	0·792	24·92	120	0·0041	0·104	0·0042	0·107	25·40
20	0·025	0·635	0·025	0·635	25·00	140	0·0036	0·091	0·0036	0·091	25·00
30	0·0167	0·424	0·0166	0·421	24·80	150	0·0033	0·084	0·0033	0·084	24·50
40	0·0125	0·317	0·0125	0·317	25·00	160	0·0031	0·078	0·0031	0·078	25·00
50	0·01	0·254	0·01	0·254	25·00	180	0·0028	0·071	0·0028	0·071	25·00
60	0·0083	0·211	0·0083	0·211	25·00	200	0·0025	0·063	0·0025	0·063	25·00

The coarseness of the riddles and sieves employed varies with the purpose for which the material is to be used. For dry clay it may be as coarse as a No. 4 or 6 for bricks to No. 16 or 20 for sanitary ware, and No. 60, 75, 100, or even 150 for fine-ware bodies. The latter must be sifted in the form of slips weighing 25–29 oz. per pint.

Where only a few gallons of slip are required, a circular sieve of the pattern used by housekeepers may be employed, the material being assisted through by means of the hand or by a soft brush. A hard brush must not be used, or the sieve may be torn.

Damaged lawns may be mended by patching; metal sieves are best repaired by solder, although, to prevent the gauze being burnt by the soldering iron, it is often wise to lay the damaged part on a steel block to take away the excess of heat.

All riddles and sieves should be of ample size, particularly when used for separating dry clay. When placed in a sloping position, the particular angle best adapted for the material should be ascertained by trial. It is scarcely necessary to add that every care should be taken to prevent any possibility of the tailings being mixed with the fine material should the riddle become choked. In other words, all riddles connected with machinery should be well boxed in.

Frequent tests of the fineness of the materials should be made, and an examination of the residue from slips made at least twice a day. This will show whether there is any unusual amount of dirt getting into the slips. Dirty slip can never be properly cleaned, and should be thrown away. Methods for testing the efficiency of sieves are described in Chap. XIII.

Air-Separators.

Air-separators have come into limited use of late years in the separation of coarse and fine clay. A powerful stream of air carries the finer particles along with it, whilst the heavier ones sink to the bottom of the apparatus and are removed through a separate opening. By adopting centrifugalization, the efficiency of the apparatus is made very high; and as it takes up but little room and is very rapid in its work, it will probably grow in favour in the future, particularly for dry materials.

For damp materials, especially if they stick to each other, an air-separator is not satisfactory unless the air passing through it is able to dry the material sufficiently to prevent the 'balling' of the particles. An air-separator has one rather serious disadvantage, however, as it tends to separate materials according to their specific gravity rather than according to their size.

Machinery for Mixing.

The various methods used for the mixing of water and of other materials with the clay may be divided into four main groups:—

1. Tempering by spades, or by the hands (*hand-wedging*) or feet (*treading*).
2. Pugging.
3. Panning in a pan mill with edge-runners.
4. Blunging, the materials being in a state of powder, to which sufficient water has been added to make, when thoroughly incorporated, a thin slip.

Where very fine clay ware is manufactured, the clay for the bodies must be blunged up in a similar manner to that described on p. 81, sifted, filter-pressed so as to remove the greater part of the water and to form a paste, and then pugged or wedged in order to mix it thoroughly. For coarser work it is not usual to make the clay into a slip, but simply to mix it with water in a tempering machine (pug mill or pan mill), as described on pp. 77 to 79 and 89. The one sifting of the dry clay as it comes from the grinding mill is then made to suffice.

Tempering by spade, hands, or feet (see pp. 53 to 54) is only used for small quantities of clay, and then only when better appliances are not available. Hand-wedging is, however, still employed in some factories for the better class of clay bodies, which, being naturally rather short, require a considerable amount of working to render them fit for use. This process then becomes a final one, the object of which is to secure thorough mixing of the materials after preliminary treatment in a pug mill.

Clay puddling, or 'treading,' in which the mixing is done by spreading a thin layer of clay about 1 inch thick on a smooth floor, sprinkling with the required amount of water, and squeezing it between the workers' toes, produces a more uniform paste than mechanical methods. The method is very costly, laborious, and demands that the work shall be very conscientiously done, so that it is only used for special articles such as crucibles for melting steel, and in countries where labour is cheap and machines are scarce, as in some parts of South America, where horses or mules are sometimes used to tread the clay prior to its being used for making tiles. A framework wheel revolving on a horizontal shaft round a central hub is sometimes used as a substitute for treading, though it is not really efficient.

Pug Mills.—The pug mill consists of a metal cylinder placed either vertically or horizontally, with a shaft running through its centre from end to end and having attached to it a number of blades or 'knives' arranged like the thread of a screw. As the shaft turns, the knives cut the clay, mix it and carry it forward through the cylinder to be re-cut and mixed by every fresh blade with which it comes in contact. In this manner a very homogeneous product is obtained, especially if the clay mass is passed through the mill several times. The shape and arrangement of these knives is highly important, and varies somewhat with different types of mill. For most clays it is convenient to have the blades arranged 'four-square,' so that every fifth blade is in a straight line. The blades do not lie at right angles to the shaft, but are arranged in a helicoidal form so as to impart a forward motion to the clay. The blades should be almost at right angles, however, or they will propel the clay forward without mixing it, the two processes of propulsion and mixing being largely incompatible. Sometimes, a few blades set exactly at right angles to the shaft are inserted among the others, but this arrangement is not satisfactory, as having all the blades set at an angle of 45° or 60° will secure a greater amount of mixing of the particular clay to be passed through the machine. The last blade in the mill nearest the mouthpiece is generally a complete screw or worm, as this one is intended to drive the clay into the mouthpiece and not to mix it. In some vertical pug mills stationary or 'counter' knives are fixed to the interior of the casing to increase the amount of mixing and to increase the output by preventing the rotation of the clay.

For driving the clay through a mouthpiece in order to give it a special shape, the blades of the pug mill should form a complete screw or helix of moderate pitch, as their object then will simply be to act as a conveyor and not to mix the clay. They should, therefore, be placed in a small supplementary cylinder, at the end of the pug mill proper, so as to work independently. When this is done, the increased percentage of sound goods will rapidly repay the slight additional first cost, while the additional power required is so small that it may be neglected. A further point to be considered in pug mills is that as new knives work better than worn ones, the blades should not be kept in use too long. The barrel or case of the pug mill should be polygonal (although very few mills are made in this shape). A round case has a tendency to carry the clay round with the blades, but if a polygonal mill is used the corners prevent this. The barrel should also taper slightly towards the exit end so as to compress the clay and produce a denser and more satisfactory paste. This is especially the case where a mouthpiece is attached to the pug mill, as the gradual tapering of the barrel is less likely to cause lamination and other defects in the clay paste than where a cylindrical barrel is used and the material is compressed solely by the mouthpiece. A conical collar may be inserted between the mouthpiece and the barrel, but it is not so satisfactory as a conical barrel. The chief objection to a tapered pug mill is the impossibility of exchanging the blades at different parts of the barrel. Where a very thorough mixing is essential, a barrel which is not tapered may, for this reason, be preferable.

For clays requiring a large amount of mixing, an open pug mill is frequently employed in which there are two shafts, each bearing a number of blades working side by side, the knives being so arranged that they cannot come into contact with each other. To secure a better mixing, the shafts may be driven at different speeds, though this is seldom considered necessary. After passing through this preliminary mixer, the clay is passed through a pug mill of the ordinary, closed-in form. The open pattern has the advantage of enabling the mixing of the clay and water to be watched during the early stages: an important matter when it is desirable not to get too much water into the clay paste. When the material to be pugged is the product of a filter-press, the open mixer may be omitted.

Where the ground clay is fed into the mixer, water added, and the mass passed straight through the pug, it will often happen that the clay is too 'short' for making ware of large size, but may then usually be rendered sufficiently plastic by storing the paste for a few days in a place where it will neither freeze nor get dry, and then passing it again through a pug mill.

The speed at which the mill is driven requires some attention in order to work it efficiently. It must be regulated so that the blades will complete the mixing by the time the clay reaches the exit end of the mill. If the mixing is complete before the end of the mill is reached, a few blades of a lesser angle and greater propelling power may be used, or the speed may be increased; if it is not completed in that time, the angle and number of the blades or the speed must be altered accordingly. The average speed is 8 to 12 revolutions per minute, though some mills may be driven faster when used for leaner clays.

The *inclusion of air* in clay by the action of the pug-mill blades is a matter requiring attention for fine ware, as it is liable to form 'blebs' and blisters when highly plastic materials are used. The amount of air so introduced may be measured by placing a known volume of clay paste in a gas-measuring tube with a wide mouth, which has been previously filled with water. The whole is then inverted in a beaker of water so as to form a gas-holder; the clay is disintegrated and the liberated air is measured.

As regards the relative advantages of vertical, as compared with horizontal, pug mills, it is generally considered that vertical mills absorb less power, but that horizontal mills mix the clay better. With some clays, vertical mills cause less lamination than horizontal ones, and there is less backward flowing of the clay. Against this advantage there is the sharp change in the direction of the clay as it issues from the mill; this does no appreciable harm in some cases, but is serious in others.

The design and construction of pug mills is a matter to which much attention has been given by some engineers, though a large amount of research still remains to be done. Detailed descriptions (with illustrations) are given in *Modern Brickmaking* (see Appendix) and other works.

Combined pug mills and rollers are becoming increasingly common in some districts, especially where the 'extrusion' process of clayworking is in use. The clay is first passed through a pair, or series of pairs, of rolls, which crush, rub, and partly mix it, and then through a pug mill which cuts up the damp clay, kneads it thoroughly, and so mixes it and passes it out ready for making into wire-cut bricks and similar articles. For successful working by this process, clays must possess sufficient natural moisture to bind together well without the addition of water, although some clays can have a little extra water added to them as they enter the pug mill. With a dry or shaly clay, the percentage of water should not be greater than 10, but no hard-and-fast line can be drawn, as each clay has its own definite percentage of water with which the best results can be obtained.

Various other combinations of crushing and mixing machines are used in different districts, each having some special advantage for the particular clay they are designed to work, the great tendency at the present time being to accomplish in one machine all the different operations necessary in the preparation of clay for use. This works well for certain purposes, and economizes power and space in addition, but the great disadvantage is that it is often sought by these means to avoid the use of natural processes, particularly that of weathering, and to use the clay directly it comes from the pit. This is an unfortunate tendency, as there is no question that clay which has been properly exposed to the action of the air, rain, and frost before grinding makes goods of far better quality and durability than if it is sent straight to the machine. The use of these 'universal' machines also tends to throw too much work on one part of the plant for which it is most probably least fitted. A pug mill, for instance, is not well adapted for giving shape to the column of clay which passes out of it, and any attempt at doing this will result in the material being less efficiently pugged than would otherwise be the case, owing to the backward pressure on the blades of the mill which cause loss of power and produce defects in the goods.

The **Pan Mill** is often preferred to a pug mill for thoroughly incorporating water and clay when the clay is simply ground and then mixed into a plastic mass. It is difficult to judge of the relative value of the two machines, although as a general rule it may be stated that a pug mill should be used in preference to a pan mill where the clay permits of its employment without requiring to be passed through the pug mill more than twice, as a pug mill operates more cheaply than a pan mill and produces a much stiffer paste. On the other hand, a pan mill effects a more satisfactory distribution of the moisture in the clay, and its rubbing or pasting action tends to increase the plasticity, so that it is preferable in the manufacture of special goods made of a moderately soft paste such as retorts, glass pots, crucibles, etc.

Pan mills for tempering or mixing are very similar to the edge-runners used for grinding (p. 77), except that they usually have a solid, *i.e.* an unperforated, bed for the runners, although the use of beds with grates through which the wet clay is pressed by the runners is becoming increasingly popular for some clays, as by this means a continuous output of clay is obtained. The ordinary mixing pan used in this country is provided with a shovel with a particularly long handle, working in a rowlock near the edge of a pan, by means of which the clay paste may be removed without stopping the mill. The bed, or pan, which is almost always of the revolving type, should have a lining made in one piece, not of several pieces as is usually done, because the joints between the sections render it much more dangerous when in use, owing to the liability of the shovel to catch in the joints, thereby possibly causing severe injuries to the man using it. The clay is fed to the mill through a shoot, if sufficiently dry to run well, or by buckets or barrows if it is of too sticky a nature for a shoot to be used, and the amount of water necessary is added from a tap, placed in a convenient position near the mill. The length of time required by the clay will depend on its nature and on the particular articles to be made from it; twenty minutes to half an hour is by no means unusual, although, with some clays, a much shorter time is sufficient. The mill must usually be emptied before a fresh charge can be added.

Various attempts have been made to supersede the shovel and to render the output of the mill continuous, but up to the present time little success can be recorded, and in most cases it will be found that, where a continuous output is required, the pug mill will work as well as, and with far less daily cost than, an 'automatic' pan mill.

Particular care and no little skill is required in the mixing of clay by these machines, as unless the proportion of water and the size of the clay particles are kept pretty constant the resulting goods will differ in size, a matter of considerable importance in the manufacture of glazed bricks, tiles, etc. Cold water is generally used for mixing clay, but *hot water* is sometimes more satisfactory and, in some cases, steam has also been used with considerable success, especially in wintry weather.

Blungers are employed for the mixing of clays, bodies and glazes with water, and in other cases where the proportion of water to material is at least 1 : 1—that is to say, where a 'slip' is to be produced. This class of machines has already been described on p. 81.

Other forms of mixing machines are also in use in special cases, but their employment is not sufficiently extended to merit mention here.

Machinery for Shaping.

Machinery for making articles from clay may be divided into two main classes—viz. for bricks, tiles, pipes, and similar goods, and for the manufacture of pottery.

Brick Machines are used for the direct formation of bricks, or for pressing bricks to which a rough shape has already been given. For forming the clay into bricks there is no doubt that machines are, wherever possible, replacing hand-moulding. At the same time, although the machine-made brick is well established, it is by no means a perfect brick, as the pressure used is not only expensive but may be actually harmful to the durability of the brick.

Omitting the machines which imitate the process of hand-moulding and have never become really popular, the machinery used in the actual shaping of bricks is of two main types—(*a*) expression machines, and (*b*) presses (p. 94).

Expression machines consist of rolls (p. 92) or a pug mill, to the exit end of which a specially shaped mouthpiece or 'die' is attached. As the clay passes through this mouthpiece it is made into the desired shape and extruded in the form of a band of clay. This band may be cut into a number of pieces—usually by means of wires,—hence the term 'wire-cut bricks' for those made in this manner. Lubrication of mouthpieces in this kind of machine is generally necessary. It consists in the inclusion of a thin layer of lubricant between the clay and the metal so as to keep the two latter out of contact. Oil, water, or steam may be used, but for most wire-cut machines the use of water under pressure is the cheapest and best. The precise pressure needed must be determined by actual test for each clay. For many machines the ordinary tap-water is sufficiently powerful, but in difficult cases it may be necessary to construct a special water-holder and to connect this with the boiler. In one works, the author found that a pipe run from the boiler (below the water-level) direct to the mouthpiece of the machine provided a supply of water under pressure, the heat of the water being an additional advantage. Some clays of a peculiarly adhesive character require the use of steam, but the author has not seen a case where water under pressure is not a more satisfactory lubricant, provided that it can be obtained as readily as steam.

Oil-lubricated dies are admirable, but are more costly in operation, on account of the price of the oil, and, except in the most difficult cases, they offer no advantage over water.

Some clays are so easily lubricated that all that is necessary is to pierce a few holes through the sides of the mouthpiece, and to connect these to the water-supply; but with more tender clays a laminated lining is preferable. This latter consists of a series of layers of thin sheet metal, usually brass or copper, which partially overlap each other, leaving a space between them through which the lubricant may be forced by its own pressure. The advantage of this form of lining is its very small liability to choke with clay—a trouble often experienced with some forms of lubricated mouthpieces.

Linings of other materials of a porous nature are sometimes employed, though they are now being replaced by all-metal mouthpieces, which are more accurate and durable. Thus, moleskin or fustian-lined dies are only seen in a limited number of works; they represent the greatest advance in lubrication made some twenty years ago, but are far from being up to date at the present time. They still have advantages in the manufacture of certain fancy bricks, but not for the ordinary run of brickmaking, unless some special quality in the clay demands their use.

A particularly ingenious means of lubrication which was patented by Dawkins in the United States in 1913 consists in connecting one pole of an electric accumulator to the mouthpiece and the other pole to a copper rod inserted through an insulated bush in the mouthpiece or collar of the machine, so that it is in contact with the clay paste. The electric current tends to separate the water and the clay, causing them to migrate to opposite poles. In this way a slight excess of water accumulates on the interior of the mouthpiece and effects the lubrication of the clay in an entirely automatic manner.

It is important, in the selection of a mouthpiece, to see that it does its work properly and to the best advantage. For this reason, it is best to make a wooden mouthpiece with which to conduct the preliminary experiments. A wooden mouthpiece may readily be altered to any desired shape; a little extra play may be given here, or a little additional resistance made in another part, without much trouble, and it is easy, by using wooden mouthpieces of various shapes, to see which gives the best results with the least absorption of power. Then, the correct shape and size of the mouthpiece for a given clay having been ascertained, it is easy to have a proper metal one made of the same dimensions. This preliminary testing may appear to the ordinary clay-worker or machine-builder as an unnecessary expenditure of time and labour, but many years' experience with a large variety of clays has convinced the author that it saves money in the end. If a 'stock' mouthpiece is used, it may give equally good results, but unless some test of the kind indicated is carefully carried out, it can never be certainly known that power is not being wasted.

Much of the success or otherwise of wire-cut brick manufacture depends on the proper manipulation of the clay, both as regards the mixing and its passage through the mouthpiece of the machine. It frequently happens that the clay is insufficiently tempered and mixed, and that it is not worked stiff enough. Some makers, on the other hand, go to the other extreme, and waste power by working the clay in an unnecessarily stiff state.

It is quite a mistake to suppose that the mouthpiece for producing wire-cut bricks or other articles may be of any shape desired. Various attempts have been made to approach the subject from a mathematical standpoint, but so far without much success, and at present no general rules can be given for the construction of mouthpieces, as apparently slight variations in the composition of the clay will sometimes make all the difference between a successful machine and a failure. A well-designed mouthpiece will deliver a column of clay at an absolutely even pressure all over its opening—the corners will be as solid and compact as the centre,—and if this is not achieved with a particular machine, the mouthpiece must be filled, or otherwise altered, until the defective portions of the clay column are remedied. As the turning of the worm or blades in the pug tends to give a slight rotary motion to the clay column, the pressure at which it issues from the mouthpiece is unequally distributed over its section; hence, the die will probably not be quite symmetrical, although the column of clay must be so. For this reason, also, it is seldom that two columns of clay can be produced simultaneously from the same mouthpiece, one of them almost always tending to assume a circular form instead of coming out straight.

'Dragon's teeth' forming on the edges of the column of clay as it comes from the mouthpiece are chiefly due to the clay issuing more rapidly from the centre than from the sides of the die. Two methods of remedying are possible—the resistance of the central portions of the die may be increased by diminishing the die, if possible, at the angles, or the resistance of the outer portion of the clay column may be lessened by lubrication before the clay leaves the mouthpiece. This lubrication is somewhat difficult to effect without the die being frequently cleaned, but there are now several water-lubricated dies on the market which work well. Existing dies may often be improved by rounding the corners on the inside where the clay enters, so that the change from the circular to the rectangular shape may not be so abrupt as is often the case. Very gradual change of shape is, in fact, the chief secret of successful die-work in clay. Dies of the type with a laminated copper lining, and lubricated with water under pressure, such as those originally made by 'Halsband,' are specially worth attention in this respect.

Brass mouthpieces have not proved successful, owing to the softness of this metal causing them to wear away too quickly, but thin, brass, or preferably copper, lining sheets have obtained considerable popularity on the Continent. In this country, a steel-lined die is usually preferred, though it is not nearly so satisfactory and is more difficult to adjust, so that its apparent cheapness does not indicate its true cost.

In choosing a mouthpiece, attention should be paid to the time actually taken to reline it, as well as to the probable number of bricks or other articles which can be made before a fresh lining is necessary.

When a clay laminates badly on issuing from a pug mill fitted with a mouthpiece, *expression rolls* may be inserted between the pug mill and the 'mouthpiece.' These rolls enable the clay to be shaped without the tendency to laminate which is so notable a characteristic of some materials, and wire-cut bricks may thus be produced to an extent quite impossible without rolls. Expression rolls do not crush the clay; they merely compress it to the desired shape and facilitate its passage through the die. One pair is usually sufficient, but two or even three pairs are sometimes used for specially delicate clays.

Stupids are used for the production of drain pipes, coping bricks, and other specially shaped goods. They consist of a box or 'chest,' at one end of which is a mouthpiece and at the other a piston. The chest is filled with clay paste and is then closed. The piston is then pushed forward by means of appropriate gearing, and forces the clay paste through the mouthpiece. When all the clay is thus forced out, the piston is drawn back and the chest filled with fresh clay. The articles are cut with wires on a suitable cutting table.

The disadvantages of a 'stupid' or 'running-out machine' are: (1) the action is not continuous, so that it is not economical for large outputs; (2) the clay must be mixed before putting into the machine.

Its chief advantage lies in its portability and in its usefulness for making small quantities of goods at irregular intervals where a power-driven machine would be unremunerative. Where sufficiently large quantities are required it is preferable to fix a suitable mouthpiece on to a wire-cut brick machine.

For socketed pipes a continuous extrusion machine is used (p. 96).

Cutting Tables, for the production of wire-cut bricks, tiles, etc., are made in a considerable variety of forms, each of which has special points of recommendation. The chief points requiring attention are:—

1. The level of the table of the cutter should be exactly the same as that of the mouthpiece of the mill or press.

2. The cutter should work easily and smoothly, should be kept well lubricated, and the wires should be kept as clean as possible in order to reduce the 'rag' to the smallest limits.

3. The wires should be fastened to the cutter in such a manner that they may be immediately replaced when broken, as with stony clays they break frequently; for this purpose, new wires, ready fitted with ring ends, should be at hand, as otherwise serious loss of time and output may ensue. The wires should be so fixed in the holder that the bricks or other articles cut are exact in size. This means that the clamping of the wires must be strong and not liable to get out of adjustment. It is advisable to test the distance of the wires from each other several times each day by means of a gauge. In order to get well-shaped articles, it is absolutely necessary to keep the wires taut, and to see that the cut faces of the goods are true and square. The cleanest cuts are made by forcing the wires diagonally through the clay column, as by this means two arrises are kept clean and the ragged ones are confined to the bottom of the brick. When the usual fixed vertical wires are used a much more ragged brick is produced. Cutters with downward moving frames are exclusively used on the Continent, and extensively in America, but no British firm of machine manufacturers supplies this type, which, when mounted on a small carriage, running on a track, is particularly advantageous.

Time is frequently lost in removing the cut pieces from the table: several attempts have been made to overcome this by the use of self-acting cutters and belt conveyors, but these have not been of such a character as to be considered really successful up to the present, as they cause the size of the bricks, etc., to vary with the speed at which the clay column issues from the die.

It is usually better to make the power-driven tables to be started by hand, as the automatic ones are always liable to cause misshapen bricks. When the power is applied by moving a starting lever by hand, any variation in the rate at which the clay column moves from the mouthpiece is unimportant, but with all the automatic machines now on the market the starting is effected by the pressure of the clay band on a light stop or release. This release works with a very small pressure, it is true, but with a soft clay it is sufficient to cause the clay column to arch towards the centre and so to spoil several bricks at each cut. An electrical starter takes a far less pressure and overcomes this difficulty, but is only used by one or two firms. The simplicity and ease of working the simple, hand-driven cutting tables makes the more complex power-driven one less necessary unless for large outputs.

4. Lubrication should be carefully attended to, but care must be taken not to waste oil. The table is usually smeared over with 'brick oil' to facilitate the sliding of the clay column along the table. The rollers on the table are lubricated either by hand or by means of an auxiliary roll which is kept constantly supplied with oil. A notable saving may be effected in many cases by erecting the cutter on a large base-plate with sides about 3 inches high and with a hole at one corner to allow of the oil being removed. If this base-plate is supported on four levelling screws similar to those used for scientific instruments, but proportionately stronger, it will be found much

easier to adjust the table of the cutter to the exact level of the die than is ordinarily the case.

Brick, Tile, Pipe, and other Presses.—The word 'press' in clayworking is applied indiscriminately to two entirely different classes of machinery, and some care is needed not to confuse them. The first class consists of the 'expression machines' just described; the second class comprises all machines in which the clay is placed in a mould, or die, of the same shape as the article to be made, and is compressed by means of one or more plungers. These are the true 'presses,' and better-shaped articles can be made with them than is possible with the machines in the first class. This is partly due to the use of a mould instead of a mouthpiece, and partly to the much greater pressures which are available.

As the density and firmness of the goods increase with the time of compression, the use of hydraulic presses for large articles is on the increase, although these are apt to be too slow in action for making ordinary pressed bricks and tiles.

In order to obtain efficient work from the second type of press at a minimum cost, several points, at present often neglected, need very careful attention.

The goods may be pressed either in the form of a 'damp dust' or 'dust' (*semi-dry* process), or in a more plastic state (*stiff-plastic* process), some classes of clay being worked more easily by one method than by the other, but it is seldom that a very soft, plastic mass can be pressed; such a material may be roughly shaped by an expression machine (p. 90) or by hand-moulding, and, when sufficiently stiffened by drying, it may then be given its final shape in a press. (This is known as *re-pressing*.)

There are, at the present time, many terms in use with regard to the plasticity of the clay fed to the press which are to some extent misleading, as they seem to imply the use of entirely different types of machine, although this is not found to be the case when the machines are examined. At each end of the scale we have 'plastic' or 'soft' clay and 'dry' or 'stiff' clay respectively, and these terms are sufficiently definite to be well understood, but when combinations of these terms are used the nomenclature at once becomes confused. Such terms as 'stiff-plastic,' 'semi-plastic,' etc., may have a claim for advertising purposes, but are of little use in actual practice. When once it has been determined, as the result of careful experiment, what proportion of water in the clay gives the best result for the press, this proportion should be maintained.

The method most suitable for any particular clay must be determined by experiment, as it is almost impossible to say from a mere inspection of the clay which is the best. Each clay must, in fact, be studied by itself, for some clays press best when in a very plastic and moist state, whilst others require to be on the 'dry side,' and others again may best be pressed in the form of dust. Thus, in the case of a clay rich in sand, the rough-formed article must be fairly dry, as, if too much water is present, no cohesion of the particles will be possible except at very excessive pressures. At the same time, such a clay must not be allowed to become too dry, or the resulting goods will have no strength.

When goods are made from a soft, plastic paste and are afterwards re-pressed, it is always desirable to weigh a few of them during different stages of drying, to press these, and, after burning, determine which proportion of moisture is the most suitable; the same weight may then be used on future occasions, and if the goods weigh more than this, the drying may be continued for a little longer before they are pressed. This method is far preferable to the rougher plan of simply inspecting the goods to see whether they are ready for the press.

When the amount of trouble involved in re-pressing is considered, the advantage of working with a stiffer paste (stiff-plastic process), and so producing goods which need less drying before they go to the kiln, is obvious, but when dust is used ('semi-dry' process) there is the disadvantage that the air imprisoned in the dry clay by the pressing may expand in the kiln and so cause the goods to burst.

Goods which have been dry pressed are more seriously damaged in the handling than leather-hard, stiff-plastic ones, and it is difficult to obtain sharp arrises on bricks and quarls unless the greatest care is taken. In order that dry-pressed goods may have the same cohesive power after firing, it is often necessary to heat them to a somewhat higher temperature than is required for plastic-pressed goods, as the finer particles of clay in the latter get pressed into more intimate contact with each other, whilst in the former this contact must be obtained by heating to incipient vitrification. For a similar reason, much greater power is necessary for pressing stiff clay than when it is in a more plastic state.

In pressing bricks, tiles, and similar articles, it is of the greatest importance to keep the die, or mould, free from small pieces of clay, particularly 'arris,' which, if not removed, will adhere to the surface of the next brick or tile placed in the press, and, in addition to spoiling its surface, will be exceedingly liable to rise, or even to drop off, during any subsequent dripping in body or glaze. The rapid passing of a slightly oiled cloth or brush over the face of the mould will often result in the saving of 500 to 600 bricks per day. This not only applies to that part of the mould which forms the face, but also to that forming the sides; the whole of the inside of the mould should be glanced at before inserting a fresh piece of clay. It is admittedly difficult to do this thoroughly and rapidly with many of the machines at present in use, but the difficulty may be easily overcome by having the mould so made as to slide backwards and forwards on the table of the press instead of being fixed, as is so often the case.

The softer the clay used in the press, the greater is the necessity for lubricating the die. For most purposes, mineral oils are to be preferred to vegetable ones, as they do not so easily act on the lime contained in many clays to form soapy matter, which is a frequent cause of unpleasant blotches on the surface of the fired goods. Sand is sometimes substituted for oil in the moulds of soft-mud machines in the production of imitation 'hand-made' bricks. With care and a suitable machine and clay, this is all right, but if an inferior sand is used, or if the mould does not go exactly into position before it is filled by the clay from the die, the bricks or other articles will stick. The die box should be re-lined as soon as it becomes worn, or bricks of poor quality will be obtained. Several special types of readily removable linings are available.

Various devices are used for supplying and removing the clay quickly to and from the press, including: (1) a revolving table, each mould in it being brought in turn under the press; (2) a revolving horizontal cylinder acting in the same way; (3) a sliding frame acting in conjunction with a rising plunger. By these means, machines are capable of outputs as high as 12,000 bricks per day from a single press, and twice that number from a duplex one.

Lamination in pressed bricks is largely due to pressing them whilst in an unsuitable state, and particularly when excessive pressure is used. One result of this is that on the pressure being removed a reaction sets in and the bricks tend to scale and laminate, or, if glazed, to craze badly. The 'Oxford clay' formation is particularly difficult to deal with in this respect.

Pipes are always made by expression (p. 90) in a press consisting essentially of a chamber to contain the plastic clay and an annular die through which the clay can be expressed. The pressure required to drive the clay through the die may be supplied either by a piston, in which case the clay must be pugged before use, or by screw or auger as in a pug mill. The latter will mix the clay, but it is advisable to pug the clay first and use a perfect screw in the pipe machine instead of a number of mixing blades, as a greater pressure can be exerted on the pipe. For small quantities of pipes a hand-driven 'stupid' (p. 92) is preferable, though not very suitable, for socketed pipes.

The piston presses are intermittent and slow, but the pressure is more uniformly distributed over the pipe than in a screw-press, so that piston presses are preferable for very large pipes. For articles up to 18 inches or even 24 inches in diameter, a continuously acting screw-press is preferable, as it has a much larger output for the same expenditure of power and labour.

On account of the pressure required being so great, machines in which the piston is driven by a belt are not generally suitable for making large pipes—an effective pressure on the clay equivalent to 60 lbs. of steam at the engine is as little as can be relied on for successful work. Direct action of steam on the piston is, therefore, used for large pipes, the smaller ones being made in belt-driven presses.

Considerable difficulty is often met with when piston presses are used, on account of the air bubbles which form on the thickness or 'web' of the pipes owing to the clay not having been pressed sufficiently tight into the cylinder when the press is filled. In spite of the valves on the machine, this air fails to escape when the press is worked, and the bubbles can only be prevented by a more careful filling of the press or by using a machine of the continuous-screw type. Care should be taken not to put too much clay into a piston press, as the power required is greatly increased and a less uniform product is obtained. Defective lengths of pipe should not be returned to such a press, but should be repugged.

Owing to the relative thinness of the walls of pipes, it is necessary that the clay shall have been very carefully prepared beforehand, if pipes of any considerable size are to be made. If put through the press in too soft a state, the pipes will lose their shape on standing. If the clay be too stiff it will not be sufficiently compressed, and a more or less laminated mass with the possible production of 'dragon's teeth' or the splitting of the sides of the pipe may result.

Lamination in pipes, though generally the result of using clay in a faulty condition, may also be due to the bridge of the die being too near the mouth-piece and so breaking up the clay. It is also important to have the 'set-off' at the correct angle for the particular class of clay used—45° is most often suitable, but is not equally suitable for all clays, and the best working angle, taken from the inside surface of the die-plate to the forming edge of the die, can only be correctly determined by trial and experiment, and, when once determined, should be rigorously maintained. Unless for exceptional reasons, the clay used for making pipes should not have a contraction of more than 1 in 12, and the total loss of weight from 'white hard' to coming out of the kiln should not greatly exceed 6 or 8 per cent. If a particularly fat and plastic clay is used, the shrinkage may be brought within reasonable limits by the addition of a suitable proportion of burned clay which has been passed through a No. 12 or a No. 20 sieve (p. 84), according to the nature of the clay and the size of the pipe, it being always remembered that pipes should be made of a body which burns to a slightly vitrified state. If the clay is particularly porous when fired, part of the burned clay added may be replaced by a suitable quantity of broken pottery or other more fusible and non-plastic material.

Pottery-making Machines.—Machines for making pottery have increased greatly in number in recent years.

The best known are the *jigger*[1]—which is, briefly, an upright spindle carrying a mould to form the outside of the article—and the *jolley*,[1] which is a piece of wood, steel, or fired clay fixed to an arm in such a manner that when the jigger is revolved the jolley cuts away the excess of material from the inside of the vessel to be made, and presses the clay at the same time to the shape of the mould on the jigger. In this way, the inside and outside of the article are made simultaneously and with great rapidity. For some purposes, the jolley may be more conveniently employed to form the outside of the article, but the principle is the same in each case. Great care is necessary in fixing the tools or 'jolleys' of these machines, as a small error in setting would spoil the article and might also spoil several moulds.

Before being placed in the jigger, the clay is beaten out in the form of a slab of suitable thickness, called a 'bat,' either by hand, with a plaster beater or, preferably, by a special 'batting' machine, but for jam jars and other hollow ware a clot of clay of suitable size is placed in the jigger. These clots may be made by hand or in an extrusion machine similar to, but smaller than, those used for wire-cut bricks.

Flower-pots and crucibles are now made in increasingly large numbers in machines consisting of a jigger which is free to rotate but is not mechanically driven, and a 'plunger' or head-piece of the same shape as the inside of the article to be made. This head-piece is driven mechanically. The cup, or mould, on the jigger is oiled, a piece of stiff clay paste dropped into it, and the mould is then raised by balanced levers. As the clay comes into contact with the rotating head-piece it is pressed and spread until it finally assumes the desired shape. The mould is then lowered and the finished article is removed. Great difficulties are experienced with some machines of this type owing to the clay adhering to the mould or head-piece. These difficulties are chiefly due to errors in the design of the machine, and may be overcome by correcting these errors or by the use of machines in which they do not occur. The selection of a machine is, therefore, a matter requiring considerable skill, so that an independent expert and not a maker of machinery should be consulted when purchasing.

A well-designed machine will produce 6000–8000 flower-pots of 7-inch diameter in a day of ten hours.

The chief points requiring attention with pottery and flower-pot machines are:—

1. Absolute cleanliness of all the parts, so that the machine works with

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[1] There is a considerable misusage of the words 'jigger' and 'jolley,' these terms being applied in the Potteries to the whole machine as well as to a part, and are frequently regarded as interchangeable. The terms *jiggering* and *jolleying* indicate the use of these machines to manufacture ware.

perfect smoothness, as an uneven motion will prevent satisfactory goods from being made. Hence, due attention must be paid to oiling the bearings. The most satisfactory lubricant for the face of the plunger and the interior of the steel cup in a flower-pot machine is paraffin, to which a little colza oil is added to increase its viscosity.

2. Accurate adjustment, especially of the jolley. To ensure this, it is best to allow only a thoroughly capable man to set the tools, and, by providing a sufficient number of tools, to ensure that a tool once set need never be altered, but may be simply taken from the holder and replaced by another.

3. Where automatic cup-making machines, and others in which particularly accurate adjustments are necessary, are employed, it is advisable to mark these adjustments in such a manner that if a screw should fall out, the machine may be adjusted immediately the screw is replaced, otherwise a considerable loss of time may ensue.

Although it is probable that electricity will be largely used for driving these light machines in the near future, the present practice is to drive them by ropes—usually of cotton,—which give a smoother drive than belting. It is essential that the splicing of the ends of the ropes should be most carefully effected, so that no jerk is produced in the machines, and breakages will be considerably lessened if a weighted pulley is hung from the rope to take up slackness and keep it at a constant tension, no matter how many machines are running. As new ropes stretch very greatly during use, it is desirable that the 'safety pulley' should be at least 10 feet from the ground when a new rope is fitted. The rope is kept constantly moving, and the workers put machines 'into gear' by means of a lever actuated by their knee, which presses the rope against a grooved pulley on the machine.

In order that the machines may be driven smoothly, the pulleys on which the ropes run should be kept well oiled. It is sometimes necessary to oil them each meal-time, and the rope should be frequently examined for signs of wear. As a break in the rope stops all the machines connected to it, the lack of these precautions may result in a serious monetary loss. For the production of first-class ware, it is necessary to keep the rope at a uniform rate of motion—about 10 or 12 miles an hour is the usual speed,—so that the men may always have their machines running at an approximately constant rate. The diameter of the pulleys on which the rope runs is a matter of some importance as regards the life of the rope, and should never be less than thirty times that of the rope.

Turning.—Certain classes of ware require to be turned on a lathe after they come from the jolleys, but the lathes used for this purpose differ so little from those used in other trades that a special description is unnecessary; greater care is, however, required to ensure smoothness of motion. These lathes are, for the most part, treadle-driven, it being found that the continual variation of speed required is difficult to get with a power-driven lathe. As the time of the assistant is not fully occupied, he may well spend some of it in driving the lathe.

Where great exactitude of form is required, turning is one of the most important methods in the formation of ware, hence, considerable attention should be paid to the accuracy with which the work is carried out. If possible, a profile should be used to secure the exact shape required. The tools used should be kept in good condition, and accurately made to shape. It is very important that any filing of the tools should not be done at the worker's bench, or iron particles may become embedded in the ware.

Special machines are used for turning oval articles, such work being done only by very experienced workers.

Turned articles are particularly adapted to glazing on account of the smooth surface obtained, the pores being partly closed up so that they do not absorb an excessive amount of glaze.

Throwing, or the shaping of articles by hand on a potter's wheel, and formerly one of the most interesting branches of the potter's art, is rapidly declining, the work being now accomplished by mechanical means at lower cost and with more regularity. For small works, it has the advantage of requiring very little plant, though this is to a large extent neutralized by the high wages required by experienced throwers and the extent to which the works depend on them.

Moulding is by far the most largely used method of shaping articles in clay, the moulds being of metal, wood, fired clay, or plaster, according to the nature of the articles to be made. They differ greatly with different classes of goods, from a simple brick-mould to the most complex mould made in numerous pieces for highly decorated work.

The size of the mould is of great importance, and in it due allowance must be made for the shrinkage of the clay. As there is always a certain alteration of shape which takes place after the article has been removed from the mould owing to the pressure exerted as the result of its own weight, moulds are frequently made rather 'out of the square,' so that when the articles have dried they may be quite symmetrical. The exact amount of allowance to make for this purpose differs with different clays, and must be found by experience.

When plaster moulds are used, care must be taken that a suitable class of plaster (*superfine*) is used and that the *correct* proportion of water is used in mixing it—a matter which does not receive the attention it deserves,—oı the mould will be too soft to wear well. If a fresh sample of plaster be tested on a No. 100 sieve, it will be found that the most suitable qualities will permit at least 70 per cent. of their weight to pass through, and that 40 to 60 per cent. will pass through a No. 200 sieve. Poorer qualities will seldom allow more that 10 per cent. to pass a No. 200 sieve.

Another excellent test for plaster is to mix 3 oz. of water and 4 oz. of plaster; the total rise of temperature should not be less than 15° C.

The amount of water required for a given weight of plaster appears to vary in a very curious manner, even when samples of almost identical fineness and density are used. For each quart of water, the amount of plaster will usually vary from 40 to 60 oz., but much depends on the setting power of the plaster and the time allowed for this setting to take place. Mr W. Emery has found that for such widely different moulds as those used for jolleying earthenware, pressing earthenware, casting china, and for china-thrown cups, the most suitable proportion was 100 parts of water to 123 parts of plaster, or 49 oz. of plaster to each quart of water. This closely agrees with the average of a large number of samples tested by the author for sanitary ware and terra-cotta (viz. 48 oz. per quart), and suggests that this will usually be found to be the correct mixture for a good plaster.

The most suitable quantity of water and of plaster should always be ascertained very carefully, and it is also desirable to make porosity tests on small cubes of plaster several days after the cubes have been made. Such cubes should absorb one quarter of their weight of water in ten minutes, but the test can scarcely be considered as reliable, though very useful for comparative purposes.

Even when the correct proportions of plaster and water have been found, there still remains the effect of the skill of the mixer. Imperfect blending of the two materials will produce a mould so irregular in strength that it will be unsatisfactory and so uneven in porosity that it will not deliver the articles properly. As the mixture of plaster and water will set in a couple of minutes, and as the particles of plaster must each be thoroughly wetted, there must be a regular method of working devised which will ensure accuracy and avoid loss of time. The most satisfactory method consists in placing the water in the vessel in which the mixing is to take place and then sprinkling the plaster into it with both hands until it is all added. Then the blender puts one or both hands into the material, and by working it between his fingers and also using his open hands as paddles the thorough mixing of the material is made. Mixing with the aid of a stick is seldom satisfactory, and it is very slow.

In making moulds for bricks and terra-cotta, it is wise to mix only sufficient plaster for one mould at a time. The additional cost of labour as compared with mixing sufficient for several moulds is more than offset by the better quality of the moulds, for, unless the man can pour with exceptional speed he will either unduly hurry the pouring, or he will have to mix his plaster in such a manner that it sets more slowly. In either case, the mould loses in durability.

Plaster may be made to set more slowly by adding a little gum tragacanth, dextrin, or sodium carbonate, but none of these additions is really satisfactory, as they reduce the porosity and strength of the mould. To increase the rapidity of setting, a small quantity of a solution of either common salt, alum, or potassium sulphate in water may be added, though it should be avoided where possible.

It is sometimes necessary to make large terra cotta moulds in several pieces. In this case, also, most of the separate parts should each be made from a separate mixing of plaster and water.

As soon as the mould has been cast, the vessel containing the mixture of plaster and water should be emptied, washed out, and every particle of plaster removed. Unless this is done at once the next lot of plaster mixed in the same vessel may not set properly. Neglect of this simple precaution is a well-known cause of short-lived moulds.

The addition of old plaster, or of ground moulds, to new is also unsatisfactory.

The use of dirty water, or water to which soda or other chemicals have been added, should be discouraged in the manufacture of plaster moulds, as it tends to lessen their durability, although sometimes increasing their initial hardness.

The following important precautions should be taken when making a mould: (1) it should be sufficiently strong to stand the rough usage it is certain to receive, and should, therefore, be made large enough and reinforced where necessary by arranging iron bars or netting which are embedded in the plaster; (2) the plaster should be of the best quality, and precautions should be taken to ensure a satisfactory rate of setting; (3) the surface of the mould which will be in contact with the clay should be hard enough to stand the constant wear due to use; (4) the mould must be sufficiently porous to absorb water from the clay promptly, so as to allow the mould to be emptied without undue delay.

Large moulds are usually reinforced by inserting iron bars or strips in the plaster so as to form a kind of 'skeleton.' It is unwise to seek to economize by a very sparing use of such rods, as the loss by breakage when they are omitted overbalances any saving in iron. The wearing power of plaster moulds is also greatly increased by drying them thoroughly between each time of filling for the first few days of their use ; this treatment appears to make them harder and less liable to 'rot' than when the drying is omitted. Plaster moulds also last longer if they are well dried before being stored away.

The breakage and damage of moulds is always a source of trouble in a clayworks ; it can be minimized by frequent and regular inspection and by a careful system of 'registration,' which shows exactly what moulds each maker has in his possession and for which he is held responsible. For this purpose it is essential to have a good mould-store, so that the makers may return the moulds as soon as they are done with, for it is unreasonable to expect men to be responsible for moulds which have to lie about the works for want of a proper place in which to keep them. A little care on this point will soon repay itself, both in the increased life of the moulds and in the saving of time lost in hunting for a mould which has been out of use for a year or more but which is suddenly required. A catalogue of moulds in stock (preferably worked on the card-index system) will be found of great service in this connection, and by keeping it strictly 'up to date' and weeding out all old and destroyed moulds, it may be made a valuable factor in the search for moulds which, in so many works at the present day, takes up so much time unnecessarily. When a mould has been used, it should be carefully dried and then promptly put away, otherwise it will rot during storage, or it may be damaged in other ways and be quite useless when required.

CHAPTER IV.

TRANSPORT: CONVEYORS, PUMPS, AND FANS.

UNDER this heading may be included the appliances used for moving anything from one place to another. The principal requirements are: (1) rapid transit, (2) safe transit, and (3) small cost both in capital outlay and in maintenance charges. In regard to this last point, it is necessary to include *all* charges, whether direct or indirect, as otherwise it might be found that a method of transport which appeared to be cheap at first sight might, by its slowness or by its interfering with other parts of the works, actually cost more than another which had at first appeared more expensive.

Hand Labour and Barrows are the most elementary forms of transport, but they should be used as little as possible, because they are, relatively, very expensive. There are many cases in which they cannot be avoided, but their advantages and disadvantages are so well known as to need no further mention here. Whenever the transportation of goods between two points is regular and in sufficient quantity, it will usually be found that some form of automatic conveyor or tramway will prove more economical than barrows, both saving time and lessening the risk of damage to goods.

There are four kinds of barrows used in clayworking: (1) off-bearing barrows, on which soft bricks are laid in a single layer; (2) crowding barrows, on which bricks are packed closely one above the other; (3) navvy barrows with sides, used for transporting raw material; and (4) dryer barrows, used for stacking goods in a special manner in dryers. These last are not so much used in Great Britain as abroad.

Off-bearing barrows consist of a light frame mounted on springs, so that the bricks are not jolted in transport. They are rapidly being replaced by racked cars in the larger works.

Crowding barrows have a base and front, but no sides, and should carry seven rows of bricks, with eight bricks in a row.

Navvy barrows should be replaced, when possible, by cars or waggons.

All barrows should be so built that they are well balanced, the weight being thrown on the wheel and not on the man's hands, otherwise they will be difficult to drive and the output will be diminished. Barrows are preferably lined with sheet steel so as to increase the durability. The top edges should be similarly protected, as these come in for considerable wear. Barrows with steel bodies and wooden frames are very light and strong, though more expensive than those made wholly of wood. As barrows are not suitable for women, small waggons or cars have largely replaced them during the last few years.

Chutes of various kinds are invaluable when they can be arranged. If properly designed and constructed they convey materials very rapidly, and require no power or attendance. More use might advantageously be made of them in clayworks.

Tramways are, in many respects, the most suitable means of transport for goods and material about the works, as they can be used in bad weather and under conditions when other appliances will fail to work. The original cost of construction is not excessive, and the cost of maintenance is small if the road is well looked after. If allowed to get into a bad state, tramways tend to cause great losses through broken goods and through excessive wear and tear of the waggons, as well as waste of power if the waggons are moved by rope haulage. If the waggons are to be moved by men, it is not well for them to hold more than three-quarters of a cubic yard of material, and for most purposes, rather less than this capacity is preferable, whilst for pony traction on a fairly level track about twice this capacity will be found convenient. If the waggons are unnecessarily small, time will be wasted, but if they are too large additional men will be required to assist who, at times, are not needed, and hence cause a waste of money. Tramways are not unduly expensive to construct, yet they greatly facilitate transport and are very adaptable, as almost any kind of power may be used to propel or draw the cars. The rails may be laid either temporarily or permanently, according to circumstances, or a combination of both temporary and permanent rails may be used. For very short distances, men may push them, but where the distance is more than about 300 yards, either horses or some form of mechanical haulage is preferable.

Cars for carrying clay and bricks are largely used. When taking bricks to dryers and kilns they are generally provided with shelves on which the bricks lie singly or in small stacks, according to their stiffness. These cars are usually pushed along by two men, but they may be hauled by a rope or chain if desired. They are constructed to fit the dryers in which they are used. Further details will be found in the author's *Modern Brickmaking*, and other special works on drying. In order that the cars may run smoothly, they should be provided with ball bearings and the track should be kept in good repair.

Waggons and tubs for raw material drawn by ropes and chains are referred to on p. 104 ('Haulage').

If the track crosses the public road, it is desirable to have some form of brake attached to the waggon; or, if this is not thought advisable, the pony should be fitted into fixed shafts and not into the usual form of loose chain traces. For tracks entirely on the works this precaution is not quite so necessary, through a brake or safety catch is still desirable.

As transport by waggon may easily form an expensive item in the cost of production, it is wise to keep a careful watch over the average cost per waggon of the different kinds of material, and, in some cases, to pay by the waggon-load or ton rather than by time. This remark applies with great force to horse haulage, but to a less extent when the transport is worked mechanically. In most works, wooden trucks are used. Steel cars are very useful, being light and strong, but they are liable to spoil some clays if allowed to become rusty. They should be made very strong, especially at the corners and arrises.

The requirements of a good waggon, tub, lorry, bogey, corve, or whatever other name these articles may be known by in different parts of the country, are: (1) strength; (2) lightness; (3) stability; (4) compactness; (5) easy running: ball bearings are increasingly used in the construction of waggons, and it is, in any case, desirable to oil or grease them at very frequent intervals if they are to run freely; (6) easy discharge. This is particularly important in the case of 'tipping waggons.' Some of the more recent designs of waggons for clayworks are particularly convenient in this respect, and combine great natural stability with remarkable ease in emptying. At the same time, the body of such a waggon must be so fastened that it will not discharge its contents accidentally. Where small waggons are used, they may be run into a 'tipping frame' and completely inverted, this arrangement being simple, strong, and easy to use, if the bearings are kept well lubricated.

It is essential that the track for tramways should be well laid on soundly bedded sleepers to which the rails are securely fastened, preferably by means of bolts, which are cheaper in the long-run than the more usual nails. Special care is needed in the case of points, particularly movable ones. In planning the tramway system of a works, care should be taken to avoid inserting too many points, as these affect the smoothness of the running, and may consequently cause damage to clay articles in transit to the kilns, etc. They also make it necessary for the waggon to run more slowly over the points in order to prevent it being derailed. Points are, however, to be preferred to turn-tables, and the latter should only be used when really necessary; it will often be found quicker to take the waggon several yards further and use points than to have a shorter distance and use a turn-table. Much will depend on circumstances, and in some cases turn-tables cannot be avoided. When used they should be kept in first-class condition, so as to (1) turn easily, (2) be dirt-proof, (3) need little attention. By using a ball-race for the turn-table most of the friction can be eliminated. It is most important that dirt should not gain access to this race, but if it should do so, the table ought to be so designed that the bearing may be cleared in a minute or two.

It is highly advisable that the maintenance of the rails and turn-tables should be in the charge of one man, who should also be compelled to keep all the tools, nails, bolts, etc., he requires for this work in a special box, which he should take with him to the places where repairs are needful. If this is done, great care being taken that the tools, etc., are not, on any pretext whatever, allowed to lie about, and the disused bolts, etc., carried right away to their proper place, many annoying incidents which result from iron getting access to the clay will be avoided, and much of the time wasted in fetching tools, etc., will be saved. These may appear to be little matters, but they are none the less important.

If care is taken in arranging the working places of the different men, considerable sums of money may often be saved in the transport of clay to the makers. Thus, in many yards it is easily possible to run the clay direct on to the maker's bench by a little arrangement, whereas at the present time it is customary to have it all carried to one heap and re-distributed from thence by means of barrows or other conveyances, thus involving a double handling. This clumsy plan may often be avoided by having a gangway some 8 feet above the floor of the making sheds for the waggons to run on.

These waggons are preferably of the side-tipping pattern, as the rails need not then be broken to allow of emptying out the clay, nor need holes be left in the track.

Haulage by rope or chain is, next to the use of ponies, the most common method of moving waggons, corves, and similar vehicles for relatively short distances. The use of a rope or a chain for this purpose is, to a large extent, a matter of choice; in some cases a combination of the two is used —part of the track being controlled by a chain, with rope terminals for the better winding on the drum. Rope is usually preferred on account of its cheapness, but for steep inclines a chain provides a better gripping power. Freshly discarded colliery ropes are usually satisfactory for haulage in brickworks.

The rope or chain, which varies from $\frac{3}{8}$ inch to $1\frac{1}{4}$ inch in diameter, may be *single* and wound on and off the drum according as the waggon is being drawn up to or lowered away from the machine. For this arrangement, the track (which is single) must slope sufficiently for the waggons to travel down it of their own accord. A single rope of this kind is only suitable for small outputs or for large waggons. It has the disadvantage of making the engine run more irregularly than when 'endless haulage' is used.

Gravity haulage may be employed in some cases, and is valuable, as it requires no power. It consists of an incline with two parallel tracks. At the higher end is a large wheel or winding drum, running horizontally; around this is passed a rope, the ends of which are connected to the trucks, one on each rail. The greater part of the material to be transported must be at the top of the incline, and require to travel to the bottom. The trucks going down will then pull the empty one, or a number of filled trucks containing clay or goods may be used to haul up a smaller number of trucks containing coal, etc. The drum should be provided with a brake to prevent the loaded trucks from travelling too rapidly.

In *main and tail* haulage, one end of the rope or chain is wound off one drum whilst the other end is wound on to another. This is the ordinary form of haulage for collieries and other works where the endless system is inconvenient. Either a single or double track may be used. The drums used for ordinary purposes are about 12 inches in diameter and 17 inches long, revolving at about 150 revolutions per minute. They may be driven by steam, oil, or electricity. The cable used is generally about $\frac{5}{8}$ inch in diameter, the above drum carrying 800 feet. The reversing is effected by means of a lever and gearing, the motive power working continually.

The cars usually carry about $1\frac{1}{2}$ cubic yards of material, and may be drawn up by a gradient of 15° at 350 feet per minute, a power of about 10 H.P. being then required for each car.

In *endless haulage* the ends of the rope or chain are joined, and the power is supplied by means of a horizontal pulley at one end. The waggons are attached to this endless band at approximately regular intervals, so that the load on the engine remains fairly constant. This, and the automatic nature of the driving, constitute the chief advantages of the endless system. A double track is essential. It is also wise to have some form of ratchet and clutch on the shaft of the driving pulley so that in the event of a temporary stoppage of the engine the loaded cars will not travel backwards.

Which of these three systems is best will depend on the number of waggons to be attached to the rope at once, and whether a double track is possible, so that the empty waggons may be drawn up by the 'slack' part of the rope. Where two tracks are possible the endless type is generally to be preferred when the loads are not excessive; the direct winding rope is, however, best suited for drawing the waggons over very uneven ground, as the engineman is then able, by watching the tightness of the hauling rope, to regulate his power to suit the changing levels of the track, whilst an endless rope, being run at one continuous speed, is not quite so suitable in such a case.

Where the track is in the form of a fairly steep incline, the use of a counterpoise will often effect a saving in the power required. This method is chiefly used for vertical lifts only, but is equally efficient for steep slopes.

The rope, or chain, may be over or under the waggons, according to circumstances. Suitable rollers must be provided for the rope to run on, and these must be well lubricated, or they will rapidly wear out the rope. For turning a curve, vertical rollers with a large flange at the bottom to prevent the rope falling off are used to replace the horizontal ones.

It is important to choose a good attachment for fastening the waggons to the chain or rope. The automatic clips for this purpose are not, as a rule, to be recommended. One of the best on the market at the present time consists of a clip which surrounds the rope and which is opened and closed by a quick-acting screw. Catches to prevent run-away cars from doing any damage are almost essential, though too seldom used.

The so-called **Ropeways** (or aerial ways) are a modification of rope haulage, in which the rope, instead of pulling the waggon along, actually carries it. To this end the 'waggon'—which is usually in the form of a box or large bucket—is permanently attached to the rope, and the material is filled into it at one end of the track and emptied at the other by releasing a pin which causes the bucket to tip over or allows one side of the bottom to fall out. Various details require considerable attention in the construction of this means of transport, but they may safely be left in the hands of the makers, who will advise as to the best speed for the rope, the size of the buckets, etc. Where the nature of the ground does not permit the construction of an ordinary tramway (as when a deep valley intervenes between the source of supply and the destination of the material), this method of transport has the advantage of reasonable cost, small maintenance charges, and a high capacity. It is particularly suitable for conveying clay and coals from the pit to the works, as it is, to a large extent, independent of the relative position of the two places, and at the same time the intervening ground may be used for any purposes for which it may be suitable. Unfortunately, the initial cost of overhead ropeways is so great that they can only be used for very large outputs or for abnormally long distances, and unless at least 5 tons per hour is to be transmitted, they are not economical. A simple overhead ropeway may sometimes be made in quite a rough and homely fashion which is economical for short distances and loads of 1 ton per hour. Care should be taken to make it of ample strength.

Mono-rail Conveyors are more rigid aerial ways, and are chiefly used for short distances and for the transport of heavy goods. In clayworking, their use is almost entirely confined to the ends of the ropeway, where they are used to form a more solid bearer for the buckets during the loading and emptying, and, to a very small extent, for conveying goods from the machines to the dryers and kilns. They are somewhat expensive to construct.

Road Traction, whether by horse and cart or by the more modern traction engine or motor van, is usually cheaper for local deliveries than the railway. The most convenient type of cart is an ordinary tip-cart of about 2 cubic yards capacity, but if the district is very hilly a somewhat smaller cart is more convenient. Carts are not economical for distances above 3 miles.

Traction engines and motor lorries are much more suitable than horse waggons for clayworks; the roads must, however, be suitable and kept in good condition, or the wear and tear on the machines is excessive. For loads over 10 tons, steam waggons are generally more economical than oil engines, and some brick manufacturers prefer steam-driven lorries to those using oil. The wheels should be carefully selected, or constant breakdowns will occur. They are preferably built of steel with riveted spokes. Oil-driven motor lorries are unsuitable for weights over 6 tons, owing to the wear and tear on the wheels and engine.

The driver should be a skilled motor mechanic, capable of telling from the beat of his engine whether anything is the matter and of repairing it at once. This means higher wages than a horse-driver's, but the increased output of the motor as compared with that of a horse and cart will largely compensate for this. It is strongly to be recommended that all motors and traction engines in regular work should not be used more than five working days, and should be thoroughly overhauled on the sixth. Including such repairs as re-boring cylinders, re-tubing boiler, and other more extensive repairs, it is not safe to reckon on more than 240 working days per year.

It is almost impossible at the present time to institute a really reliable comparison of working costs and standing charges of horses and carts with other forms of traction available, as so much depends on local conditions. The question of depreciation also complicates the problem. It is probably correct to write off a quarter of the cost of a motor or engine at the end of the first year's working, and each succeeding year to take off one quarter of what is left; thus, a motor waggon costing £800 would depreciate to £600 at the end of one year, to £450 at the end of two years, to £190 at the end of five years, and after eight years' use it would have on the books a value only one-tenth of its original cost. This method of calculating depreciation is much safer and fairer all round than the more usual one of writing off 10 per cent. of the original cost each year. In estimating the cost of motors and engines with a view to comparing different types in actual use, errors of considerable magnitude often creep in owing to the careless way in which repairs are not charged tc the transport, but to a general account for the whole works. The wisest course is to open a separate bank account for the motor waggon or steam engine with its attendant trailers, to pay all expenses in connection with them out of this account, and to place to its credit all sums received for delivery of the goods.

It is generally found that for journeys of 20 miles or more a load of 4 tons on a motor is more economical than the use of horses and carts. For shorter journeys the load multiplied by the journey must not be less than 60, so that the critical point is 5 tons for 12 miles, 6 tons for 10 miles, and so on, though with improved construction this may be reduced. For a number of journeys in quick succession and on good roads, a 6-ton lorry, when fully loaded, should be able to make at least four journeys of 5 miles each in a day, but much depends on the facility with which it is loaded and unloaded. The use of additional bodies which can be lifted on and off the chassis by means of a crane greatly facilitates loading. Special care is needed to ensure a minimum amount of time being spent in loading and unloading, as during this time the driver's wages and the interest and depreciation charges in the lorry are earning nothing.

As regards the size and type of motor, it may be taken roughly that loads under 5 tons are most economically carried on the motor itself, but larger loads are best distributed between the motor and a trailer. The relative advantages of oil (petrol, etc.) over steam are most marked in the smaller loads—10 tons and under—and consist chiefly in economy of power production per ton-mile, in the rapidity of starting, and the smaller cost of attendance. For larger engines, the cost of petrol is too great for economy, but if an engine burning heavy oil could be constructed, the adoption of a heavier type of motor waggon would make great progress.

In consequence of the expense of repairs, many firms now sublet all their carting to engineering or other firms at a rate depending on the load and distance, and in this way save themselves the worry and responsibility of repairs and depreciation. For establishments of moderate size this plan is to be commended.

Water Carriage is deservedly popular where it is feasible, as it is not only cheap, but also has the advantage that finished goods suffer less damage in transit than by any other form of conveyance. The chief disadvantages of this means of transport are the low level at which the goods must necessarily be delivered and the slowness of their transit.

Railways always form the chief means of transport over long distances, and for economical working it is, therefore, advisable to have a siding in the yard wherever possible.

Conveyors are of many forms, the most important being belts and chains, screws and worms, buckets and drag-plates, and gravity or roller conveyors.

Belt and chain conveyors are mostly used for carrying material (chiefly dry ground clay) for short distances in an almost horizontal direction. The belt is made of strong woven hemp, or specially prepared canvas (rubber stretches too much), and the edges should be bound with cord, to prevent their wearing too rapidly. Belts of thin laths and of metal sheets are occasionally used, but cotton, hemp, or canvas belts are the most common. As the material stretches considerably in use, it is desirable to have some means of regulating the tension, either by moving one of the rollers on which the belt runs, or by adding an additional ('lazy') roller to take up the slack. To secure economical working it is essential that the belt should travel at a fair speed, but an excessive rate must be avoided, especially with finely ground clay, or the material will be wasted in transit by being thrown off the belt. A speed of 200 to 240 feet per minute is usually satisfactory, except for very fine clay, when belts up to about 12 inches in width carry on an average about 200 to 250 cubic feet per hour, whilst for every 2 inches increase in width up to about 30 inches an extra cubic foot per hour may be carried. Plain belts may be used on an incline of not greater than 1 in 5, though for dry material this is excessive. By fastening strips of wood across the belt or by attaching buckets (see "Bucket Elevators"), any desired inclination may be used. Belts are not economical for distances over 1000 feet, owing to the cost of maintaining the belts. Where damp material is handled, a scraper can advantageously be placed at the delivery end to clean the belt. Chains cannot well replace belts for conveying purposes, as in most cases in clayworks the material would drop through the links of the chain. If, however, buckets or boards are attached to the belt or chain, it practically becomes a bucket or drag-plate conveyor.

Screw and worm conveyors are seldom used as such in clayworking, although in pug mills the clay is usually forced forward by some such means.

Screw conveyors are also used to secure a regular supply of material to edge-runner mills (see 'Feeders,' p. 79).

In some works where bricks are made of semi-dry material a special form of screw conveyor is used to mix and convey the crushed material from the screws to the brick-presses.

Gravity conveyors are increasingly used for conveying bricks, etc., from the kiln to the packing room, railway trucks, or stack. They require no power to drive them, in most cases, though in some works it is convenient to include a short belt elevator. Gravity conveyors of the type most suitable for clayworkers consist of a light framework, constructed in sections so as to be portable and adjustable, each carrying a series of rollers mounted on ball bearings. These rollers form a 'track' along which the goods placed on the conveyor slowly slide.

There must be a gentle slope from the beginning to the end of the conveyor, but, as already mentioned, if a short belt elevator is used, any ordinary difference in level can be negotiated. Owing to the easily moving rollers the slope required is extremely small, and the ease with which the goods can be carried around corners and over irregular ground is remarkable. The bricks or other articles are placed on pallets on one end of the conveyor and are carried quite automatically to the other end. The adjustability of this type of conveyor makes it of special value.

Jiggers or shaking troughs are useful for hard clays and shale, but are worthless for wet materials. The trough is supported on light springs and is vibrated longitudinally by means of an eccentric, so as to shake the material from one end of the conveyor to the other, the velocity of motion of the trough being less in the outward than on the return stroke, so that the material is carried with it as it moves forward and slides over it on its return. This conveyor has an unusually large output of coal or ores for the width of trough used and the power required, the cost of transport of these materials being about half that of a belt conveyor of the same output. The data available as to the cost of transporting shale by jiggers is too slight for an accurate estimate, but suggests that jiggers should be very useful in conveying fireclays and shales.

Drag-plate and bucket conveyors are really modifications of the simple belt conveyor, designed for lifting goods through a greater angle than would be possible with a plain belt. In the drag-plate conveyor, the width of the belt is of small importance, and it is, therefore, reduced as much as possible, and a chain or metal rod is frequently substituted on account of its greater strength and durability. To this 'belt,' plates of wood or iron are attached at right angles to the direction of travel and on the lower side. These plates are of such a size as to fit loosely a metal or wooden trough which runs the whole distance the material has to be moved. On setting the conveyor in motion the plates are moved forward, dragging along any material which may have been placed at the beginning of the trough, carry it to the end, pass over the pulley, and so back to the beginning of the trough, where they again draw the material forward. The importance of the trough will be seen when it is observed that its sides practically convert the plates into temporary scoops. The weakness of this form of conveyor for ground clay is that it is very prone to stick fast if the clay becomes wet by exposure to the weather, otherwise it is a useful and very practical appliance for clay transport. There is a considerable amount of friction on the inside of the trough, only power is absorbed unnecessarily, and there is also a great tendency to contamination of the clay with the material of which the trough is composed. The use of bucket conveyors greatly reduces this friction, and that form of transport is usually preferred in a clayworks, where it is, as a rule, highly important to keep the materials as pure and clean as possible.

Bucket conveyors (or 'elevators') are largely used for crushed clays. They are commonly formed of a series of small vessels ('buckets') attached at regular distances from each other on an endless belt or chain. These buckets dip, at the lowest point of their travel, into the material to be carried, and, as they fill, are carried up to the top of the elevator, where they turn upside down and so empty themselves.

Some workers prefer a belt and others a chain as the medium for carrying the buckets; it would appear that the wear of linked chain is very great, and tends to introduce iron into the clay (when this material is being carried), so that for most purposes a belt of leather or of specially prepared canvas (such as 'balata') will be found best; indiarubber stretches too much, though it may be used for light work. The bucket chain is also very heavy when used in great length for a small slope, though when the rise is steeper this weight is of less moment. For wet clay, the bucket chain is more economical than the belt, as it does not perish so soon.

The capacity of the buckets must be determined by the quantity of the clay turned out per minute by the mill, and care must be taken that, no matter at what speed the buckets are driven, they are still capable of carrying away the whole mill output. If this is not the case, and the buckets are too few in number or too small in size, the elevator will become choked and damage may be done if it is not stopped. Thus, if a mill were grinding 50 to 60 tons of dry clay per day, or 2 cwts. per minute, this would need a bucket capacity of at least 2½ cubic feet per minute (on the assumption that ground dry clay measures 25 cubic feet per ton). In actual practice, an allowance of 3 cubic feet per minute would be better, as the buckets are seldom quite full. If each bucket has a capacity of 100 cubic inches (or $\frac{1}{17}$th cubic foot), at least 17 × 3 = 51 buckets must be filled each minute. If the number of revolutions of the belt is known, the number of buckets which must be on the belt may be readily calculated. It is, however, not advisable for the buckets to travel at a greater speed than 200 feet per minute, or they will throw the clay about too much, especially if they discharge on to a riddle.

The capacity of the buckets in cubic inches and the speed of the elevator (= number of buckets passing a given point per minute) being given, the following table shows the number of cubic feet of material the elevator will deliver per hour:—

Capacity of buckets. Cubic ins.	Number of buckets per minute.									
	60	70	80	90	100	125	150	175	225	275
10	20·8	24·3	27·8	31·2	34·7	43·4	52·1	60·8	78·1	95·5
15	31·2	36·4	41·7	46·9	52·1	65·1	78·1	91·1	117	143
25	52·1	60·8	69·4	78·1	86·8	108	130	152	195	239
35	72·9	85·1	97·2	109	121	152	182	213	273	334
45	93·7	109	125	141	156	195	234	273	351	430
60	125	146	167	187	208	260	312	365	469	573
75	156	182	208	234	260	325	391	456	586	716
100	208	243	278	312	347	434	521	608	781	955
125	260	304	347	390	434	542	651	759	976	1193
175	364	425	486	547	608	760	911	1063	1367	1671
225	469	547	625	703	781	976	1172	1367	1758	2147
275	573	668	764	859	955	1193	1432	1670	2142	2625
325	677	790	903	1015	1128	1410	1692	1975	2538	3102
375	781	911	1042	1172	1302	1627	1953	2279	2929	3580

It is difficult to calculate the exact sizes and strengths of chains suitable for conveying if the particular patterns are not known; hence, it is better to consult reliable makers and to be guided largely by their advice in such cases. The great point is to have ample capacity and power, so that no choking can take place.

The power used to drive these elevators is usually obtained by gearing, or belting, from the main shaft of the grinding mill. This method has the advantage of not requiring much power, but also the disadvantage (often met with in edge-runner mills) that when the mill runs very slowly, from overfeeding or other causes, the buckets will also travel slowly, and their carrying power may thus be reduced more than the grinding power of the mill, with the result that the buckets become overloaded and finally choked and the elevator stopped.

The tightness of the belts or chains must also be determined by trial, and if they slip too much the belt may be shortened or 'lazy rollers' fitted so as to take up slack.

Lifts in clayworks are chiefly of the 'cage' variety, and are principally used for conveying goods from one storey of the building to another.

The ordinary lift consists of a box, or cage, raised or lowered by means of a rope working on a revolving drum, or reel, driven by a suitable engine or motor. If carefully worked, such hoists may be run very smoothly, but there is a tendency to uneven running, which is serious in the transport of pottery and similar goods in the unfired state to the kiln. Double hoists are very useful, as one acts as a partial counterpoise to the other. Some proved device should be used whereby, in case of breakage, the winding will stop, and the cages should be fitted with safety catches to prevent overwinding, and to hold them in case the rope breaks.

Hydraulic lifts are much steadier in their motion than those driven mechanically, but have the disadvantage of much higher first cost. This may, however, be usually compensated by the smaller quantity of goods spoiled in transport and by the greater safety of the lift for the men using it.

Water ballast lifts are occasionally met with, and, when water is cheap, are a convenient form of hoist. The principle of working is very simple—two cages are used with one rope over a single pulley, and so arranged that when one cage is at the bottom of the lift the other is at the top. Each cage contains a large tank (usually placed beneath its floor), which can be filled with water at will. When it is desired to lift the cage loaded with goods, water is run or pumped into the tank of the upper cage in sufficient quantity to more than balance the load of goods. The catch holding the cage is then released, and the loaded cage rises to the height required; a break or catch is then applied to prevent it rising too far. When it is desired to lower the cage again, the water is run out of the tank, care being taken to leave sufficient in to prevent the cage from falling too rapidly. Though a primitive form of hoist, this plan is working satisfactorily in several places. The supply of water as well as the emptying of the tanks when necessary can be made almost automatic, and the water can be used over and over again, so that the actual working cost is extremely small. The chief point in construction is to provide sufficiently large pipes for the conveyance of the water to and from the tanks on the cages.

All lifts should be fitted with safety appliances, so that, in the event of a breakdown, damage to life and limb may be prevented, or at least reduced to a minimum.

Cranes are only used to a very limited extent in clayworks, and are chiefly of the simple hand-winch type. Travelling cranes fitted with buckets or a grab of about 1 cubic yard capacity are useful in some large clayworks. In most cases they should be in the form of a steam navvy (p. 45).

Mechanically driven cranes require careful and skilful selection, as the use of too small a crane is a frequent cause of accidents. Cranes may be driven by steam, oil, or electricity, and whichever source of power is used, they should be placed in charge of a thoroughly competent man, as an accident is much more likely to be serious with a power-crane than with almost any other machine in a clayworks.

Great care should be exercised in lowering goods with a crane, the speed being regulated by brakes to avoid suddenly stopping the goods, as this is an almost certain cause of breakages. Even the sudden contact of a heavy weight with the ground will often cause serious damage to the crane if it has been lowered with great rapidity and has only been stopped by the load touching the ground.

When goods are beyond the sweep of the crane-arm, but can, nevertheless, be reached by the chain, or rope, care should be taken not to lift too much at once, as the moving of the chain outwards from the vertical is equivalent to lengthening the arm of the crane, and with heavy loads this may result in straining the machine beyond its safe limit.

The construction of the crane hook is a matter requiring considerable care, as probably more accidents have resulted from the hooks breaking than from any other single cause. Particulars as to the sizes and dimensions will be found in books of Engineering Tables.

The metal of which crane chains are made tends to undergo internal changes in structure owing to the irregular strains to which the links are subject. They should, therefore, be thoroughly annealed at regular intervals, certainly not less than once every three years.

For hand cranes, the winch handle should have a radius of 15 to 18 inches (17 inches is the best), and the height of the axis of the handle should not be more than 3 feet 3 inches nor less than 3 feet from the ground. The power of the crane should be so proportioned to the work to be done that a continuous speed of 220 feet per minute shall be attained by the men's hands, so long as they are actually working the crane. The actual pressure exerted by each man should not be expected to exceed 20 lbs. for regular work, though a somewhat larger amount may be obtained once in a while.

Certain regulations imposed under the Factory Acts in regard to cranes, etc., should be ascertained from the proper authorities, and fully adhered to, as official inquiries follow accidents.

Pumps.—For the conveyance of water, clay slip, and other liquids, some form of pump is usually necessary, the particular variety depending on the work to be done. Thus, hand pumps are largely used on account of their portability, especially for irregular work.

Steam pumps are better where there is sufficient work for their almost constant use. They must not be too far removed from the boiler, however, or the amount of condensed steam formed will prevent their efficient working. Steam pumps may be constructed with or without pistons; in the latter case the steam acts directly on the water to be raised, or indirectly, as in the diaphragm pumps or in the centrifugal machines.

The *ordinary pump* (with piston or 'bucket lifts') can be used for almost all purposes, though for very dirty water other varieties are more suitable and less liable to become choked. For general work it is difficult to beat the three-throw pumps of the best makers.

For the transport of clay slip, nothing is better than a well-made plunger pump with long stroke (24 to 30 inches). A foot-valve is necessary on the suction pipe, and the pump must be placed close to the surface of the slip, or slurry, to be transported. The wear and tear is small, even with sandy clay, and a pump with 4-inch plunger will deliver over 900 gallons of thick slurry per hour with 15 strokes per minute.

Plunger pumps require frequent overhauling as, unless specially designed for clay slips, they wear rapidly by the grinding action of these materials.

The chief difficulties experienced with water pumps are:—(1) short strokes; (2) leaky packing round the piston rod; (3) leaky valves and piston, and (4) air leakages in the suction pipe. Unless these matters receive prompt and careful attention, much power will be lost. The use of a pulsometer avoids all the piston troubles, and is, therefore, very much used for drainage purposes in clay pits (p. 46). The pumping line should be as straight as possible. This is particularly important in ordinary piston pumps, as power is lost in forcing the water round bends, particularly if these are sharp.

For filling *filter-presses*, a special force pump is required capable of working against great pressure. It is driven direct from the shafting, and must be well fixed in position on account of the great strains it undergoes. Such a pump should also be provided with a safety pressure-valve opening when the press is full into a special tank. To prevent ramming, an air-cushion (a piece of pipe about 3 feet long closed at one end) should be attached to a T-joint in the supply pipe between the pump and the press. The fittings of pumps used for filling filter-presses need continual supervision, as they rapidly wear with the great pressure and the contact with the clay.

Diaphragm pumps are popular on the Continent for transporting slurry and dirty water, but as they are essentially hand pumps, they are not adapted for large deliveries. The internal wear and tear is exceedingly small compared with that of an ordinary pump, as in the diaphragm pump the ordinary piston, or bucket, is replaced by a diaphragm of rubber which rises and sinks with the motion of the pump rod and so produces the necessary vacuum. The barrel is made short and wide on account of the shorter stroke of the diaphragm. Repairs are simple and not expensive.

Diaphragm pumps are capable of pumping over 3000 gallons per hour when hand worked, and rather more if power driven. They are very portable, and can be connected, if desired, to a flexible hose, but are not suitable for high lifts.

The *pulsometer*, though very inefficient as a thermal engine, works so admirably in many situations where other pumps cannot be used that it finds a sphere of usefulness peculiarly its own. It requires no fixing, but can be slung into position and used with very dirty and gritty water, although not so well for slurry. It consists essentially of two bulbs side by side, which are filled alternately with water and steam, the vacuum caused by the condensation of the latter causing the water to fill the bulb. The valves are of the simplest possible make, and the pump will work for several years without need of repairs and with practically no attendance, so long as steam and water are supplied to it. Pulsometers are made in various sizes to deliver from 900 to 80,000 gallons per hour.

The *centrifugal pump* is particularly suitable for a large delivery of water (not necessarily very clean) at a height not above 25 feet It consists of a wheel with curved blades which revolves rapidly in a casing, the water being drawn in at the centre and discharged at the circumference in a manner similar to a 'fan.' Centrifrugal pumps are not suitable for use with long suction pipes, but the pump itself may, when necessary, be immersed partially in the water. The horizontal pattern appears somewhat easier to clean than the vertical type. A small tank should be provided at a short distance above the pump to contain water with which to start it, as, unlike some other forms of pump, the centrifugal type will not start until it is full of water. The arrangement of the blades, guide passages, and some other portions of the interior require careful construction and adjustment. It is excellent for dirty water, and if solidly constructed even an occasional stone may be passed through it without damaging the pump.

In choosing a centrifugal pump, care should be taken to select and fix one which can be readily opened and cleaned or repaired and the wearing parts easily and cheaply renewed. The engine may be direct-coupled to the pump, or a belt may be used for driving, the speed of the pump and the power required depending on its size and on the amount of water it is required to move per hour. Electrically-driven centrifugal pumps are excellent, as the power is constant and may be switched off when not required. A pump to deliver 100 gallons of water per minute requires a 10 H.P. motor running at about 1800 revolutions per minute. It should be connected direct to the pump.

Hot-water Pumps.—That the ordinary pump will not transport hot water is well known; the reason being that when the piston rises so as to produce a partial vacuum the pressure on the hot water is reduced, and as some of the water is immediately converted into steam the pump is unable to produce a proper vacuum but simply draws steam indefinitely. The water should flow into the pump by gravity, and care should be taken that the composition of the valves and packing is suitable. When pumping hot water against a considerable pressure (as when filling a boiler) it is advisable, if possible, to pump into feed-heaters, and from thence, by pressure, into the boilers. By this means, only cool water passes through the pump.

Some information on the use of pumps for feeding boilers will be found in the chapter on 'Boilers' (p. 59).

The power required to lift x cubic feet of water per hour from a depth of y feet is equal to

$$\text{H.P.} = \frac{x \times y}{20909}.$$

The quantity of water which will be delivered (in cubic feet) per hour

$$= \frac{\text{D}^2\text{LMN}}{37},$$

where D = diameter of pump-barrel in inches.
L = length of stroke in inches.
M = efficiency of pump (usually ·66).
N = number of strokes per minute.

Allowance must be made for friction and to overcome the inertia of the pump; this is often taken as $57\text{D}^2 \times \text{H}$, where H = height of lift in feet. The valve area should be such as to give the water a velocity of 250 feet per minute.

If the output is required in gallons per minute, multiply the piston speed of the pump (in feet per minute) by 34 and divide by 1000, and multiply the result by the square of the diameter of the piston. It is, however, advisable to multiply this figure by $\frac{3}{4}$ in order to allow for friction in working. For example, a pump $5\frac{3}{4}$ inches diameter and with a piston speed of 90 feet per minute may be expected to deliver $\frac{34VD^2}{1000} = \frac{34 \times 90}{1000} \times 5\frac{3}{4} \times 5\frac{3}{4} = 100$ gallons per minute, but in practice only $\frac{3}{4}$ of this volume, viz. 75 gallons, would be expected.

To find the diameter of piston of pump required, divide the gallons to be raised per minute by the speed of the piston in feet per minute, divide the answer by 34 and multiply the result by 1000, then take the square root. It is usual to select a pump $1\frac{1}{4}$ times the diameter thus found, in order to overcome the friction; thus, if a pump is required to deliver 100 gallons per minute with a piston speed of 90 feet per min., $\frac{100}{90} = 1{\cdot}111$ and $\frac{1{\cdot}111}{34} \times 1000 = 32\frac{2}{3}$, and the square root of $32\frac{2}{3} = 5\frac{3}{4}$ inches.

Air Lifts and Siphons.—In addition to pumps of various kinds, water is often conveniently moved by means of compressed air. An exceedingly simple way of raising water from a narrow bore-well is to insert a tube down the centre of the rising main and to blow air through this at constant pressure. If the main dips sufficiently below the surface of the water the air escaping from the lower end of the air-tube will, in rising through the main, be broken up into short cylinders, air and water alternating, and in this way the water will be lifted to the desired height. This method is useless for working against pressure, but is often convenient for draining a place where, on account of sand, etc., choking the valves, an ordinary pump cannot be used. It is, however, essential to have ample submersion of the main, or the air will not break up properly and no water will be lifted. Hence, this arrangement will never pump a well dry, nor can it be considered at all an economical method where a pump could be equally well employed.[1]

Siphons are only employed to a very limited extent in clayworks. As is well known, they consist of a tube or pipe bent into the shape of an inverted U, with one arm shorter than the other. The shorter arm is placed inside a tank or other vessel to be emptied, the longer one forming the outlet. To start the siphon it must first be filled with water, or by suction at the lower end, before it will begin to act. It is also essential that the end of the longer arm be at a lower level than that of the shorter one. A siphon is very useful for decanting the water from tanks after the clay has settled. It is also very useful for supplying a given quantity of liquid from one vessel to another. When a siphon can be used for draining a clay-hole, it is much cheaper than a pump, as no power is required to maintain it in its action. Unfortunately the conditions favourable to its use for this purpose are uncommon. Such an arrangement is often of great value in a glaze-house or similar places where definite volumes of water are often needed.

Fans and Chimneys.—For the purpose of furnishing draught, chimneys and fans are chiefly used. The chimney is most in favour for this purpose, as it is generally thought to cost nothing to work it. This is not by any means always the case, and there are numerous instances where the air-supply

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[1] Messrs. Isler & Co., Bear Lane, Southwark, S.E., are pioneers in "Air Lifts," and Adams' Hydraulics Ltd., York, in patent siphons.

to a boiler fire or for ventilating or drying purposes might be more cheaply obtained by mechanical means, such as a fan. The reason for this is that the draught produced by a chimney is proportional to the difference in temperature between the air inside and outside it, and to cause this difference by the burning of fuel is a wasteful method if better use can be made of the heat.

Owing to the temperature at which gases sometimes leave kilns, and in the absence of any means of utilizing the heat they contain, a chimney may be more economical than a fan. At other times, mechanical power is cheaper. Further information on chimneys will be found by referring to the Index.

The height of the chimney is dependent on a number of factors, but Prof. H. Adams gives the following figures in terms of the coal consumption:—

Fuel burnt.	Height of the chimney.
4 tons in 56 hours	75 feet
13 ,, ,,	100 ,,
26 ,, ,,	120 ,,
50 ,, ,,	150 ,,
100 ,, ,,	180 ,,
150 ,, ,,	200 ,,

Fans are generally essential for drying goods when temperatures higher than that of the atmosphere are used, and when the output of a drying plant is intended to be large, as chimneys are less under control and cannot usually overcome the air resistance in such a case.

Fans are constructed for either sucking in or for blowing out air. It is extremely difficult to decide definitely in favour of one rather than the other, as much depends on the local conditions. Suction fans are often preferable, because they produce a more even circulation of the air in the room where the goods are piled some distance from the floor, on shelves, etc., but for an open room the 'cone' of air formed by a blowing fan is sometimes an advantage. For most clayworkers' purposes, a suction fan is best.

Fans are of two main types—screw and centrifugal; the former are more suited for moving large volumes of air at a comparatively low velocity and against little or no resistance, but they are quite unsuitable for forcing air through narrow passages (between goods, etc.) or against high resistance. The greatest effective pressure of a screw fan is about $\frac{1}{2}$ inch of water, or $\frac{1}{4}$ to $\frac{1}{5}$ oz. per square inch. Centrifugal fans may be used more efficiently as blowers, though even with them there is great loss of power in forcing the air through narrow channels, and round sharp angles, or from narrow to wider channels, or the reverse. Centrifugal fans should be provided with vanes of sufficiently wide radius, or they will be wasteful of power owing to the insufficient supply of air to the centre. When used for drying delicate goods, the air is generally drawn through a flannel or wool screen so as to exclude any dust in the air. The screen must not be allowed to become choked with dust, or the air-supply will be seriously diminished.

The volume of air moved by different types of fans varies greatly with the make and size of the fan, and the published figures, emanating as they do almost entirely from the manufacturers, must be taken as the maximum output under the best conditions. The author has, however, found that after several years' use a 48-inch Blackman (screw) fan is still moving 2000 cubic feet per minute with an average expenditure of rather more than 2 H.P., a value well within the limits claimed by the makers of the fan.

The power required for driving a fan, according to Charnock, may be calculated roughly from the following formula:

$$\text{H.P.} = \frac{DAV}{35420}$$

where D = the diameter of the inlet in feet;
A = the area of the discharge in square feet; and
V = the velocity of the air or gases in feet per second.

The volume of air or gas passing through a fan depends on the temperature, and as the gases and air increase $\frac{1}{273}$ for each one degree rise in temperature above 0° C. (so that a volume of air at 273° C. is exactly double the volume of the same air at 0° C.), it is important to bear this fact in mind when dealing with hot gases. Where air under high pressure is required, a Root's blower is preferable to a fan. A blower to deliver 650 to 700 feet of air per minute at a pressure of 21 to 28 inches water gauge, requires about 2½ to 3 H.P. Similar blowers are used for delivering air to blast furnaces, etc., at a pressure up to 10 lbs. per square inch.

The use of fans to improve and regulate the draught of kilns has greatly increased during the past few years on account of the saving effected in fuel and the superior quality of the goods. When a chimney is used, the fires are subject to great variations according to the wind, but with a fan a perfectly steady draught may be maintained as long as may be desired.

The most generally satisfactory velocity for driving air through pipes by fans is 2000 feet per minute.

The fear formerly felt that a fan might break down and spoil the goods is so seldom realized as to be neglected.

It is highly important that the fans should be designed by those having practical experience of the requirements of the clayworker—which are somewhat unusual,—as a home-made fan or one purchased without sufficient knowledge may lead to serious inconvenience.

When properly designed, rightly constructed, and satisfactorily installed, a fan will be found to be much more economical than a chimney for a continuous kiln. Its value for single intermittent kilns is still a matter for further investigation.

CHAPTER V.

DRYING AND DRYERS.

Drying.

It is very desirable that each master clayworker should be as fully acquainted as possible with the changes which take place on drying the particular clay he is using, as it is chiefly by such knowledge that he will be enabled to secure the efficient and economical working of his plant.

In ordinary plastic clay, the water present fills all the interstices between the clay particles but, as the clay dries, this water evaporates and air takes its place. The actual removal of the water takes place at first at the surface of the clay, its place being taken by water from the inside of the clay so long as the pores of the clay can transmit it by capillary action. This is the first stage of the drying, and it varies in duration with the proportion of water which has been added to the clay. It is also the stage where the largest amount of contraction occurs, as the clay particles tend to move over each other and to take the place previously occupied by the water, with the result that the amount of contraction generally approximates in volume to the amount of water evaporated. A strong, porous clay which requires a large proportion of water to make it plastic will consequently contract considerably at this stage, whilst a milder, more permeable and sandy clay with less 'water of manufacture' in its composition will show much less shrinkage and will require a shorter time for drying in the first stage.

The completion of the *first stage* of the drying may be determined by drying a carefully weighed and measured block of clay and repeating the weighing and measuring at frequent intervals; as soon as the loss in weight commences to be greater than the loss in volume of the block by shrinkage the first stage of drying is complete. If metric weights and measures are used no calculation will be needed, as the loss of weight in grammes can be compared directly with the loss of volume in cubic centimetres; if, however, English weights and measures are employed, the loss of volume (shrinkage) measured in cubic inches must be multiplied by 0·578 in order to convert it into fluid ounces, which can then be compared with the loss of weight in ounces.

As distortion is a common result of unequal shrinkage caused by some portions of the goods losing moisture more slowly than the rest, all small projections should be covered over until the thicker portions are nearly dry.

In the *second stage* of drying, evaporation takes place far more rapidly than the change in volume of the goods, and the completion of this stage is characterized by no further shrinkage taking place; the clay is then no longer plastic.

In the *third stage* of drying, evaporation of the water takes place entirely from the inner parts of the clay, no shrinkage or change in volume of the clay occurs, and the spaces left by the removal of the water are filled with air; there is now little or no danger of distortion, and the drying may be carried out as rapidly as desired. It therefore pays to accelerate the drying at this stage.

As the shrinkage is less when the clay is dried rapidly from the start, since the clay particles do not then have time to move so freely over each other, it is advisable to dry goods as rapidly as is consistent with safety; but, as in the second stage of drying the outer surfaces tend to dry more rapidly than the inner portions of the clay, cracking will probably ensue if the water be removed too quickly. Thus, each clayworker should determine how rapidly he may safely dry his clay, so as not to waste both time and money by having it too long in the dryers.

In the case of large articles, especial care is needed to ensure their being thoroughly dry, and some enterprising firms now insist on every such article being marked with the date of manufacture (either plainly or in cypher), and are in this way able to learn whether goods have been sent too soon to the kilns or whether they have been delayed unduly in the dryers.

Although, with small pieces of clay, the colour will often show when they are dry, this is not the case with larger goods, so that with the latter it is well, when they are urgently needed, to weigh them at frequent intervals, and to continue the drying for at least twenty-four hours after they have ceased to lose weight. It is hardly needful to remark that damp or 'green' goods should never be sent to the kilns.

Methods of Drying.—Although various methods are employed for drying clay goods, they may be arranged in two groups, according to whether cool or warmed air is used. This division is indeed an arbitrary one, as in both cases it is the air which acts as a vehicle for the removal of the water. It does this by means of its power of holding a definite, measurable quantity of water in suspension, the exact quantity varying with the temperature of the air, just as hot water will dissolve a larger proportion of soda than cold water will. If air at a high temperature, and saturated with moisture, be cooled, it will no longer be able to retain all the water, and will deposit some of it in the form of dew, the amount deposited depending on the degree of cooling which the air has undergone. Thus air at 80° F. will retain nearly twice as much water as the same volume of air at 60°, so that if the air at 80° be cooled to 60° it will deposit about half its contained moisture; whilst if, on the other hand, the air be warmed from 60° to 80°, it will, at the higher temperature, be able to carry more water than at the lower, and if a damp surface be exposed to its action, the latter will part with its dampness until the air has absorbed sufficient water to saturate it, whereupon no further drying will take place. If the damp body does not contain sufficient moisture to saturate the air, it will be completely dried by the air. It is, therefore, important to keep the air in the dryers at such a temperature that it is unsaturated, and to remove it as soon as its capacity for taking up water from the goods has been reached. The instrument used in measuring the moistness of air is called a hygrometer (see Chap. XIII.), and by its means it is possible to learn at any time whether the air will dry the goods efficiently or not. This is important, as air at ordinary temperatures in this country is generally more than half saturated with moisture.

When cold air is used for drying the goods, the amount required is not usually of much importance, but if hot air is employed the cost of heating must be taken into consideration. This cost will vary with the method of applying the heat, but there are certain limits which it must reach. It is a proved fact, for instance, that a brick of dry clay weighing 7 lbs. can be raised from 60° to 61° F. by only 1·4 units of heat, but if the brick contained $\frac{1}{2}$ lb. of water, as it probably would do before drying, it would require no less than 537 units of heat to drive off this water, and, at the same time, raise the temperature of the brick by one degree. In other words, there can be no drying without the absorption of a certain definite amount of heat by the water evaporated from the goods, although the temperature of the goods may remain constant. In a general way, if heat is applied to a substance, the temperature of that substance will steadily rise, and *vice versa*, but under certain conditions, this is not the case. The application of heat to water or to certain materials containing water are instances to the contrary.

Care must be taken to distinguish between the temperature of a body and the number of heat units it contains.

As is well known, temperature is usually measured in 'degrees,' two scales of degrees being in common use, viz. the Fahrenheit (F.) scale, on which the melting point of ice is represented by the number 32 and the boiling point of water at normal pressure by 212; and the Centigrade (C.) scale, in which these two points are represented by 0 and 100 respectively (see Appendix).

Heat, on the other hand, is measured in 'British Thermal Units' (B.T.U.) or in 'Calories' (Cals.), one B.T.U. being the amount of heat required to raise the temperature of one pound of water one degree (from 60° to 61° F.), and one Calorie being the amount of heat required to raise one kilogramme of water one degree Centigrade (strictly from 0° to 1° C.). Hence 1 B.T.U. = ·252 Cal.

The British Thermal Unit is the standard unit of heat in this country, but the more scientific unit of heat is the Calorie.

The Amount of Heat required to raise 1 lb. of water 50° F. is 50 B.T.U., or, if 2 lbs. of water have their temperature raised 50° F., $2 \times 50 = 100$ B.T.U. will be needed.

When water is evaporated (as when articles are dried) a certain amount of heat is required to drive the water from the wet substance, and yet it does not raise the temperature of that substance. This is called the 'lost' or 'latent' heat, or, more correctly, the 'heat of vaporization.' The amount of heat thus rendered latent in the conversion of water into vapour has been very carefully determined by Regnault and other observers, who found it to be 967 B.T.U. or 537 Cals. when water, at its boiling point, is converted into steam of the same temperature, and proportionately more if the water is below the boiling temperature. The actual amount of heat used in effecting vaporization at any particular temperature may be found from the following formula:—

$$L = 1114 - 0{\cdot}695\ F., \text{ or } l = 606{\cdot}5 - 0{\cdot}695\ C.,$$

where L = Latent Heat in B.T.U., l = Latent Heat in Calories, and F. and C. represent the temperature according to the Fahrenheit and Centigrade scales respectively.

Clay and similar materials require less heat than the same weight of water to raise their temperature by a given amount; in fact, most clays, when perfectly dry and free from combined water, only need *one-fifth* as much heat to raise their temperature one degree as the same weight of water would require. From this it follows that the minimum number of heat units which will be needed to raise the temperature of the goods (when perfectly dry) is as follows:—

$$\text{B.T.U.} = \frac{\text{Weight of goods in lbs.} \times \text{rise in temp. in °F.}}{5}$$

$$\text{Calories} = \frac{\text{Weight of goods in kilos.} \times \text{rise in temp. in °C.}}{5}$$

Thus, to heat a brick weighing 7 lbs. from 60° to 61° F. needs $\frac{7 \times 1}{5} = 1{\cdot}4$ B.T.U. if the brick be dry.

With a 'green' brick containing $\frac{1}{2}$ lb. of water at 61° F. the latent heat of water $= 1114 - {\cdot}695 \times 61 = 1114 - 42{\cdot}4$ per lb. $= \frac{1071{\cdot}6}{2} = 535{\cdot}8$ B.T.U. for the $\frac{1}{2}$ lb. of water present, and the total B.T.U. to dry the brick and raise its temperature to 61° F. will be $1{\cdot}4 + 535{\cdot}8 = 537{\cdot}2$ B.T.U.

If the weights had been in kilos. (7 lbs. $= 3{\cdot}078$ kilos. and $\frac{1}{2}$ lb. $= {\cdot}227$ kilo.) and the temperatures in °C. (60° F. $= 15{\cdot}5°$ C. and 61° F. $= 16°$ C.), the calculation would have been:—

To raise temperature of dry brick ·5° C. $= \frac{3{\cdot}078 \times {\cdot}5}{5} = {\cdot}77$ Cal.

To drive off water at 16° C.—

$$\begin{aligned} &= (606{\cdot}5 - {\cdot}695 \times 16) \times {\cdot}227 = (606{\cdot}5 - 11{\cdot}12) \times {\cdot}227 \\ &= 595{\cdot}4 \times {\cdot}227 = 135{\cdot}15 \text{ Cals.} \end{aligned}$$

Total heat-units required, $\cdot 77 + 135{\cdot}15 = 135{\cdot}92$ Cals.

It is, of course, to be understood that the results so obtained are the *minimum* values, and that in most cases considerably more heat will be required in order to replace that lost by radiation, etc. In some cases, the additional heat required to make up for these is very considerable, but it is scarcely possible to calculate its amount with exactitude without long and tedious calculations. As an instance of the sort of losses which are met with, it may be mentioned that a 5-inch cast-iron steam pipe with steam at an absolute pressure of 115 lbs. will, if uncovered, condense about 1 lb. of water per foot per hour, in doing which 1000 B.T.U. are liberated. A table showing the loss of heat by the condensation of steam in pipes is given in the Appendix.

The Amount of Air required depends upon (*a*) the dryness of the air; (*b*) the pressure; (*c*) the temperature of the air and of the goods; (*d*) the volume of air; (*e*) the area of exposed surface of the goods.

The dryness or otherwise of the air is determined by means of a hygrometer (see Chap. XIII.). The amount of air required will vary directly as the amount of moisture it contains; thus, if 50 lbs. of air were sufficient to dry $\frac{1}{2}$ lb. of water from a brick at 75° F. when the air is only 50 per cent. saturated with moisture, about 100 lbs. of air at 75 per cent. saturation would be required to effect the drying of another brick containing the same amount of water. For at 75° F., 50 lbs. of air at ordinary pressure can hold almost exactly 1 lb. of moisture; so that, if only 50 per cent. saturated, it would have only ·5 lb. moisture in suspension, and could take up another ·5 lb. from the brick; but if 75 per cent. saturated, it would contain ·75 lb. moisture, and so could only take up another ·25 lb. from the brick, with the result that to evaporate ½ lb. of water $50 \times 2 = 100$ lbs. of 75 per cent. saturated air would be needed.

A table showing the amount of water required to saturate air at different temperatures will be found in the Appendix. This table also shows the great increase in water-carrying (drying) power which air undergoes when its temperature is even slightly raised.

The specific heat of air is only ·237; that is to say, ·237 unit of heat is required to raise 1 lb. of air 1° F., whereas to raise the temperature of 1 lb. of water the same extent would require 1 unit, and 1 lb. of dry clay would require ·2 unit (B.T.U.). Hence, to calculate the number of lbs. of air required to evaporate 1 lb. of water from a given weight of clay, it is necessary to first calculate the 'latent heat of vaporization' at the particular temperature at which the drying takes place (p. 120), and then to divide this by the product of the fall in temperature of the air as the result of its passing over the goods and by ·237. Thus, the minimum weight of air which will yield sufficient heat to drive off 1 lb. of water from a piece of clay weighing 10 lbs. (= 9 lbs. clay and 1 lb. water), the air being supplied at a temperature of 90° F. and being cooled by the clay to 65° F., will be $L = 1114 - (\cdot695 \times 65) = 1069$.

$$\frac{1069}{(90 - 65) \times \cdot237} = 180\cdot6 \text{ lbs.};$$

and as each lb. of air requires ·237 B.T.U. to raise its temperature 1° F., assuming the air to be at 50° F. before heating to 90° F.,

$$180\cdot6 \times \cdot237 \times (90 - 50) = 1712 \text{ B.T.U.}$$

will be required to heat the air sufficiently for this purpose. In addition to this, a certain amount of heat will have been absorbed by the heating of the water in the clay from 50° to 65° F., and also in heating the clay, viz.

Heating 1 lb. water from 50° to 65° = 1×15 = 15 B.T.U.,
Heating 9 lbs. clay from 50° to 65° = $9 \times 15 \times \cdot2 = 27$ B.T.U.,

or a total of 1739 B.T.U.

If the goods are supported on wooden racks or on iron cars, a further quantity of heat will be required to raise the temperature of these. This is calculated as follows:—

Weight of supports × rise in temperature × specific heat of support.

The specific heat of wood may be taken as ·55, and that of iron as ·114.

Losses of heat by radiation are not easy to calculate; they may easily amount to a quarter of the total heat supplied if the dryer is carelessly designed or badly managed. In addition to these losses of heat, there is another caused by the fact that it is not generally advisable to allow the air to pass away in an almost saturated state, as it is then liable to deposit some of its moisture on the goods at the end of the dryer; it is usual, therefore, to pass the air out at about 90° F.

The volume of air required may be calculated from the weight of air required as follows:—

$$1 \text{ lb. air} = \frac{(\text{Temperature °F.} + 491) \times 13\cdot35}{491} \text{ cubic feet,}$$

$$1 \text{ kilo. air} = \frac{(\text{Temperature in °C.} + 273) \times \cdot8}{273} \text{ cubic metres,}$$

the air being at standard pressure (30 inches or 760 mm.) in both cases.

Thus, 1 lb. air at 32° F. measures 13·35 cubic feet, and 1 kilo. at 0° C. measures 0·800 cubic metre. If the air is driven through the dryer at a high pressure, more air will be required, because it passes out of the dryer before it has had time to become fully saturated with moisture.

If the heat is not allowed to leave the dryer until it is saturated, it may deposit water on the bricks. To avoid this, the air should not usually be cooled below 90° F. when it leaves the dryer, as at that temperature there is less chance of water being deposited. There is little or no risk with dryers in which the goods and the air both travel in the same direction, and the heating is progressive.

The Rate of Drying depends upon (*a*) the dryness of the air, or, conversely, upon the vapour pressure, which varies with the temperature; (*b*) the volume or weight of air available; (*c*) the temperature; (*d*) the area of exposed surface of the goods.

It will thus be seen that, provided a sufficient amount of air is supplied to carry off all the moisture in the goods, the drying will take place most rapidly when a large surface of clay is exposed to very dry air. But as the relative dryness of air increases very rapidly when the air is heated (see Appendix), it follows that the hotter the air (providing that it is not saturated with moisture when cold), the more rapid will be the drying, though hot air which is nearly saturated will not dry the goods no matter what its temperature may be. It is too seldom realized that in damp, summer weather the air, though of higher temperature than on a dry winter's day, may yet be more nearly saturated with moisture, and so less capable of drying goods. In such a case the air must be still further heated until it is sufficiently removed from its saturation point to do its work satisfactorily.

Supply of Heated Air.—As the quantity of heat required for drying is considerable when artificial heat is used, it is desirable to utilize sources of waste heat when possible. Thus, a large amount of heat can often be obtained by passing the air through pipes or 'economizers' fitted in the kiln-chimney flue, or the waste heat from the engine exhaust may be used to supplement, though it cannot entirely replace, live steam direct from the boiler.

The chief sources of heat are—

a. Coal or coke.
b. Hot water.
c. Steam (live or exhaust).
d. Kiln gases.

One pound of good *coal* will, on complete combustion, yield on an average about 7000 Calories or 13,000 B.T.U., so that, in the example given on p. 122, the 1712 B.T.U. required will be furnished by about 2¼ oz. of coal.

Coke is sometimes used instead of coal for drying-floor fires, but unless very carefully tended the variations of heat cause irregular drying, and there is a general waste of heat because different parts of the floors cannot be shut off when the goods are dry. The cost of drying on a coke or coal-heated floor prior to the war averaged about 4s. per 1000 bricks.

For further information on the relative heating (calorific) power of coal and coke, see 'Fuel' (p. 35).

Steam, on account of its high latent heat and moderate temperature, is admirably adapted for the transmission of heat in drying clay goods, especially as it yields as much heat as ten times its weight of water, or forty times its weight of air, in cooling from 200° to 100° F.

As few engines are capable of utilizing more than 25 per cent. of the total heat in steam by converting it into mechanical power, it is often economical to use the exhaust steam for drying, though the condensed water it contains necessitates more of it being required than if live steam were employed. In any case, the plant must be capable of using live steam at night and at such other times as the engines may not be running.

One pound of good coal will convert from 8 to 10 lbs. of water into steam, which on condensing will yield 7750 to 9670 B.T.U., according as the water is cold or at the boiling point.

As exhaust steam cannot heat the air used for drying to more than about 160° F., it is generally wise to use as much of it as possible on account of its low cost, and to supplement it with live steam to raise the temperature of the air, when necessary, from 170° to 180° F.

When exhaust steam is used it is necessary to prevent any back pressure on the engine, or the higher boiler pressure which will be required will rapidly neutralize any economy which would otherwise have resulted from its use.

Superheated steam has practically no advantage over ordinary live steam for drying purposes.

Hot-water pipes are still largely used in the Potteries, and where the goods have to be frequently handled, this method of heating has its advantages, the heat being less concentrated than when steam pipes are employed. The water may be under low or high pressure, according to the heat required in the pipes.

Kiln-gases or *flue-gases* are often available as a source of heat, and should be used when this can be done economically. With the commonest classes of goods, they may be diluted with air until reduced to a suitable temperature and then passed over the goods, but for most purposes it is best to pass the gases over tubes through which air is drawn or through tubes placed in the dryer in a manner similar to steam pipes, or the air may be heated by passing it through a radiator which is heated by the gases. This latter method has the advantage of keeping the air clean, but it is not quite so economical as the former.

The available heat in kiln or flue gases may be calculated thus:—

(*a*) Calculate the weight of the gases from molecular formula or ascertain it by other means. At 32° F. (or 0° C.) 11·58 cubic feet of kiln or flue gases usually weigh 1 lb., and conversely 1 cubic foot of such gases at that temperature will weigh $\frac{1}{11\cdot58}$ lb., 0·086 lb. Hence, 1 cubic foot of these gases at t° F. weighs[1]

$$\frac{1}{11\cdot58} \times \frac{460}{460+t} = \frac{1}{11\cdot58 + \frac{t}{40}},$$

so that V cubic foot at t° F. $= \dfrac{1}{11\cdot58 + \frac{t}{40}} \times \text{V}.$

(*b*) Multiply the weight of the gases by ·237[2] and by the difference in temperature at which the gases enter and leave the drying room in °F.

Thus, a Hoffmann kiln of modern type will supply about 5000 cubic feet of gases at 200° F. per minute if a fan is used, instead of a chimney, to create

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[1] In this calculation, the figure 460 is added to the temperature to convert it to the absolute scale, for a description of which see a good text-book of elementary chemistry or physics.

[2] 0·237 is the specific heat of the gases.

the necessary draught. Supposing that these gases are cooled in the dryer to 100° F., the heat units available per minute will be:—

(*a*) The weight of 5000 cubic feet gases measured at 200° F.

$$= \frac{1}{\frac{200}{40} + 11{\cdot}58} \times 5000 = 300 \text{ lbs.}$$

(*b*) Weight × sp. heat × difference in temperature $= 300 \times {\cdot}237 \times 100 = 7110$ B.T.U., or ·6 lb. coal.

At first sight this method of using the kiln gases appears to be excellent, but the temperature of the gases from single kilns is much too high and dilution is not easy to control, whilst the gases from a continuous kiln can only be used when the kiln is not working efficiently; hence, the saving is not so great as might be supposed. Yet, notwithstanding these objections, where a continuous kiln is too short to be efficient the waste gases may be used advantageously in a dryer, by means of a fan. Those from single kilns may also be used if the relative positions of the kiln and dryer are suitable.

Dryers.

In order to determine the value of different dryers, it is necessary to ascertain the cost in fuel and upkeep per unit of goods made. The latter may be taken either as 1000 pieces (*e.g.* bricks) or as a ton of clay, depending on the kind of goods manufactured. The length of time required for drying the goods must also be taken into consideration as well as the capital cost of the installation.

The number of heat units (B.T.U.) required by the goods must be first determined, as described on p. 120, and the amount of fuel used by the dryer in supplying this amount of heat ascertained. This will give a means of comparing the dryers as far as cost of fuel is concerned, but to this must be added, as stated, the cost of upkeep (wages of attendants, etc.), and a correction for the time required.

In comparing different dryers, it is also important not to fall into the error of supposing that, as some manufacturers claim, heat can be used over and over again. From what has been said in the section on 'Drying,' it will be understood that this can only occur when the air or other heating medium is at an excessively high temperature in the first place—a state of affairs which should never be allowed, as it not only means a waste of heat, but is also likely to result, sooner or later, in the production of damaged goods.

The most important methods now in use for drying clay may be classed under four heads:—

(*a*) Drying by unwarmed air in the open or in sheds.

(*b*) Drying by air heated outside the dryer.

(*c*) Drying by conduction, *i.e.* by contact of the goods themselves with a hot floor, the heating of the air being of secondary consideration.

(*d*) Drying by radiation, the goods being at the same time supplied with warm air to carry off the moisture.

Hacks.—The first of these methods can only be used during the summer months. It costs little, but is very slow. The uncertainty of the weather in this country prevents hacks being used in the midlands and the north, but they are largely employed in the south and south-eastern counties and also in countries where the climate is more favourable. The extensive area required

—owing to the slow rate of drying—also adds greatly to the cost of carrying the bricks to and from the hacks, so that this method of drying is little, if any, cheaper than artificial drying in properly constructed dryers.

The ground used for drying bricks in 'hacks' should be as even as possible, and, to secure efficient drainage, it is often convenient to dig small trenches in the direction in which the hacks run, and to use the soil so turned up for the foundation of the hack itself. Some consideration must be given to the direction of the hacks, and in this country they should usually run north to south or north-east to south-west. For most bricks, the centres of the hacks should be about 10 feet apart, the hacks themselves being 2 feet 6 inches wide and 4 inches above ground level. They should be evenly sprinkled with a fairly thick layer of sand. The length of the hacks will vary with the shape and size of the ground; about 80 yards is by no means uncommon. A ground area of one acre is usually sufficient for a million bricks. The bricks are set on the hacks by means of boards similar to those used in 'setting down'; they must on no account be handled by the workman's bare hands or their shape will be spoiled. The hacks are set one course at a time, so as to enable the bricks first placed to become sufficiently stiff to carry the row placed on them; the total height will vary with the nature and stiffness of the clay, but will usually be equal to eight or nine bricks.

The covers for hacks (hack caps) may be portable or fixed. In former days, the hacks were simply covered with straw, but this is neither satisfactory as a covering nor so cheap as proper wooden or galvanized covering. With very delicate clays dried on hacks, straw is still often used in addition. The portable form consists of boards nailed so as to form a roof of the ordinary 'A' cross section, about 3 feet long and 3 to 4 feet wide.

In order to keep the ends protected, matting or loose boards must be provided. The matting is preferable, as it effectively keeps off the rain whilst permitting a free circulation of air.

The chief disadvantages of hack drying are its extreme slowness, the loss through bricks damaged by the weather (which is seldom less than 5 per cent. and often greater), and the very considerable expenditure necessary for repairs. The wheeling to and from the hacks, skintling, attending to matting, etc., are also expensive, and it may be taken as a general rule that, from the machines to the kiln, the bricks cost at least 3s. 3d. per 1000 for drying with wages at 25s. per week.

In order to overcome the excessive slowness of the drying at ground level, trestles are sometimes used, particularly in America, to raise the bricks a few feet and obtain greater circulation of air. The use of such trestles is particularly advantageous at the beginning and end of the season and in wet weather. The trestles are permanent, and are spaced so that the cars can pass between them when charged with brick pallets. For wire-cut bricks a self-loading set of pallets may be picked up when fully charged, wheeled to the ground, and there deposited in rows, and when dry are conveyed in the same manner to the clamps or kilns. These cars effect a great saving in time over barrows, as they can carry 200 bricks or more at a load. The bricks on the trestles are protected from the weather, when necessary, by canvas roofing hung on wires, so as to form a roof and sides. This protection is very efficient and fairly cheap.

Sheds.—Drying sheds provided with racks for the goods form an improvement on the simpler hacks. This form of dryer may be built in any convenient situation, but it is an advantage to erect it around and over

Hoffmann kilns, as on the Continent, the racks being placed tranversely to the building. This gives a much larger output than when no attempt is made to supply warm air. Ventilation is secured by means of louvres in the roof and by movable shutters at the sides. The repairs to this form of dryer are very small, and the loss of goods through the weather practically nil; no skintling is necessary, and no expense is incurred in storing the covers, etc., through the winter. On this account, the use of a permanent shed is less expensive than hacks. An ordinary drying shed may be about 36 feet wide and 150 feet long, the height being generally about 9 feet at the eaves. Permanent stillages are fixed in the shed, and on these are placed loose boards to serve as shelves, arranged about 6¼ inches apart so as to leave plenty of room for the effective circulation of air. If preferred, permanent shelves of thin laths 1 inch apart may be used, and the bricks laid thereon until dry.

Artificial Drying.—Artificial drying is chiefly to be distinguished from the so-called 'natural' drying just described, in that the latter uses a large volume of air at a comparatively low temperature, whilst the former uses a smaller volume of air at a higher temperature, thereby securing greater control and rapidity in drying, which, with delicate clays, or goods liable to spoil on exposure, more than compensates for the cost of the fuel.

The simplest method of artificial drying consists of placing the goods in contact with a hot floor or other substance in such a manner that the goods themselves, as well as the air around them, become warmed; the warm air thus carries off the moisture, and is changed, in the more effective dryers, by some simple process of ventilation. At the present day, however, the most successful dryers employ a combination of convection and radiation, and the goods are only to a very limited extent placed in contact with hot solid bodies. In many modern dryers, too, the goods are moved through the dryers, which are consequently given a more or less tubular or tunnel-like form, though for many goods a travelling device of this kind has not proved satisfactory. In the form of dryer known as a *potter's mangle*, the goods are placed on shelves supported on two endless chains in a vertical shaft provided with steam pipes or other source of heat. The goods are introduced through a small opening at a convenient level, and on turning a handle are moved forward until another shelf is brought to the opening.

The heat for the dryers may be supplied from kilns, coke fires, coal fires, or steam. The heat from kilns may be obtained by means of flue gases, or by drawing air over the hot goods in kilns which are cooling, and passing into the dryer, thereby using air free from soot and other condensation products which tend to spoil the goods. Portable heaters of various kinds are also used, on occasion, for supplying hot air to the dryer. Ventilation must be carefully secured by natural means, or by the use of fans, chimneys, etc. Sometimes, the heated air is allowed to find its way out of the dryer as best it can, but this is not a desirable method of getting rid of the moisture, as there is a great tendency to draughts and uneven drying. A porous roof of pan-tiles will secure a more uniform drying, but it is liable to become choked with dust and vegetable growth.

The use of *steam* or *fuel-heated floors* is widespread in England, although it has found but little favour abroad. The fuel consumption is high for a simple heating floor, averaging 1 lb. of coal for every 3 lbs. of water evaporated, but a reasonably low cost may be obtained by using a mixture of exhaust and of live steam. The great danger of such floors is that the goods tend to crack if the heating is carried out rapidly, as there is so little movement of the air, and 'steam' may frequently be seen rising from the goods. This is, however, bad practice. If steam is used, some arrangement should be made for draining off the condensed water. Exhaust steam is preferable to that direct from the boiler; but if the latter is used, it should be reduced to a very low pressure (about 6 to 10 lbs. per square inch), so that it may distribute itself uniformly through the flues. It is sometimes desirable to carry the steam in overhead mains, and to take branches off these to different portions of the floor. Considerable skill is required to build the flues under the floor so as to secure even distribution of the heat, and at the same time to render the flues steam-tight. The under side of the floor on which the bricks are dried should not be less than 7 inches above the sub-floor, or the drying capacity of the shed will be very low. The drying floor should be level, but the sub-floor should slope a little in the direction in which the gases or steam travel, so that the condensed water may escape. Some firms, on the contrary, prefer to keep the sub-floor covered with water to a depth of 2 to 3 inches, as they claim that this retains the heat better and avoids the use of live steam at night. The correct arrangement of the flues is very important, as on it largely depends the rate at which the bricks can be dried. The most efficient construction is to divide the sub-floor into sections of not more than 70 feet in length and about 17 feet in width, and to fill these with sufficient bricks laid checkerwise to support the floor. Each section should be quite independent of the others, and should have a separate steam pipe from the main flue. The floor is often covered with a thin layer of cement to make it damp-proof, but this causes a great loss of heat. The sub-floor should be properly protected from damp by a layer of waterproofed concrete 3 to 4 inches thick, so as to prevent the ground from softening and undue settlement caused by the condensed water. The joints between the bricks or slabs, of which the floor is made, should certainly be cemented. Where a clay can be dried very rapidly without harm, the floor may be covered with iron plates, but it is difficult to keep them steam-tight, and they rapidly lose their heat when the steam has been cut off, as, for example, during the night. 1 lb. of exhaust steam will usually drive off 5 lb. of water.

A particularly useful floor of this class consists of hollow slabs, or quarries, usually salt-glazed and bedded in cement, the joints being made with the same material. This floor is very clean, easy to construct, and of great durability. It was originally known as Sabine's patent, but hollow quarries of this type are now made by several firms for various purposes where a light fireproof flooring is required. Iron plates cost more than slabs or concrete, but the output from them is more than double that of the other floors mentioned, so that, where they can be used, they are really the most economical. Salt-glazed drain-pipes arranged in parallel rows with solid concrete between do *not* produce a good drying floor, as its temperature is too irregular for delicate clays and its heating power is too low for clays which can be dried rapidly.

In some dryers, the flues are separate from, and above, the floor instead of below it, and therefore take the form of pipes, usually of about 6 inches diameter. When these are used, the goods are generally placed on racks, so that the heating really takes place by radiation. Unless, however, some system of distributing the air evenly throughout the dryer is used (an extremely difficult matter), this method cannot be made really economical. The ordinary hot-water systems so common in the Potteries are worked on this system, which is more suited for drying small goods where steadiness of drying is an important consideration and where they have to be repeatedly handled during the drying. The use of hot water under pressure is becoming increasingly common, and radiators of various types are proving useful for rooms which must be kept at 70° or so throughout the year, as in the manufacture of much 'small ware' of high quality.

For some classes of work it is convenient to let the steam pipes used for heating simply lie in open trenches in the drying room, a rough lattice-work being placed over the top, or the goods being placed on boards which lie across the trenches. A greater movement of the air in the room is thus secured, and the goods are less liable to crack, as they are not in actual contact with a hot floor.

In the ordinary *drying stoves* in the Potteries numerous shelves are provided in a kind of huge cupboard, on the bottom of which a grid of hot water or steam-piping is placed. Sufficient room should be left between the floor and this piping, and between the piping and the bottom shelves, for both floor and pipes to be swept out, as pieces of clay fall from the goods, and, in course of time, tend to prevent the heat being properly distributed through the dryer.

The 'stove' or dryer will vary in size and construction with the class of goods made (for a plate-maker it should not be less than 12 feet in each direction), and the shelves should be attached to a vertical iron shaft or 'dobbin,' which can be rotated so as to bring a different set of shelves to the front when it is turned. By this means, much time and space are saved. As heat alone will not dry goods, some form of ventilator should be fixed at the top of such a dryer, and should be kept clean and open. The shaft holding the shelves will require occasional oiling so that it may turn easily. Doors should be provided, and kept shut as much as possible so as to keep in the heat, and two or more frames of shelving may be placed in the same casing, although it is generally better to keep them separate, so that one may be allowed to cool for emptying, cleaning, etc., without disturbing the rest.

In some works, the dobbins are arranged on the 'revolving-door' principle, so that no other doors are then required. The grids of steam pipe may be supplied with either live or exhaust steam, and should have all the pipes draining to one spot—an inclination of 1 in 20 being usually desirable to give sufficient fall for the condensed water. The steam inlet must always be at the highest point in the grid. The trap for draining off the water must be kept in order. The foreman potter alone should control the steam cocks for these dryers.

Ventilated dryers are, on the whole, the most satisfactory and economical for most classes of goods which do not need handling after they have once been set aside to dry. The general idea is to draw a current of air through, or over, a heater to distribute it among the goods to be dried, and then to remove it at such a temperature that it will not deposit any of its moisture on the goods. The heater may consist of a special appliance of the kiln flues, or of exhaust steam from the engines in the factory, it being generally understood that as much as possible of the heat shall be obtained from sources which would otherwise waste it, so that the greater part of the heat may cost nothing. It is seldom possible to obtain all the heat required in this way, and supplementary heaters (live steam, coke or coal, etc.) must, therefore, be provided for use when required.

The motion of the air is controlled and regulated by means of a chimney or a ventilating fan, each of which has its special advantages and disadvantages.

On the whole, a well-designed fan of ample capacity may be preferred, as it is independent of the changes in atmospheric temperature and pressure, while the power consumed is so small that it is really compensated for by the ncreased certainty and rapidity with which the goods can be dried.

A number of simple and efficient methods of chimney ventilation are used in connection with Hoffmann kilns, as when the chimney is used to draw a current of air over the goods in the chamber last fired and into a chamber in which the goods are drying. This can, obviously, be only used where the goods are fired in an open kiln; if placed in saggers, they would never dry. In some districts the goods are often placed in one of the kiln chambers and a small fire is built at the wicket, the dampers being so arranged that the products of combustion, very largely diluted with air, are drawn through the chamber into the chimney. The heat thus introduced is so slight as not to damage newly made bricks produced by the stiff-plastic process; and as only about $\frac{3}{4}$ ton of coal is used during the time occupied by the drying, the method is one of the most economical known. Where the goods are made of stiff-plastic or plastic paste, and so are liable to scum, this method is not suitable; they should be dried in a dryer.

The use of fans and chimneys for dryers is chiefly practised in connection with the most modern form of dryer—the tunnel. **The tunnel dryer** exists in numerous forms, which may, however, be divided into three main classes: (1) *periodical dryers*, in which the goods are stacked on shelves or cars and remain stationary during the whole period of drying; (2) *progressive dryers*, in which the goods travel and dry progressively, and (3) *inverse dryers*, in which the goods travel in one direction whilst the air travels in the opposite direction.

The cars consist of an iron framework so formed as to allow the free circulation of the air amongst the goods. They should be fitted with roller or ball bearings, and should travel along rails in the floor of the dryer to ensure smooth running. They usually carry about 360 bricks each.

The air in these tunnels is heated by waste gases from the kilns, by exhaust steam, live steam, or by coke or coal fires. The heat from the kilns is rarely sufficient, except for bulky goods of relatively small weight, small hollow goods, and similar articles. If exhaust steam is employed, great care must be taken that no back pressure is put upon the engines, or it will prove more costly in use than live steam direct from the boiler. The use of coke or coal is often rendered inefficient because the waste gases escape at a comparatively high temperature into the air, and the heat in them is lost. Live steam is generally too costly to use alone; hence, as much heat as possible should be obtained from the waste kiln-gases and from the exhaust steam, the deficiency being made up with live steam or coke fires.

In using steam, it is best to pass it through a radiator or grid of pipes over which the air to be heated passes. This grid must be well trapped, and kept in thorough working order. The pipes composing the grid may be arranged in vertical or horizontal rows, or a long pipe may be repeatedly bent upon itself. The essential point is that there must be a sufficient surface of heated pipe to raise the air passing over it to the required temperature, and to prevent any back pressure on the engine if exhaust steam is used. The condensed water is, whenever possible, returned to the boiler-feed, but before it enters the boiler it must (if exhaust steam has been used) be carefully freed from oil, or an explosion may occur in the boiler.

The temperature of the air admitted to the tunnel can be regulated with great accuracy by means of dampers in the flues. When a dryer of this type is in use, the air-supply must not be reduced merely to secure a high temperature, as the air, rather than the heat, is the drying medium, and it is possible to pass bricks through a hot dryer and yet not dry them.

A considerable increase in the capacity of a dryer may be made by the construction, when it does not already exist, of a false ceiling of corrugated (not galvanized) iron, over which some of the heated air is allowed to pass. This causes a considerable radiation of heat from the top of the dryer downwards; and if it is provided with openings at intervals to allow some of the heated air to rise and be carried away, it will be found that the goods are less liable to crack when they travel in the opposite direction to the air current.

The use of a false ceiling and of a heat radiator below the goods form two of the main features of the Wolff dryer. The radiator, already mentioned, consists of a number of pipes connected in series, so that the uncondensed steam flowing from one is caused to enter another, the operation being repeated until no steam is left to escape uncondensed from the last of the series. In this way, the heat rises gradually from about 95° F. at the cool end to 115° F. at the hotter. In this, as in all dryers on the 'inverse' system, there is a great tendency for condensation to occur on the goods when they enter the dryer, if the air is at a lower temperature than 90° F., and a 'tempering' room or preliminary warmer about 40 feet long must be used for delicate clays. Motion is imparted to the air by means of a tall chimney of wood, but if a fan is used instead it would be an improvement, as it would eliminate variations due to changes in the atmosphere. The Wolff dryer is heated entirely by steam, and does not, therefore, work so economically as some forms in which waste heat from the kiln is used. The drying is rather slower in this than in the more efficient tunnel dryers, as the air is very moist. In most cases, about fifty hours is required.

When the goods and cold air are gradually heated as they progress through the dryer (both travelling in the same direction), no condensation can possibly occur, and a serious difficulty is thereby overcome. The hot air at the end of the dryer is not allowed to pass out, but is returned to pipes at the cooler end, so that it may, in passing through them, warm the air near the entrance to the dryer. As a smaller volume of air is required than with the inverse dryer, and the goods are for a considerable time in contact with practically cold air, the most delicate clays may be dried with safety. The makers of the Moeller and Pfeifer dryer, which is of this latter type, claim to dry any class of bricks in one of their dryers on this 'direct' principle in twenty-four hours. The direct system of drying originated, apparently, on the Continent, and the Moeller and Pfeifer dryer, which is an improvement on the one by Bock, is probably the most efficient on the market, but is unfortunately expensive both in first cost and in power. This is due to the number of fans employed and to the arrangements made for giving the air in the dryer a spiral motion. Various attempts have been made to simplify the construction and to accomplish most, if not all, the work of the more expensive dryer at a considerably less cost. This is brought about in the dryer designed by Mr A. E. Brown by the use of a false ceiling with an overhead flue, through which the hot air from one end of the dryer is returned to the cooler end. The radiation of heat from this ceiling is said entirely to obviate the necessity of providing mechanical means for imparting a transverse direction to the air in the dryer. The heated goods (bricks) are run into a small cooling chamber, where they are cooled by air drawn over them before it passes to the radiators, which are heated by waste kiln-gases, by exhaust steam, and by a supplementary coke furnace. The designer states that the use of live steam instead of coke effects no economy. The necessary suction and air movement is produced by a single fan placed near the cool end of the dryer.

The relative costs of drying will be found later (see Appendix), from which it will be seen that artificial drying is preferable to 'natural' drying, even in the case of bricks, not only on account of the greater rapidity of output, but also because of the reduced risk of damage to the goods. A tunnel dryer, with care, is very economical in labour and fuel, as one man and a boy could easily attend to it, whereas for a floor, or hack, a much larger staff is required. On the other hand, the cost of construction is very great (almost equalling that of a continuous kiln), so that many firms are not able to take advantage of this type of dryer. As several defective and badly designed tunnel dryers have been erected, care should be taken to obtain impartial advice before erecting so expensive a piece of plant. 'Cheap' tunnel dryers are, as a rule, useless.

For further particulars and more detailed descriptions of dryers, the reader is referred to *Brick Drying*, by A. E. Brown, and to the author's *Modern Brickmaking* (see Bibliography in Appendix).

CHAPTER VI.

ENGOBING AND GLAZING.

THE application of an engobe or glaze to clay goods may be made either before or after the first firing of the goods, according to the shape and nature of the goods themselves and to the properties of the clay of which they are made. The primary object of firing the goods before engobing or glazing them is to increase their strength and so lessen the chances of damage through roughness in handling, though in the case of very large or very delicate articles it is not usually possible to apply the engobe or glaze to the raw goods, no matter how much care is taken, unless special methods of application are employed. Whenever it is possible to do so, it is better to apply the engobe, or glaze, or both, to the green clay, so that the article is only once fired, as in this way a greater uniformity between the clay, the engobe, and the glaze is secured than when these are fired at temperatures specially adapted to bring out a special quality in each, without much regard to the rest.

Glazes and engobes are prepared for use in the form of slip by grinding the materials to impalpable fineness and mixing them with water, or, in the case of certain coloured materials used in decorative work, with fat oil or some other vehicle. It is generally advisable that the materials should be insoluble in water, or uniformity of composition will be almost impossible after the mass has dried on the goods. The case of vaporous glazing must be considered separately. When it is necessary to employ soluble substances, such as soda or potash compounds, it is usual to render them insoluble by 'fritting' or heating them with silica in some form in which it can be used in the glaze; the silicates thus produced can then be ground with the other constituents of the glaze or engobe in the usual ways.

The *preparation* of engobes and glazes has been described on pp. 23 to 27.

The precise manner in which the slip is applied to the goods varies with its composition and with the nature of the goods themselves. Four methods are in general use—dipping, pouring or teeming, painting, and sprinkling or spraying. When the glaze is in the solid form and not a slip it may be applied by dusting or by volatilization.

Dipping consists in immersing the ware, usually in the biscuit state, in a vessel containing the slip, in such a way that the article is completely covered with a uniform coating of the material. The relative proportions of solid matter and water in the slip are of great importance in securing a coating of the correct thickness. If too little water be present, the coating will be uneven and too thick, whilst if an excess of water is present an insufficient coating of material will be given to the article. The correct proportions can only be found by making slips of different strengths and sending trials dipped in these through the kilns. The 'strength' of the slip is a function of its specific gravity, and is most conveniently expressed in terms of 'ounces per pint'; that is to say, a pint of the slip accurately measured is carefully weighed, its weight, in ounces, being used to express its relative density. When the correct weight per pint has been once ascertained for a particular slip and for a particular workman, the slips can always be made up to this weight until the workman, or the composition of the slip, is changed. As the personal equation is an important factor in dipping goods, each workman may require a slip of a different density, though most dippers of experience can tell with sufficient exactitude the density of a slip by merely placing their hand and arm in it. Others scratch a piece of glazed ware with the finger-nail, and claim, by this means, to be able to ascertain if it is of the right consistency.

In order that a slip may be suitable for dipping, it is necessary that it should contain sufficient plastic material to enable it to adhere to the article when it is dry; hence, it is seldom advisable to frit all the constituents of a glaze, but the more plastic materials should be added to the powdered frit. When, for any reason, this is not possible, the adhesiveness of the slip may be increased by the addition of a little dextrin, starch, or gum; this will also prevent the slip 'settling' too rapidly, although where this settlement is very pronounced the material is best treated with gelatin or oil and painted on to the goods (p. 135).

Hard-fired ware does not absorb the water from the slip so readily as more porous ware, and should, therefore, be dipped in a slightly thicker glaze, whilst specially soft or porous ware should be first dipped in water and then into the slip. Articles of moderate size—when sufficiently stoutly made—may be dipped in the green state, the slip having a density of 26 to 28 oz. per pint. This cannot be done in the case of very large or delicate pieces, as the strain would be too much for the clay if the goods were dipped in an unfired state.

It is important that the dipper shall not move his fingers over the goods whilst dipping, or parts will not be glazed; a hook is frequently used to prevent the man's fingers from touching the goods where they have to be glazed.

As the ware absorbs the glaze very quickly, all parts must remain in the glaze for the same time: the part which enters first must be the first to leave it. The speed at which the articles are passed through must also be kept constant, and the passage should not be too long, or an uneven coating will be produced.

Hollow ware should be dipped with the bottom upwards, so as to avoid an extra thick layer in it.

Retouching of those parts of the articles which have been insufficiently coated with slip is generally necessary, but the less this is required the better.

Dust and grease (including perspiration) must be carefully and completely removed from the goods before dipping them, unless the grease is applied with the definite object of preventing the article from taking the slip in certain parts.

It will sometimes be found that an article which has been dipped in engobe ('body') will not take the glaze properly on a second dipping; in such a case the addition of dextrin or gum will often facilitate the adhesion of the second coating, or the article may be fired before glazing, passed through the kilns, and dipped when the engobe has been fixed by firing, or both engobe and glaze may be mixed with an adhesive and painted on the ware.

Various defects in engobing and glazing are treated under their special headings and in Chapter XI. on 'Defects.'

Much may, however, be done by attention to small details, such as the removal of superfluous slip from different portions of the articles, retouching where the coating of slip is thin, carefully mixing the slip, and seeing to its freedom from impurities and coarse particles of all kinds. Above all, it is most important that all utensils and the workman himself should be perfectly clean, as it is better to avoid dirt getting into the glaze or on to the goods than to endeavour to remove it.

Pouring.—In cases where the articles are too large, or are in other ways unsuitable for dipping, the method of pouring or teeming may be used; that is to say, the engobe or glaze may be poured over the object, an even coating being obtained by a dexterous turning of the hand. This method is especially used for glazing the inside of vessels, or for those bodies which are only slightly porous, and so will not retain a sufficiently thick coating of material when dipped.

The slip should be somewhat thicker than for dipping; the addition of gum or other adhesives may be made, or not, as is found to be desirable. Retouching with a brush dipped in the slip is generally necessary. The method is crude and its use is diminishing, painting and spraying being very satisfactory substitutes.

Painting is the commonest means of applying a number of different colours and glazes to a piece of ware, and the great value of art ware of the best class is chiefly due to the skill with which the pigments are applied. For this purpose, the colours are mixed with fat oil or other medium and applied before or after the vessel has been glazed, according to the effect which it is desired to obtain. The art of painting in this way would, however, require a treatise to itself to describe it efficiently.

The application of engobe and glaze by means of a brush is, however, so important in certain cases that reference must be made to it here. When articles with designs in high relief are to be executed in glazed or engobed ware, it will often be found that when they are dipped the excess of material accumulates in the hollows of the ware and so tends to destroy the outline or to induce crazing. In other cases, too, such as when the goods are too large to be dipped and their shape does not allow of simple pouring, the material may conveniently be painted on. The ordinary engobe or glaze slip may be painted on the wet clay with a camel-hair brush, and any inequalities of surface smoothed out before the engobe is quite dry. This method gives excellent results in careful hands, but with less skilful workers it is desirable that the slip should be made pasty or even solid. As, however, the mere omission of water introduces other difficulties, it is usual to add some solidifying medium, such as gelatin, to the slip. The proportions of slip and of gelatin will naturally vary with the amount of water in the slip and with the temperature of the workshop, but for slip at 28 to 30 oz. per pint, 6 oz. of good gelatin per gallon will usually be ample. This proportion will convert an ordinary slip into a blancmange-like mass, which can be easily and rapidly applied to the goods with an ordinary sash-tool brush. It will generally be found that several coats are necessary before a sufficiency of material has been applied, but even then the method allows of a fairly rapid output, and, in addition, has the great advantage that the goods may frequently be painted in the green state and so the cost of biscuit firing is saved. In summer, the gelatinized slip melts and is not then capable of being applied satisfactorily; it may be restored to its solid condition by cooling it sufficiently, provided that putrefaction has not set in, or a little formalin may be added to the freshly made slip.

Spraying the material on to the goods is useful when a variegated or a rather thin coating is required. An arrangement of two tubes at right angles to each other, and similar to the 'atomizer' used in toilet accessories, is employed, the glaze or engobe being in the form of a thin slip. This method is scarcely suitable for covering coloured clays with an opaque white slip, as it is difficult to get a sufficiently even coating of sufficient thickness without a great expenditure of time. For applying a graded or shaded effect in colour on the top of a glazed or vitrified article, this method is particularly useful. In order to obtain dark tones, it is desirable to let one coating of the sprayed material become dry before another is applied, or the slip may trickle into unpleasant-looking masses. The older method of *sprinkling* the glaze on to the goods by hand or with a brush is now almost obsolete.

Dusting the powdered glaze material on to the goods whilst they are still damp is only used for the commonest sorts of earthenware. The dust is usually applied by means of a sieve, but as glazes so applied are usually highly plumbiferous, the process is so dangerous to the workmen that it should be discarded.

The principle of *volatilization* is largely used for certain classes of goods, the two commonest forms being 'salt glazing' and 'flowing.'

Salt Glazing was first introduced into England by the brothers Elers in 1690, and is still considered to be one of the simplest and most perfect methods of glazing, although it has the disadvantage that it can only be applied to certain highly siliceous varieties of clay, as highly aluminous clays will not decompose the salt sufficiently to yield a good product.

Although the process of salt glazing is simple, there are many points which require very careful attention, or failure is sure to follow.

The clay must contain sufficient fine silica, be of as constant a composition as possible, and of a suitable fineness.

It is entirely useless to make the clay more siliceous by the addition of common sand, for unless the free silica so added will pass through a sieve of at least 100 meshes per linear inch, it will not be sufficiently finely divided to decompose the salt. As pure silica does not 'salt' easily or perfectly, it is necessary to avoid an excess of this substance—too much is almost as bad as too little.

A synthetical investigation by Mackler in 1905 showed that the composition of salt glazes lies between the following limits: 1 to 2 $Na_2O . Al_2O_3$, 3·3 to 7 SiO_2, the average 1·5 $Na_2O . Al_2O_3$ 5SiO_2 giving the best results. This may be expressed in other words by stating that for every 100 parts of alumina contained in a clay, there must be not less than 200 and not more than 450 parts of silica.

The exact nature of the reaction which takes place between the salt and clay is not absolutely known. It has been found independently that the action of salt on pure silica and alumina is only very slight, so that its much stronger action on clays appears to be of a very different character. It is notably increased in the presence of iron compounds, buff-burning clays forming a much better glaze than those practically free from iron. Moisture appears to be necessary for the reaction to take place, hence damp salt is used. But this is by no means always the case, though most authorities maintain that the action takes place directly between the free silica of the clay and the salt with the production of sodium silicate or alumino-silicate and hydrochloric acid.

The most important conditions for the proper production of a salt glaze are: (1) sufficient salt on the surfaces to be glazed, applied in a suitable manner; (2) sufficient heat to maintain the ware at the required temperature; (3) sufficient time for the reaction to occur; (4) means for carrying off the waste products of the reaction.

As salt decrepitates violently on heating, it is not applied to the goods before they enter the kiln, but towards the conclusion of the firing.

The salt is added through openings in the kiln in such a way that it does not fall directly on the goods themselves, but is carried on to them by its decrepitation, and by the gases in the kiln. It is important to add the salt when the goods are in a suitable condition to receive it, and special tests should be made to determine this point exactly. Some burners rely on the colour of the goods or on the examination of 'trials' drawn from the kilns. The most satisfactory way is to heat the goods to the point of incipient vitrification. This point must be determined by an expert once and for all, for the particular clay used. This temperature having been determined, it is then easy, by means of Seger cones, to raise the temperature of the kiln to this point, usually about 1250° C. or Cone 8. The fires are then cleaned, and when the kiln is at an even temperature throughout, the damper is partially closed and the first dose of salt (a large shovelful) is thrown on the back of each fire. Coal is added to the fires after each addition of salt to keep the temperature of the kiln high and to ensure the salt entering the kiln. As the addition of the salt lowers the temperature very considerably (often as much as 200° to 300° C.), it is desirable to add the salt in at least two or three portions, at intervals of twenty minutes, in order to allow of the temperature being maintained at the proper point. The fires should be stirred during the salting, in order to prevent the clogging of the fuel by the fluxing action of the salt on the coal, and to keep a thoroughly oxidizing atmosphere in the kiln. The colour of the salt glaze may to some extent be varied by the state of the atmosphere in the kiln. For light colours, the atmosphere should be highly oxidizing, whilst by partially closing down the dampers and restricting the air-supply, darker colours can be obtained. It should, however, be remembered that a reducing fire will not give such clean-looking goods as an oxidizing one, and that, unless great care be taken, carbon or soot particles may be deposited on the goods, and cannot be afterwards removed. As a general rule, the burning fuel will supply sufficient moisture for the glazing to take place; if it does not, the salt may be damped, but should not be so moist as to stick together. 'Tears' are frequently formed where an excess of salt has accumulated or as a result of the wear of the kiln.

Irregularities in colour are commonly attributed to the loss of heat due to the salt. This is seldom correct: it is the faulty heating after the addition of the salt that is chiefly responsible for piebald goods.

Opinions differ as to the length of time the heating should be continued after the addition of the salt; equally good results can apparently be obtained by continuing the firing for eight, ten, or twelve hours, provided that the temperature is not allowed to fall. However, if the glaze has had sufficient time to form properly, so that the reaction between the salt and clay is complete, any additional firing is simply a waste of fuel and time, and may even produce crystallization of the glaze.

The amount of salt required varies with the clay, but with care, 10 to 20 oz. per cubic foot of kiln capacity will suffice. The number of additions of salt required depends largely on the nature of the clay and the skill of the burner. Three doses should suffice, but some men use as many as nine. As the glazing progresses the ware hardens on account of the fluxing action of the salt. By drawing trials after each addition of salt, the glazing can be kept under perfect control. When the trials are properly glazed and sufficiently hard, the salting is discontinued, but before closing the kiln the fire should be fed with coal and a good heating given to ensure a bright glaze.

It is also important to remember that the salt acts on the walls of the kiln as well as on the goods, so that whenever possible the bricks should be made of clay rich in alumina, mixed with bauxite, if necessary, to render it sufficiently refractory.

The cooling of salt-glazed ware should be as rapid as possible consistently with the safety of the goods, as slow cooling, especially at first, tends to a dulling of the glaze and often to crystallization. Prolonged soaking of the kiln after the final batch of salt has been added is, for a similar reason, undesirable.

It is necessary to have a sufficient draught through the kiln to cause the uniform dispersion of the salt particles as soon as they have decrepitated, this decrepitation being one of the most useful properties of salt, and greatly facilitating its use as compared with that of other soda compounds.

Salt-glazed ware may be coloured by painting with colours which form fusible compounds with the glaze itself, but which are, of themselves, infusible at the temperature of the kiln; it is, however, essential in this case that a fully oxidizing atmosphere be preserved in the kilns, or the dark colour of the salt glaze will spoil that of the other colours.

In **flowing**, the goods are decorated with a material capable of forming an easily volatile chloride, and are then heated in a sagger containing a small vessel of chloride of lime, or one of the numerous other 'flowing powders' now on the market. The chlorinated atmosphere which thus surrounds the decorated article converts the colouring material into the chloride, which is again decomposed by the silica of the clay, so that the colouring matter is 'condensed' on the previously white portion of the ware. A pretty shaded effect is thus produced. The chief oxides used for this kind of decoration are those of cobalt (blue), copper (green), nickel (brown), and iron (yellow), the last not being, however, very satisfactory.

In some cases, the whole of the glaze is volatile, and is simply placed in cups in the saggers, the vapours being decomposed by the silica of the clay. Though only a slight glaze ('smear') is produced in this way, the method is well adapted for work in very delicate relief, where it is especially important that the cavities shall not be filled with an excess of glaze. In both this and the foregoing case it is necessary that the saggers should be well luted in order that the vapours may not escape before they have done their work.

Whatever be the manner in which the goods are coated, whether with an engobe of clay or of glaze, it is necessary that the room in which the operation is performed should be as free from dust as possible, and, to prevent confusion in the placing of goods in the kilns, it is advisable to keep each colour separate, and even to stain the materials with a little aniline dye. This will burn off in the kiln, but its use is invaluable in preventing goods being accidentally placed in a wrong part of the kiln.

It is also very necessary to keep the engobe and glaze materials free from all kinds of oil or fatty matters, including sweat.

Finally, for rapid and efficient working it is necessary to have plenty of shelf or stillage room on which to dry and store the goods before they are sent to the kilns, and to insist that the goods are despatched to the latter in proper order, after all unnecessary drops and splashes of glaze or engobe have been removed.

A slightly glossy surface may be produced without the use of any added glaze by heating articles made of a vitrifiable clay or body to such an extent that partially fused material fills the pores near the surface. A similar glossy surface is also produced by mixing various fluxes with the clay of which the goods are made, with the result that the fused material, instead of being confined to the surface, is distributed throughout the whole thickness of the ware. Attempts have also been made to utilize the tendency of soluble salts to rise to the surface of the goods during drying in order to glaze them; thus soda and potash salts present in or mixed with the clay are more or less completely carried to the surface on drying, but such material still left in the body of the ware often causes it to lose its shape when in the kiln, or the surface glaze is so uneven as to be practically useless. Insoluble fluxes, on the contrary, do not rise to the surface to the same extent, but produce fusible matter in the body of the goods.

CHAPTER VII.

SETTING OR CHARGING.

Methods of setting or charging goods into the kiln vary with the nature of the goods themselves, but are roughly divisible into three classes :—

(*a*) Setting direct in the kiln itself (bricks and unvitrifiable ware).

(*b*) Setting in cupboards built of quarries, or slabs.

(*c*) Setting in saggers or fireclay boxes erected in piles with a roll of clay between each sagger. This method is chiefly used when the goods would be spoiled by the direct action of the flame, and when it is not desirable to fire them in a muffle kiln.

A description of each method of setting would be out of place here (see p. 142), but the following points should have attention :—

(1) As many goods as possible should be put into the kiln so as to secure economy of fuel, but, on the other hand, if the goods are unduly crowded, particularly in the upper part of the kiln, some of them will be spoiled. When kilns are set on piecework there is a great likelihood of their being incompletely filled.

(2) When various sizes and shapes of goods or saggers are set, care should be taken that they are well and solidly built together, as the expansion on heating causes movement amongst the goods, and this is increased by the contraction of the clay, so that unless skilfully set they may easily fall and suffer damage.

(3) Although damp goods should never be placed in a kiln, yet if this rule be broken in special circumstances they should be placed in such positions that they cannot harm other goods. For this reason they should be set where they will be heated last of all the goods in the kiln, so that the steam they evolve may not condense on other and cooler goods. Goods which are damp when placed in the kiln not only have a poor colour themselves, but are liable to spoil the colour of the surrounding goods.

(4) Glazed goods, when not burned in saggers or in muffle kilns, should be so placed that their glazed faces are together and are protected as much as possible from direct contact with the flame. Under no circumstances may glazed surfaces be placed close to unglazed ones, or the former will be spoiled.

(5) For glazed goods, the inside of the saggers or the muffle should be covered with a coat of glaze (waste glaze will do), as otherwise the beauty of the glaze on the goods will be spoiled.

(6) Coloured glazes must be placed according to their composition, as a slight variation in the heat will often make a considerable difference in the colour. The best positions can only be found by trial, but, as a general rule, the lighter and more delicate the shade the more moderate the heat which

will be required. At the same time it is not wise to place coloured goods too near the walls of the kiln, as crazing and chilling are thereby facilitated.

(7) In setting bricks great care must be taken to leave sufficient spaces between the bricks to secure a good draught, and at the same time these spaces must be carefully regulated so as to obtain as even a draught as possible in the different parts of the kiln. 'Finger-room' is correct, but rather vague; two stretchers to five headers (fig. 1) is much more accurate.

It is often best to put a double row of headers on the bottom of the kiln so as to ensure sufficient draught. If the bricks are sufficiently well made they may be set in this way throughout, otherwise headers and stretchers must be set alternately one above the other. Towards the top of the fire-screen the bricks may be set rather closer, so as to secure sufficient heat at the bottom of the kiln.

Various mechanical arrangements for setting goods in the kiln have been devised, though they are scarcely used in this country.

The bricks near the walls of the kiln are sometimes 'skintled' or set obliquely to each other, to counteract the retarding effect of the kiln walls in circular kilns, and to facilitate the setting.

The bricks are usually set within 6 inches of the walls of a rectangular kiln, leaving a space above them to facilitate the distribution of the gases and to ensure a more uniform temperature throughout the kiln. In round down-draught kilns, a deeper space should be left. In fact, very few bricks or other goods should be set above the top of the straight walls of the kiln. The dome-shaped crown acts as a peculiar reflector of heat, and, if properly shaped, converts the convergent rays into parallel ones, thereby ensuring a uniform heat among the goods. If, on the contrary, the crown is filled with goods, this peculiar property is destroyed and the burning is irregular.

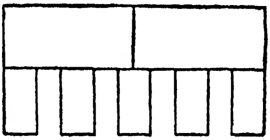

Fig. 1.

In order to ensure the fire-boxes being directly under the fire-holes in a continuous kiln, a lath of 1–4½ inches diameter may be passed into the kiln through each fire-hole to act as a guide to the setters (p. 150). Laths for setting the bricks horizontally are also desirable in the absence of really skilled setters or 'placers.'

If the bricks are to be glazed later, their faces must be set together so as to prevent damage by exposure to the flame. Where difficulty is experienced in getting sufficient top-heat in a continuous kiln, Niendorf's plates may be used. These are small tiles placed vertically in the fuel shafts in such a way that they may be knocked level one after the other as the different parts of the kiln get sufficiently heated, and in this way raise the fuel in the shafts.

(8) Tiles must be set very carefully on account of their thinness and fragility. They are usually burned either (*a*) in cupboards built of bricks or slabs, (*b*) in sets or 'blocks' of about a dozen tiles, these sets being arranged in rows across the kiln, each set being at right angles to its neighbours, (*c*) in layers between the bricks in the upper part of the kiln, where they will not be crushed by too great a weight above them. Glazed tiles must, of course, be placed so that their glazed faces do not touch anything solid. Tiles with 'nibs' are placed back to back, with the nibs projecting beyond the edges of the tiles.

(9) Careless handling of the goods by the placers is a source of great loss in some factories, especially in brickworks. The greatest care should be

taken to keep the arrises clear when setting, or they will be chipped, and the bricks spoiled for best work. The workman should use a board wrapped with several thicknesses of cloth or felt when standing on the bricks, so that his boots do not damage them.

(10) Care should be taken that the goods, when set, do not 'baffle the draught' unduly, and that there is a direct passage both horizontally and vertically whenever possible. For example, in a long rectangular kiln-chamber, it should be possible to see through all the horizontal openings from one end of the kiln to the other. Unless this is possible, the kiln-gases may be baffled, and whilst the goods may be burned satisfactorily as regards their quality, fuel and time will be wasted.

(11) Great care is needed in setting certain classes of goods that the glazed portions do not adhere to the sagger or to other parts of the kiln. The saggers or cupboards should be well sprinkled with flint or quartzose sand, and a little of this material may at times be suitably placed on the goods themselves to prevent adhesion. In supporting articles by means of clay cubes or stilts, etc., attention should be paid as to where the marks formed by these supports will appear; carelessness in fixing these supports should on no account be tolerated.

(12) When setting kilns, arrangements should always be made for the withdrawal of trial pieces. Seger cones should be placed in suitable positions in different parts of the kiln and at different heights, where they can be seen from suitably placed sight-holes.

Detailed descriptions of methods of setting, with illustrations, are given in the following and other books. The names and addresses of the publishers will be found on reference to the Bibliography at the end of the present volume.

Modern Brickmaking, by A. B. Searle.
Treatise on Ceramic Industries, by E. Bourry, translated by A. B. Searle.
Roofing Tile Manufacture, by E. L. Raes.
Manufacture of Earthenware, by E. A. Sandeman.

A comprehensive article on setting bricks (by A. B. Searle) also appears in vol. xxiv. of the *British Clayworker*.

CHAPTER VIII.

KILNS.

THE construction of kilns is a subject which, like so many others, must be left largely in the hands of experts. At the same time, the subject is one of the most important the clayworker has to deal with, for, if his goods go wrong in the kiln, no amount of care afterwards will remedy the damage.

Many kilns are correctly constructed, but fail in actual use because their construction is not sufficiently understood by those using them. A kiln may, for instance, have too much draught, and so cause the heat to pass so rapidly through the flues that parts of the kiln never become properly heated until the speed is checked by the use of a damper or some other means of partially closing the flues. On the other hand, the flue is sometimes partially closed by the builder in such a manner that it may be opened out if more draught is found to be necessary; but unless this is known, the kiln may be condemned as useless owing to it not heating up properly.

The first thing, then, is to know the construction of the kiln, and by this is meant a practical knowledge as well as a theoretical one derived from books or from studying the builder's plans. Only in this way can serious losses be avoided when the kilns are not working quite satisfactorily, or when some part breaks down. In addition to this, a good knowledge of the construction of the kilns in use will not only enable the proprietor to realize the full value of the maxim that a stitch in time saves nine, but will often be the means of suggesting minor improvements in construction which, although small in themselves, are frequently the means of saving considerable sums of money in the course of time. Thus, the saving of half a ton of coal a day represents a man's full wages at the end of the week.

The first consideration in erecting a kiln is the selection of the *site*, for if this is wrongly chosen it may be impossible to obtain good results from the firing. The prospective kiln-builder must watch carefully to see where the water runs and stands after rain, and must choose the driest spot. If the kiln is in the vicinity of a river or of underground springs, it is necessary to ensure that these shall have no effect on the foundations. It is, in fact, essential that the kiln bottom be kept dry, and it must be well drained so as to remain so even in the wettest weather. More than one yard has failed as a commercial success for want of attention to this matter. A foundation 3 feet thick of broken stones laid on concrete about 6 inches thick is also very satisfactory if properly drained.

Drainage pipes should also be arranged in and around the foundations, so as to drain off any water which may find its way into them. Kilns should on no account be built at the bottom of a slope, as all the surface water will drain into them.

The depth to which a foundation must be taken to ensure dryness of the kiln floor depends, to a large extent, on the nature of the ground, but is usually much greater than is generally supposed; and Bock states, as the result of a very long experience, that no kiln should be built on ground in which the water stands at a less depth than 6 feet in the subsoil, and, where floods are likely to arise, the floor should be raised above ground level and arrangements made for draining beneath the kiln. This matter of raised floors is also important in connection with kilns built near to the banks of a tidal river. Of the various materials used for rendering the floor of the kiln damp-proof, asphalt or bitumen is undesirable, because it is affected by the heat, and concrete, although excellent when new, is apt to crack, and is then useless. A simple yet effective foundation consists of a layer of moderate sized stones about 18 inches deep, well drained with pipes and covered with a layer of gravel, over which a bed of clay or loam is well rammed into place. A bed of sand may be added if desired, and the whole paved with hard-fired bricks. As the heat from the kiln causes moisture in the ground below to evaporate, the ground shrinks and may endanger the foundations of the kiln. It is, therefore, advisable to build the kiln on a rocky foundation if possible or to prepare so strong a foundation that no damage to the kiln will occur. It is very undesirable to erect a kiln on a clay foundation without providing a sound and non-plastic foundation. Kilns should not be built on 'made ground' for the same reason. In several cases, kilns have collapsed because they have been built on 'ashes' which contained unburned fuel and the latter was gradually burned away by the heat penetrating to the foundations of the kiln. Where the ground is very wet, properly built flues should take the place of the stones, these flues being connected so as to drain from one channel. Small wooden chimneys are also added in some cases to secure the proper ventilation of these flues, but if the chimney draught is strong enough the flues may be more conveniently connected to the chimney-stack.

The *masonry* of kilns is often too thin, and sometimes the various dampers and caps fit so badly as to be almost useless. Such defects have all to be paid for by an excessive fuel consumption.

The strength of the arches is a matter often needing special care, for it must be remembered that the masonry must not only be sufficiently refractory to withstand the high temperatures, but must also be possessed of such resisting power that it can bear the strains set up by the continual expansion and contraction. Flattened arches are, therefore, to be avoided, as are also those with a very pronounced point. In almost every case a portion of a true semicircle is the best form of arch.

A good *roof* for protection from snow, rain, etc., is beneficial for permanent kilns; this roof should extend beyond the walls for some distance around, so as to keep the approaches to the kiln dry. Above all, care must be taken that the water draining from the roof is properly removed. If goods are to be dried under the roof of a kiln, some provision must be made for as much as possible of the heat of the kiln to be retained. The roof should be made of slates or tiles, but felt-covered wood, asbestos, and sheet iron are sometimes used, though less satisfactory. A lantern roof with open troughed eaves to secure ample ventilation without exposure to rain is usually the best for kilns.

The advantages of a good roof are: (1) it protects the burner from the weather, and enables him to do his work better; (2) it keeps the coal dry, and prevents it wasting away; (3) the top of the kiln may be used as a dryer; (4) a roof increases the durability of the kiln, and (5) it improves the quality of the goods burned.

The *dampers* leading to the chimney-flues require care to keep them air-tight. In the case of kilns of the Hoffmann type, this is best accomplished by having deep double rims and caps fitting into sand placed between them, so as to act after the manner of a water-seal, the sand taking the place of the water. There are four important types of dampers:—(1) *bell dampers*, which are not very satisfactory, as they soon cease to fit well and are usually difficult of access; (2) *cone dampers*, which are usually satisfactory, permit of accurate regulation of the gases and air, but are often difficult of access; (3) *plate or sliding dampers*, which, if well designed, are usually quite satisfactory: the large ones should be properly counterpoised; (4) *paper dampers* for temporary purposes in continuous kilns are often preferable to dampers of iron or other material.

The *collecting flue* of a kiln should be sufficiently roomy for an ordinary man to easily get inside it for cleaning purposes, and should be provided with so many openings that, no matter which part of the kiln is under fire, the flues may be entered in the cooler parts direct from one of these manholes. The covers for these manholes must, of course, be kept air-tight—usually by means of sand, and a second cover of wood, or iron, employed.

The construction of the 'smoking apparatus' requires care; the walls are frequently far too thin, and the connection to the kiln is often badly made.

Chimneys are often too slightly built, and so lose heat and draught-producing power. Lined chimneys have a great advantage in this respect. Round chimneys resist the wind better, and are largely used for this reason, but they have a smaller capacity than square ones of the same diameter.

Another matter to be considered is the *nature of the goods* to be fired. This influences the construction of the kiln in several ways, chiefly in regard to (*a*) the method of heating—whether the goods may be mixed with fuel or not, if they may be fired in an 'open' kiln, or if they must be completely protected by saggers or muffles; (*b*) the temperature to be reached, and its influence on the nature of the fuel and on the materials used in the construction of the kiln; (*c*) where two or more methods may be used, it is important to choose the one which will cost least in setting and discharging, in fuel, and in labour of firing.

In regard to the *fuel*, but little need be said, as coal is almost exclusively used in this country. Producer gas is excellent for kilns, and for high temperatures it is much more convenient and capable of adjustment than coal, though it is not usually more economical. Oil has also been used satisfactorily, but is not a serious rival to either gas or coal. The fuel may be burned in special fire-boxes or into flues left in setting the goods, and, in the case of some kinds of bricks, a certain proportion of sifted cinders ('breeze') is worked in with the clay so that the fire, once started, will continue burning, each brick forming a kind of fire-ball, and supplying the fuel necessary for its own baking.

The coal should be kept under cover as much as possible, as it burns better and clearer than when it has been exposed to inclement weather. This is especially true of small coal. For further information on 'Fuel,' see p. 35.

In considering the different ways in which the heat from the burning fuel may be applied, it is first necessary to decide whether the goods will be injuriously affected by the flame: if so, they must be protected by placing them in fireclay boxes called 'saggers,' or the kiln must have a protective lining or 'muffle' to prevent the flame obtaining access to the goods. Sometimes sufficient protection may be afforded by a special method of setting, as in the case of glazed bricks.

Although, from an academic standpoint, it would be more convenient to classify kilns according to the manner in which the goods are heated by the fuel, it is more convenient to clayworkers to regard kilns as 'intermittent' or 'continuous'—the former term being applied to those which are lit, heated to the finishing point, and are then allowed to cool completely before being emptied; and the latter being used for what is really a series of 'intermittent' kilns all connected in such a manner that, although some portions are at the full heat and others are heating, cooling, being filled or discharged, yet the fire is never allowed to die out in every part of the kiln.

The subject of kiln construction is so large that only a comparatively small amount of information can be included in the present volume. A much more detailed consideration of the subject (illustrated) will be found in the author's *Modern Brickmaking* and *Kilns and Kiln-building*.

Intermittent Kilns are of three main types :—

(*a*) Top-draught or up-draught.
(*b*) Down-draught.
(*c*) Horizontal draught.

Up-draught kilns are, on the whole, wasteful of fuel; the flame, having only a very short distance to travel before it reaches the goods, is unduly cooled and smoke and products of incomplete combustion result. The fuel should have a sufficient space for a perfect flame to be formed before it comes in contact with anything to be heated, this being more satisfactorily accomplished in a down-draught kiln on account of the greater distance the flame is able to travel.

In the down-draught kiln, also, the products of combustion have more opportunity of mixing with each other and so producing a more uniform heat than is possible in an up-draught kiln, and there is less tendency for the goods to be heated to a greater temperature at one part of the kiln than they are at another, a common fault of the up-draught type in which the bottom goods are almost always overheated. Also, as they have to bear the weight of the goods above them, they are particularly liable to become twisted or crushed. 'Flashing' of the goods by the flame impinging directly on them is also much more serious in up-draught kilns. In spite of these disadvantages, most of the earthenware made in this country is still fired in up-draught kilns, which have the advantage of simplicity of construction, are easy to repair, and, with sufficient care in placing the goods so as to suit the different heats in various portions of the kiln, give satisfactory results. In the 'Hovel' up-draught kiln, the kiln proper stands inside a large cupola with just sufficient space left between them for the fireman to wheel his fuel and to stoke. The object of the cupola or hovel is to protect the kiln-mouths from the wind and outside air-currents, and it is very effective in this way; but the space for firing is usually so small that the fireman is much exposed, and, owing to the use of so small a chimney, the draught is often poor. A modified up-draught kiln, known as the 'Skeleton' oven, has become exceedingly popular of recent years, being simple in working, easy to repair, clean, and giving satisfactory results. The principle on which it is constructed is that of a stack supported round the oven proper by a series of arches, leaving between the shell or arches and the oven proper a space of 3 to 7 inches.

Hence the lowest 3 feet of the oven and outside brickwork (*i.e.* up to the top of the mouths) are built solidly together, but above this point the oven proper is quite out of contact with the shell. The most suitable size for such a kiln is 18 feet inside diameter for biscuit, and 14 feet 6 inches for glost ware. A kiln of this kind is very fully described by Sandeman in *The Manufacture of Earthenware.* (Crosby, Lockwood.)

Down-draught kilns have now largely superseded those with an up-draught for general purposes, apart from pottery proper, and even for earthenware they have come largely into use, as the temperature of the goods is more evenly distributed and they use less fuel. On the other hand, they cost more to build and to repair than up-draught kilns, and the flue arrangement is in most cases more complex and so needs more attention. Down-draught kilns may be divided into four main classes, viz. :—

Rectangular kilns;
Round kilns;
„ „ with an upper chamber; and
„ „ „ a lower chamber.

Though of so many patterns, the main principle—that of allowing the flame and hot gases to travel first to the top of the kiln and then be drawn down and away at the bottom—is the same in all. Strictly speaking, they should be termed 'up- and down-draught,' as the heat has a strong upward direction before it descends. This much greater length of travel is the cause of the high efficiency of this type in the matter of fuel; it also helps very considerably in the production of a uniform temperature, as the air necessary for the combustion becomes thoroughly mixed with the gases before they come into contact with the goods. A minor point is that the most strongly heated goods are at the top of the kiln, where, having no other goods placed above them, they are better able to retain their shape than in an up-draught kiln where the greatest heat is near the base. The placing of the goods in the kiln requires some care in order that the flame may not go direct to the flue without first passing round the goods. The number of openings in the false bottom of the kiln depends on the class of goods made; salt-glazed articles require a large number of relatively small openings, whilst for other goods the openings may be fewer and larger.

Rectangular kilns consist of a rectangular chamber with fireplaces in two sides and a false or perforated bottom connected to one or more chimneys. The doors for filling and discharging the kiln are placed at each end. Rectangular down-draught kilns are more expensive to build than the round ones, and are not quite so economical in fuel consumption, but they have a greater capacity, as there is no loss such as that occasioned by the curved interior of a round kiln.

Round or circular down-draught kilns vary in diameter from 11 to 56 feet and in height from 6 feet (salt glazing) to 23 feet. The medium sizes give the best results, but the larger kilns are more economical in fuel.

Additional chambers to the kilns are frequently added with a view to greater economy in fuel, and may be placed either above, below, or alongside the first one. The heat they receive is, naturally, not so intense as that in the first chamber, but when suitable connecting flues are used it is more than sufficient for biscuiting the clay.

Horizontal kilns are characterized by the use of a single fireplace, or its equivalent, placed at one end of a rectangular chamber through which the gases are led, more or less horizontally, to the chimney. In this type of kiln, which is greatly used in the North of England, the floor may be solid or furnished with a perforated (false) bottom through which the gases may ascend or descend according to the design of the kiln. For firebrick-burning a solid bottom is most commonly used, the three openings to the chimney-flue being placed near the floor at the back of the kiln. This type is known as the 'Newcastle' kiln.

For burning building bricks, it is more usual to build two kilns 'end on' to each other, but without any partition between them. This gives a kiln double the ordinary length and with a fireplace at each end. The outlets to the flues are then placed at the centre of the side walls or in the centre of the floor. The goods are then placed so that the gases travel slowly round them in a horizontal direction and are gradually drawn downwards to these openings. If the setting of the kiln is properly carried out there should be no difficulty in getting the temperature evenly distributed, especially if sufficient loose bricks are left in the front wall of the kiln and are removed as the firing approaches the finishing point so as to prevent the front tiers of goods being overheated. This class of kiln is far from economical, but, unless of great length, has the advantage of a sufficiently even distribution of temperature combined with a moderate first cost. It can, however, only be used for such goods as can be placed in the kiln in such a way as to secure an even distribution of the combustion gases, and its use must, therefore, be chiefly confined to the production of certain classes of bricks, tiles, and quarries. There is usually a considerable amount of ash adhering to the goods burned in horizontal kilns, owing to the absence of a 'bag' wall or 'screen.' Although very long kilns of this type are more economical, they tend to cause a deposit of moisture and acids from the gases on the goods near the exit end of the kiln. This defect seldom arises in kilns up to 30 feet in length. Horizontal draught kilns may be connected in series so that the waste gases are passed from one to another, and the greater part of the heat utilized before the gases pass into the chimney. This effects a considerable saving in fuel, but if the output is sufficiently large to enable such connected kilns to be used, it would generally pay to replace them by a continuous or semi-continuous kiln.

Continuous Kilns.—With the pursuit for economy in firing came the invention of the continuous kiln, in which a number of chambers are so connected to a system of flues that the heat from any one of them may be conveyed to the rest or not at pleasure. Hence, it is possible to so work the kiln that various stages of the firing may be proceeding in different chambers at the same time.

The first kiln built on this principle was the famous 'Ringofen' designed by Hoffmann, and copies of this, more or less modified, are largely in use at the present time for the manufacture of terra-cotta, bricks, and roofing or paving tiles, as well as for the calcining of limestone and similar minerals. Since its first introduction, in 1856, many modifications have been made, and the number of varieties of Hoffmann kilns now in use is very large, but the underlying principle in all is to have a more or less ring-shaped tunnel in which the goods are set, the firing being so arranged that whilst part of the kiln is being fired, other parts may be filled or discharged, the kiln being divided up into a number of chambers by means of movable partitions.

In its most compact form, the kiln is square in plan, but in the more usual form for large kilns two parallel walls are terminated at each end by semicircular ones. Kilns of the original circular shape are now no longer built. The interior of the modified Hoffmann kiln now most in use consists of an endless tunnel to which access is gained by 12 to 18 doorways, the space between these being divided into 12 to 18 imaginary 'chambers,' though no actual partitions exist. Each of these 'chambers' usually measures 13 feet by 14 feet by 8 feet 6 inches, the width being varied according to the output required. The doorways or 'wickets' are often inconveniently narrow. In the 'Lancashire' continuous kiln they are wide enough and high enough to enable an ordinary cart to be backed into the kiln. Very long kilns, when used for clays which may be burned rapidly, are usually worked as though they formed two or more independent kilns. The capacity and drawing power of main chimney and the rate at which the goods may be heated are the chief factors controlling the length of a continuous kiln.

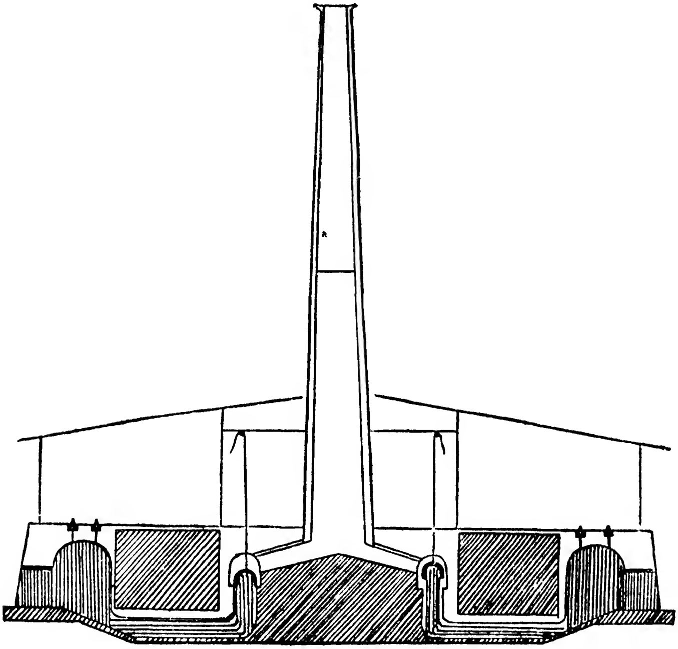

FIG. 2.—Vertical Section of original Hoffmann Kiln.

Reduced to its simplest dimensions, the *Hoffmann kiln* may be represented as in figs. 2 and 3, though, as already mentioned, the circular form is now seldom constructed, the oblong form shown in fig. 4 being usually preferred.

The kiln proper consists of a circular or elliptical tunnel of suitable section, which receives the goods through doors placed in the circumference or outside wall and built up in the firing. The fuel is fed through apertures in the roof of the tunnel. Flues lead from the tunnel to the 'smoke collector,' which surrounds the base of the central chimney, the communication with which can be cut off by means of bell-shaped cast-iron dampers. These flues may be at the base or near the top of the tunnel, according as the kiln is worked with an up- or down-draught. Immediately behind each flue a suitable opening is made for the insertion of a damper-plate, which forms, when in position, a complete partition across the kiln and so prevents the leakage of air or hot gases. As metal dampers are not perfect in this respect, many firms now employ so-called 'paper dampers,' or large sheets of a specially made paper which are pasted on the inside of the kiln during the setting and are later burned down by contact with the travelling fire. These paper dampers do away with one of the great sources of air-leakage, viz. through the damper slots, and, although apparently expensive in maintenance, rapidly repay themselves in the amount of fuel saved. The paper used is a kind of coarse tissue-paper which is light, tough, and free from pin-holes.

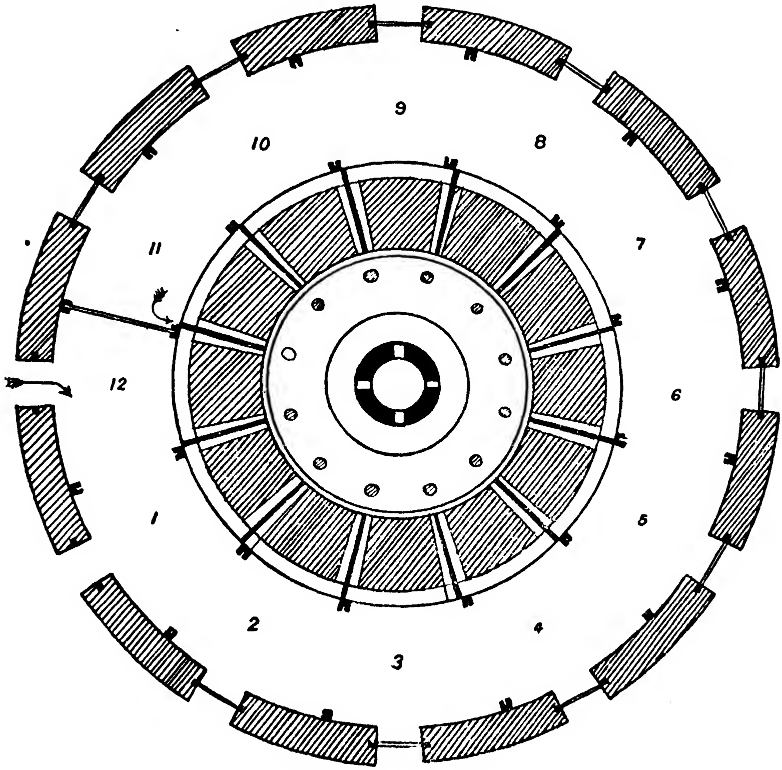

FIG. 3.—Plan of original Hoffmann Kiln.

The fuel falls through vertical columns arranged by the setters in filling the kiln, and some skill is required to so arrange the goods that these columns, with their radiating channels (or 'traces'), shall be properly constructed, for on this the success of the firing depends to a large extent. It is usually wise to fix 'setting laths' vertically in the kiln through the fire-holes, and to instruct the setters to use these as guides in the placing of the goods. The laths are removed through the fire-holes when the chamber is full (p. 141).

The number of chambers in a kiln is, theoretically, of no importance, although in practice it should bear a definite relation to the time required for warming and burning the clay and to the desired output. If too many chambers are used, the goods will be too long in the slow firing, whilst if too few chambers are employed (*i.e.* if the kiln is too short), sound goods cannot be obtained. It is seldom wise to construct a kiln with less than fourteen chambers. If a kiln of given size would have too large an output, the width of the tunnel, and *not* the number of chambers, must be reduced proportionately. It is essential that all the chambers should be in use if the fullest economy of fuel is to be reached. Twelve chambers is really too small a number for yards making common bricks, and it is far too few for one making terra-cotta or facing bricks, or working a delicate clay. Referring to fig. 3, it will be observed that all the chambers (numbers 1 to 12) are connected to each other by a free passage, but that a damper across the kiln prevents any passage between No. 11 and No. 12. Assuming that the kiln is in full operation, the doors in chambers 1 and 2 being open, No. 12 will serve for filling with the fresh goods, and No. 1 for taking out those already burned. The chambers 2, 3, 4, 5, and 6, which are already filled with burned goods, are gradually cooled by the air which enters through the doors of 12 and 1, and this air as it passes on becomes warmer and warmer, until at last it is as hot as the glowing ware, and consequently, the fires in the kiln are supplied with air almost as hot as a furnace itself.

In chamber No. 7 the fire is burning, and when its contents have reached the desired temperature those of No. 8 will have become so heated by the waste heat from No. 7 that the fuel fed into No. 8 after No. 7 is finished becomes instantly ignited. Chambers Nos. 9, 10, and 11 will be dried off by the waste heat which passes through them, and the damper in No. 11 will turn the gases into the chimney through the small flue at a temperature only just sufficient to support the draught. When No. 12 chamber is filled and closed, the damper is removed and placed between Nos. 12 and 1, the bell-shaped damper over No. 11 being lowered, the one over No. 12 lifted, and the one between Nos. 1 and 2 lowered. The contents of No. 2 will then become sufficiently cool to be drawn.

In most places, a modification of this process of firing is employed, a small separate fire or some of the air from the hot goods being used to dry those freshly set into the kiln, and to warm them sufficiently to prevent any condensation products forming upon them when they come into contact with the burning gases. An additional damper is then placed on the other side of the chamber so heated, *i.e.* between Nos. 10 and 11 in fig. 3. In this manner, the chamber is temporarily shut out from the round of the kiln. This is a very important matter with clays liable to scum or 'whitewash,' but some degree of loss of heat is experienced. This arrangement also offers additional facilities for lengthening or shortening the fire-space, as by the additional flues required the flue-gases may be led from almost any one chamber to any other.

In the more modern type of Hoffmann kiln (figs. 3*a* and 3*b*) the same process of burning occurs.

When the flue-gases are used to dry the freshly set goods, there is a great danger of the sulphur compounds they contain being condensed on the cold, damp goods, and so scumming them with a deposit of sulphates. This may be prevented by using a 'stove' in which air is heated before it enters the kiln, and the gases from the fuel in the main burning zone of the kiln are not used until the goods have become so heated that there is little or no danger of condensation occurring. The preliminary drying and warming generally referred to in this book as ‘smoking’ or ‘smouldering’ is sometimes known as ‘stoving’ from the use of the supplementary stove or air-heater (p. 169).

The use of a stove requires careful attention, or the difficulty of scumming will not be removed. The usual fault consists in allowing the fuel to burn too low or not brightly enough ; the amount of air heated is then very small, and as the products of combustion from the stove are mixed with the air used for drying, these very products may, if too concentrated, occasion the defect which the stove is expressly intended to avoid.

Many improvements have been suggested at one time or another, but up to the present the Hoffmann kiln in this country remains practically unaltered from its original forms (p. 149). At the same time, it must be admitted that for some purposes an alteration is desirable, and in others the diminished cost of construction is sufficient to make a modification of the standard type well worth consideration. In Bock's kiln, the walls are of earth, this kiln being constructed by excavating the tunnel and building in the necessary flues in the central piece of ground. This kiln has, therefore, the top of its walls level with the ground, and in this way a considerable amount of heat, which would otherwise be lost by radiation, is preserved. The Bock kiln also differs from most other kilns in having no permanent roof, the ‘roof’ being composed either of a layer of clay or one of sand or soil about 4 inches thick. To fill the kiln, the goods are slid down boards from the ground level to the men inside the kiln.

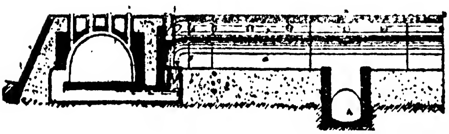

Fig. 3*a*.—Section of modern Hoffmann Kiln.

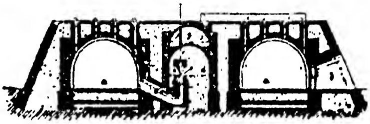

Fig. 3*b*.—Cross-section of modern Hoffmann Kiln.

More recently, H. Harrison has patented a kiln almost identical with that of Bock's, but built on the ground instead of being excavated. It is, therefore, rather cheaper to construct than Bock's kiln. Such ‘archless’ kilns are only suitable for common bricks, and then only for temporary yards, as the cost of renewing the top of the kiln is as great, if not greater, than a permanent arch, though it avoids the initial capital outlay. There is also risk of the goods being damaged by prolonged wet weather, unless a portable roof is erected over the part of the kiln containing the unburned bricks.

The advantages of archless continuous kilns are : (1) low cost of construction ; (2) ease in noting the progress of the fire ; (3) greater speed and comfort in filling and emptying, as, the top of the kiln being open, the chambers are cooler, and the setting can be done in a better light ; (4) the fuel consumption is lower than in single kilns, but heat is lost through the top of the kiln, and through the thinner walls of the Harrison kiln.

The *Zig-zag* kiln is another modification of the Hoffmann kiln, designed to avoid the great length of ground required by the original ‘long’ form brought out by Hoffmann in 1870 as an improvement of the earlier circular form. In the Zig-zag kiln the main part, forming the chambers, is turned repeatedly on itself, as its name implies, so that the goods are loaded in through the ends instead of through the sides of the chamber. Kilns of this type, designed by J. Bührer, have accomplished remarkable feats as regards rapid burning, speeds ten times as great as those ordinarily obtained in this country, together with a considerable saving in fuel, being quite usual.

Zig-zag kilns are particularly useful for small and medium outputs, but for very large ones they are apt to prove a less durable form of construction than the more usual type of continuous kiln.

In order to overcome the difficulty of some of the goods (bricks) being damaged by the ashes from the fuel falling on them, permanent walls and fire-boxes may be erected. These undoubtedly serve the purpose, but at a slight loss of fuel. Still, for many classes of goods their use is quite unavoidable. In addition to this, the horizontal direction of the flame, which tends to prevent its proper and even distribution through each chamber, may be avoided. The simplest of these *continuous chamber kilns* is obtained by building permanent 'flues' for the fuel to fall into when fired, as in the ordinary Hoffmann kiln; but this not being altogether satisfactory, it is more usual to build a complete partition to form each chamber, and to provide close to this a fire-box or row of fire-boxes to contain the fuel. It is advisable to leave plenty of holes in the lower part of the partition for the gases from the previous chamber to pass into the fire-box of the succeeding one. These fire-boxes then impart a strong upward tendency to the stream of gases which, being drawn from near the bottom of each chamber, has a much better chance of being diffused throughout the entire space than when the direction of the gases is more horizontal. In some forms of this class of kiln, the bottom is perforated, and the gases are led beneath the partition instead of through it to the fire-box of the next kiln after having been mixed with a certain proportion of fresh (heated) air in order to maintain proper combustion.

The arrangement of the flues in a continuous kiln is very important, as the rapidity of firing and the fuel consumption depend upon it. The hot-air flues may be arranged in various ways. In some kilns, the air enters at the bottom of the cooling chamber and is drawn off at the top (up-draught), whilst in others the hot gases are withdrawn through the floor.

The down-draught type is generally used, as the opening into the main flue is usually placed near the floor of the kiln, though the method has the disadvantage of causing moisture to settle on the lower bricks, thereby unfitting them to bear the weight of the goods above. Sheet-iron pipes are sometimes used as temporary hot-air flues, but they are not very effective on account of the heat lost through radiation. Whichever arrangement of hot-air flues is used, they should be tested periodically to ensure their tightness and general efficiency, and a proper regulation of the current of air through them should be maintained by the use of suitably placed dampers.

In the 'Belgian' kiln, a grate in each chamber runs across the whole width of the tunnel; in the Brown and Guthrie kilns, a trough occupies the same position, and is equally satisfactory in most cases.

The number of modifications of the original pattern of continuous kilns is so great that no further details of them can be given here. As an illustration of a kiln which combines all the advantages of the down-draught type of kiln with the economy and low fuel consumption of the continuous type, it would be difficult to find a more suitable kiln than that known as the *Staffordshire*[1]

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[1] It must be clearly understood that the author has no financial interest whatever in this or any other kiln.

kiln, patented by Dean and Hetherington, which must not be confused with the ordinary pottery kiln used in North Staffordshire or the rectangular down-draught kilns used for blue bricks, although such a mistake is natural, considering its title.

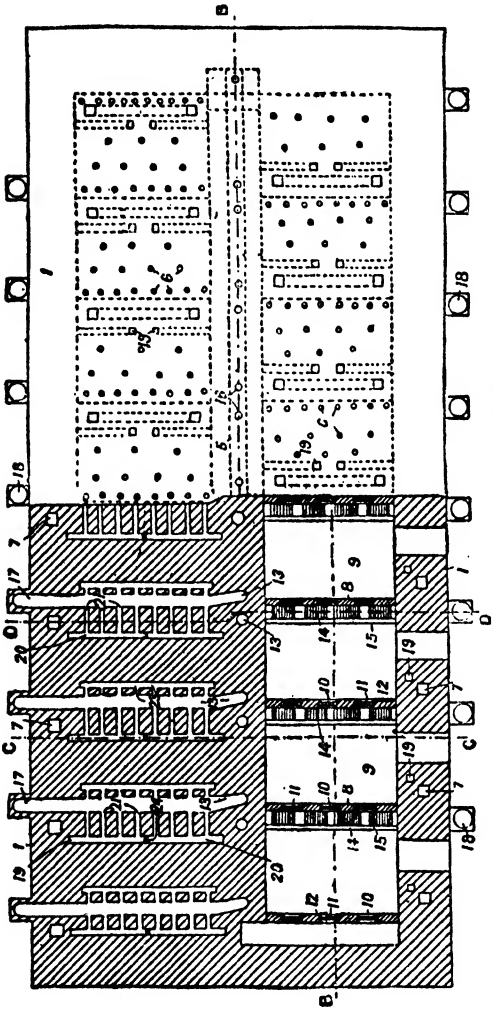

Fig. 4.—Plan of '*Staffordshire*' Kiln.

The general form and construction of the Staffordshire kiln closely resemble those of a Hoffmann kiln of similar capacity, the improvements consisting in the addition of grates, hot-air flues, and partition walls.

In the Staffordshire kiln, the means of supplying hot and cold air to different parts of the kiln are unusually complete, and, as only one face of fire is used in each chamber, this kiln is capable, under good management, of giving results equal to the best down-draught kilns with coal consumption as small as in continuous kilns. This is brought about by the combination, in a continuous kiln, of damper-controlled passages leading from the outer air to flues under the fire-grates in the bottom of the kiln in each chamber, as shown in the illustration, and of similar flues leading from the hot-air flues and from the outer air in such a way that, by appropriate connections, air of any desired temperature and in any desired volume may be admitted to any part of the kiln.

By suitably working the dampers shown in figs. 4 and 5, the following results may be obtained:—

(*a*) By opening dampers 11 and 18 the whole or part of the hot air from the finished or cooling chambers may be admitted to the chambers containing the freshly set goods, and the steam resulting from the heating of these goods led away from the top through flues 7 and 3 to the chimney.

(*b*) By opening the dampers (16) of the flue (13) hot air from flue 5 may be led under the grates (14) to develop the highest possible temperature in the finishing chamber, or to distribute hot air uniformly from the hot-air flue (5) to a chamber containing green goods.

(*c*) The admission of cold air to a cooling chamber is kept under perfect control by means of dampers (18) and flues (17).

(*d*) The temperature of the hot air entering a hot chamber from one that is cooling may be perfectly regulated by the admission of air through flues 17 and 19.

(*e*) The volume of air admitted through the various flues allows of nice adjustment for reducing and oxidizing atmospheres.

(*f*) The fire and hot gases may pass from chamber to chamber through openings (10), whilst cold air only is admitted to the under side of the grates (14) through flues (17).

(*g*) Any chamber can be completely sealed by closing all the dampers, thus allowing a good annealing. This arrangement is also of great value where the goods are liable to catch fire spontaneously.

Other well-known continuous-chamber kilns of a simpler type, suitable for many purposes but giving less complete control over the burning, are the *Manchester*, *Lancashire*, *Ideal*, *Excelsior*, *Belgian*, and *English* kilns. These and many others are described in the author's *Kilns and Kiln Building*.

Modifications of continuous-chamber kilns constructed so as to burn gas instead of coal are increasing in popularity. Whether much expense and labour will be saved thereby remains to be proved. In Scotland the Dunnachie continuous gas-fired kiln has long been famous, and several large gas-fired kilns have been in use in the United States for many years (see p. 158).

The manner and method of setting and firing the goods is of the greatest importance in continuous kilns; they are referred to in fuller detail in the chapters on 'Setting' and on 'Firing.'

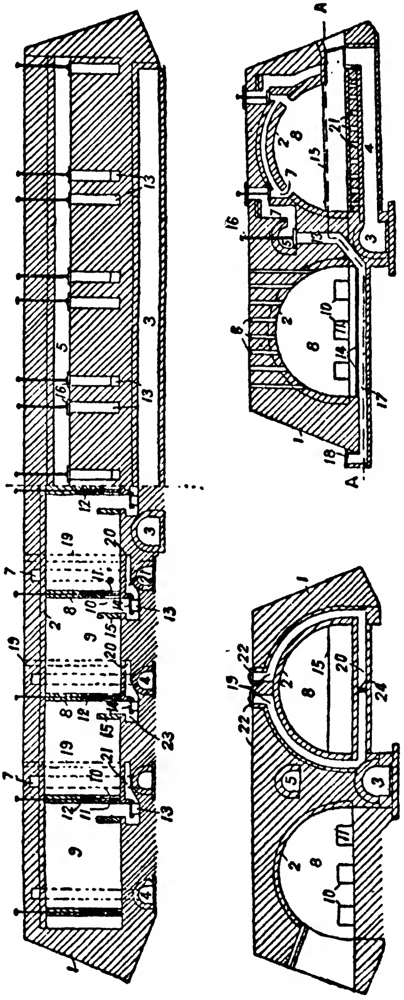

FIG. 5.—Sectional Views of '*Staffordshire*' Kiln.

Tunnel Kilns.—A term applied to two forms of kiln, viz. (*a*) the ordinary Hoffman continuous kiln, to distinguish it from continuous kilns with separate chambers, and (*b*) to a structure up to 400 feet in length through which the goods pass on cars; the latter is generally to be understood when the term '*tunnel kiln*' is used. In this kind of car-tunnel kiln, the cars carrying the goods enter at one end and are slowly preheated by the kiln-gases; as the cars travel forward, they enter the 'firing zone' and eventually the cooling zone, through which they pass and then out of the kiln.

Such kilns are now used for many kinds of clay wares, including bricks, tiles, domestic pottery, sanitary ware, electrical insulators, and various refractory articles. The rate of burning is much greater than in single kilns.

Car-tunnel kilns are similar to tunnel dryers (p. 130). They are very economical in fuel, as only one part of the kiln is heated directly, whereas in other continuous kilns each part of the brickwork is heated and cooled in turn. A great saving of labour can be effected, as the cars can be filled and emptied with great facility, and the control of the firing is all that can be desired. There appears to be no limit to the temperature attainable, a small tunnel kiln having been in regular use for some time burning refractory bricks at a temperature sufficient to bend Cone 17 (1480° C.). All the successful kilns consist of a tunnel 300 feet to 400 feet in length, 3 feet to 9 feet wide, and 4 feet to 9 feet high internally, through which a series of trucks or cars run on rails, the metalwork of the cars being suitably insulated from the heat, or the cars may be constructed throughout of refractory material. The fuel may be either solid, liquid or gas; it is burnt in fireplaces at each side of the hottest part of the kilns or in long tubular chambers placed longitudinally in the kiln. The air required for the combustion is supplied in the same manner as in other kilns, but is supplemented by a current of air which is drawn in through the whole length of the tunnel, being heated by the burned goods which are correspondingly cooled thereby, and then passing forward with the products of combustion in order to heat the freshly set goods. In the Dressler tunnel kiln, the products of combustion are confined to two tubular chambers, but the air in the tunnel circulates round these chambers and round the goods to be heated or cooled.

The chief advantages of tunnel kilns are: (1) the respective parts are always at a constant temperature, so that there is less wear and tear on the kiln-structure than in other types of kiln. This effects a saving of time and fuel, as the brickwork has not to be heated and cooled; (2) the goods are more easily set and unloaded than in other types of kilns; (3) the saggers, if used, last much longer, but in the Dressler tunnel kiln they are not required and setting is still further simplified; (4) the whole of the fuel is used effectively, and there is much less loss through the walls of the kiln; (5) a saving in the cost of brickwork is realized, as only the hottest part need be constructed of fire-brick: this is counterbalanced by the cost of the cars; (6) the ground space is less than any other kiln of the same output. The chief reasons why the tunnel kilns are not used more extensively are: (*a*) the difficulties of earlier kilns which have not yet been overcome; (*b*) the necessity for burning only dry goods; (*c*) the cost of repairs to the cars (which is usually exaggerated); (*d*) the fear of too rapid cooling, which need not occur; (*e*) the natural disinclination to instal a kiln costing several thousand pounds which has not previously been used for the same class of goods. These difficulties are almost wholly due to defective design and construction, and may be obviated by using a properly designed tunnel, and since several tunnel kilns of various types are in general use, their advantages are being increasingly appreciated.

Clamps are only used for burning bricks and (less frequently) for tiles. Strictly, they are not kilns, as there is no permanent structure; the bricks to be burned are arranged in such a manner, with layers of coke or other fuel, that, when they are covered with a temporary casing of bricks, the whole resembles a continuous kiln. The powdered fuel mixed with the clay used to form the bricks, together with the coarser fuel on which the bricks are laid, suffices to burn them, so that when a clamp is once lighted it needs little further attention until the burning is completed.

Scarcely any two clamps are built exactly alike, the idiosyncrasies of the foreman as well as local conditions and customs having an important influence on the details. Usually, a clamp consists of a number of walls or 'necks' 3 bricks or so thick, about 60 bricks long, and 24 to 30 bricks high. The ground on which the clamp is built is raised slightly at each side, so as to cause the bricks to lean slightly to the centre of the clamp and so form their own buttress. The centre of the clamp is practically upright, and is formed by building two 9-inch walls, about 45 feet apart, of burned bricks laid on edge; these walls are about 4 feet 6 inches long and 6 feet high. The ground between these walls is paved with burned bricks on edge to keep off the moisture of the ground, and upon this paving two courses of bricks laid diagonally—about 2 inches apart for the lower course, and parallel to the ends of the clamp for the upper one. A 'live-hole' or flue is left about 7 inches wide down the centre of the whole length of the upright, and this is then filled with faggots up to the level of the second course of bricks. The whole of the surface is next covered with breeze or ashes to form a level bedding. The building of the raw bricks is then begun, these being laid on their edge and quite close. A 7-inch layer of breeze is placed over this first layer of raw bricks, the depth being increased at the ends of the uprights by padding the breeze with a few additional bricks. On this breeze is laid another row of raw bricks at right angles to those below, and covered with about 4 inches of breeze. Another course of bricks parallel to the first is now laid and covered with a 2-inch layer of breeze. This process of building is continued, the layer of breeze diminishing as the height of the clamp increases, except the top course, which has a moderately thick layer. The bricks must be carefully tied at the angles, as it is necessary to keep the upright perfectly firm. The neck or walls leaning against the upright are built in a similar manner, with the difference that they are parallel walls built alternately of headers and stretchers laid on edge, each stretcher course of one neck being opposite to a header course in the next. The clamp is completed by a casing of burned bricks, the lower six courses being laid flat and the remainder on edge, roughly bonded together. In most cases, the whole clamp is plastered with a mixture of sand and sufficient clay to form an adherent mass, but not sufficient to cause the mass to crack when in use.

Live-holes must be built for every seven or eight necks, and the casing bricks are omitted when their employment would cover the holes.

The air required for the combustion of the fuel is admitted through special openings in the casing, and it is distributed throughout the clamp by numerous small 'eyes' or flues.

The clamp is lighted by applying a coal fire to the mouths of the live-holes, and after the faggots are fully alight (which often takes twenty-four hours) the mouths of the holes are stopped up with bricks and clay.

No general rules can be laid down for the proportion of breeze required; with too little, the bricks will be imperfectly burned, whilst an excess of breeze will tend to run the bricks to a slag. On this account it is desirable, in lighting a very large clamp, to begin with only a few live-holes and to light the others as the firing progresses. The time of firing varies from two to six weeks, according to the spacing of the flues and the length of the clamp. It will readily be understood that much skill is required in forming a clamp, for if a mistake is made in the arrangement of the bricks it may be impossible to burn a large proportion of the clamp, and this will be spoiled.

Muffle Kilns are employed for burning glazed and other goods which it is essential should be kept entirely free from all contact with the flame or fuel. As is well known, they contain a lining of fireclay bricks which effectively keeps off all flame from the goods. The main difficulty in the construction of muffle kilns is obtaining a perfect distribution of heat around the top, sides, and bottom of the muffle, so that a regular and even heat is obtained inside it. Muffles are heated either by up-draughts or by down-draughts, the latter being preferable and more economical of fuel. As the material of the muffle has to be heated anew each time the kiln is fired, these kilns waste fuel when compared with others; but this cannot be altogether avoided. As there is only a very limited circulation of air inside the muffle, it is essential that it should be well filled with goods so that the radiation may be regular.

Muffle kilns are usually fired separately, but they may readily be coupled together, so that the first may heat a second or even a third. The connected kilns are usually so arranged that glost goods are placed in the first, the waste heat from which is (if the flues are rightly constructed) sufficient to biscuit the second for most sanitary ware. For china and earthenware, the use of muffles has no particular advantage over saggers. Muffles are preferable for firing large articles which require protection from the flame, and are too cumbersome to be placed in saggers. The fires may be placed at the ends or along the sides of the kilns, the former being more economical and quite as satisfactory as the latter, and in addition they allow the kilns to be built in ranges of three and more, thus saving heat and material by passing the waste heat from one kiln into the succeeding ones. Muffle tunnel kilns may also be used, or a special tunnel kiln patented by C. Dressler may be employed.

Gas-fired Kilns are increasingly used; the Dunnachie, Shaw, Dressler, and Mendheim kilns being the best known in this country. When properly constructed, they undoubtedly effect a saving in the cost of fuel, as a much lower grade will suffice, but the most marked saving is in greater durability of the kiln and the saggers. They are mostly worked by means of gas-generators, which form a kind of producer-gas rich in carbon monoxide, but with a shorter flame than that from coal-gas. Regenerators are used to heat the air and to reinforce the heating power of the fuel. The advantages of a gaseous over a solid fuel consist chiefly in the greater ease in regulating the heat, the greater cleanliness of the goods when fired in an open kiln, and the reduced labour, both in firing and in transporting the coal to the kiln, and to the much less trouble involved in dealing with clinker and ashes which are produced when coal is used in a producer as compared with an ordinary fire. Gas-fired kilns are much cheaper than coal-fired ones, and the goods are less likely to be contaminated by the ashes and fire-gases. The temperature and rate of heating are under much better control, and the work is easier for the burners. Gas-fired kilns are particularly useful for temperatures above 1250° C., as coal fires cannot produce such temperatures economically; for lower temperatures, coal is sometimes more economical than producer gas. Saggers have a much longer life when used in gas-fired kilns, as there is less corrosive matter in the wasted gases. Unfortunately, the majority of the gas-fired kilns which have been placed on the market have not been satisfactory in regard to the first of these conditions, especially in the larger sizes, although the Dunnachie kilns have proved excellent for many classes of work. As is to be expected, the most successful gas-fired kilns are all connected in series, so that the waste heat from one may be used by another.

Gas-fired kilns are specially suitable for heating in a reducing atmosphere, which is much more easily obtained with a kiln of this description than an oxidizing atmosphere, which necessarily requires more air.

On the whole, gas-fired kilns cannot be safely recommended to firms with a small capital; but larger ones will often be able to effect a considerable economy by their use, although at the cost of much experiment and labour in the earlier stages.

The Output of Kilns is a matter of very considerable importance in these days of great competition, and the question of how it can be increased is one which is occupying the minds of many clayworkers at the present time.

The output of single kilns cannot, as a rule, be increased to any notable extent, but with continuous kilns there is considerable possibility of this being done. The most direct way of doing so is to increase the rate of travel of the fire, and great progress has been made in this direction of recent years. For instance, the older kilns would not permit the fire safely to travel forward at more than 4 or 5 yards a day, but in the more recent continuous kilns a daily speed of 10 or 12 yards is by no means uncommon, and higher rates are general in a few works. This means that a modern kiln has at least three times the output of an older one of similar capacity.

In many continuous kilns, the capacity of the chimney is the factor which regulates the output, because, unless the chimney is large enough, it is impossible to add to the number of chambers without lessening the draught. It is a curious fact that whilst most boilers are fitted with an excessively large chimney, in most continuous kilns the opposite is the case.

For this reason, the use of a small wide chimney and a good *fan* will often double or even treble the capacity of a kiln, and will probably improve the quality of the goods at the same time.

A defective foundation to the kiln (usually recognizable by the arch and upper portions of the kiln becoming red before the bottom) is a frequent source of diminished output. The steam rising from a defective sole admitting damp to the bottom of the kiln occupies space in the chimney which should be occupied by flue-gases, and the amount of heat required to volatilize this moisture prevents the kiln from heating as rapidly as it otherwise would do. Similarly, the capacity of a chimney is often seriously lessened by leaks in the kiln walls through which air is drawn in. This may be detected by means of a draught gauge applied to various parts of the kilns.

Wet fuel lessens the output of the kiln by taking longer to heat, partly because the water it contains has to be evaporated, and partly because it lessens the speed of travel of the fire.

Frit Kilns are used for melting materials for glazes (p. 25), and are of well-known construction. They usually resemble a reverberatory furnace, though some are heated from below. Owing to the excessively corrosive nature of the gases and materials, it is necessary to build the frit kilns of specially resistant fire-bricks and to lay them with the thinnest possible joints. Many makers lay the bricks in flint dust, as this does not shrink like plastic clay. The brickwork must be good and well laid; in other respects, their construction presents no special difficulties to the potter's builder. When heated by gas instead of with solid fuel they enable a cleaner frit to be produced, usually with a smaller consumption of fuel. In such cases, they may advantageously be fitted with a regenerator or recuperator.

CHAPTER IX.

FIRING.

In many ways the firing of boilers resembles that of kilns; the reader is, therefore, referred to p. 60 for information not contained in the present chapter.

In order that the firing may be efficiently carried out, and the kilns, or boiler, heated to the desired temperature with a minimum expenditure of fuel, it is necessary to consider the objects to be attained, and the changes undergone by the fuel in bringing these about.

Air-supply.—Taking coal as a typical fuel, the first change which it undergoes in burning is decomposition into a large volume of gas and a mass of practically non-flaming coke. The gas so produced will, in presence of sufficient air, take fire and burn with a brightly luminous or with a blue non-luminous flame, according to the proportion of air which has become mixed with it. The luminous flame is not possessed of such great heating powers as the blue flame, owing to its admixture with numerous particles of unburnt carbonaceous matter (soot) which are deposited on any cooler object which comes in contact with the flame. Soot is particularly difficult to burn, so that it is very important that all precautions should be taken to prevent its formation. Soot is produced as a result of a cold body being placed in a current of hot products of imperfect combustion. Hence, to prevent soot-formation, it is necessary to supply sufficient air to properly burn the fuel, at any rate until the goods are sufficiently hot for soot not to condense on them.

Although a blue, non-luminous flame is the hottest and best for boilers, it is usually too short to be effective in kilns, and, in order to produce a flame of sufficient length, a sufficient number of unburnt particles must be present in the gas after it leaves the combustion chamber. These particles will burn at some distance from the fireplace or gas-burner, and so lengthen the flame and enable it to produce results which are otherwise unattainable. For this reason, in gas-fired kilns, the use of a scrubbed or purified gas is seldom satisfactory, the best results being obtained with gas containing minute particles of tar, etc.

Carbon, on burning, may form one of two compounds with the oxygen of the air—namely, carbon monoxide and carbon dioxide; but the greatest heat is only produced when the dioxide is formed, hence, it is the object of the fireman to secure as plentiful a supply of air to the fuel as possible, at the same time avoiding such an excess as would waste heat by cooling the flame. As solid carbon when completely burned requires nearly three times its weight of pure oxygen, or twelve times its weight and 13,000 times its volume of air, it will be readily understood how large a volume of air is necessary for an ordinary fire. Yet seldom is anything like this quantity of air supplied to the fuel. As the gas is set free somewhat suddenly soon after the fuel is charged into the furnace, it follows that the greater part of this large volume of air will be required very shortly after the addition of fresh coal; and as the effective combustion of the gas depends upon each particle coming in contact with particles of air, it is equally clearly necessary that the air and gas must be well mixed before combustion can effectively take place. In the ordinary furnace, it is not possible to mix the air and fuel-gas as intimately as might be desired, as they cannot be sufficiently long in contact with each other for diffusion to take place completely; hence the advisability of dividing the air-supply into as many fine jets as possible. This may be accomplished in a manner suggested many years ago by C. W. Williams, viz. by boring numerous holes of about half an inch diameter in the door and front of the furnace, the total area of these holes being not less than half the area of the grate. If too many holes are bored, it is easy to close some by iron plugs; but in practice it will seldom be found necessary to do this. It is impossible for the air and coal-gas to be properly mixed by the common practice of opening the furnace door of a boiler, or if the mouth of the fire is filled with coal, as in many kilns at the present day. It is not so easy to supply sufficient air to kilns as to boilers, and reliance is generally placed on the flues, which are presumably made of such a size as to draw in sufficient air for the complete combustion of the fuel before it passes into the chimney.

In boilers, a supplementary supply of air is admitted at the 'bridge' or further end of the grate. If the supply at this point is properly regulated, almost all smoke may be prevented and a saving in fuel effected. This is the underlying principle of most systems of smoke-prevention—the use of a highly heated combustion chamber and an ample supply of air admitted in a suitable manner. In kilns, this question of the supply of air to ignite the gaseous fuel requires much more attention than it has yet received.

The coke remaining on the bars, after the gas has been driven from the coal, being solid, it is clear that the mixture with air can only take place at the surface of the fuel in contact with the air—that is, near the grate-bars. If these are unduly choked with clinker, the fuel cannot burn for lack of air; if, on the other hand, the fuel lies unevenly on the bars, and in some places does not cover them, air will rush through the uncovered portions and into the flues without properly oxidizing the fuel. It is, therefore, necessary to see that the bars are covered as evenly as possible with fuel; but the layer must not be too thick, or the air will be unable to penetrate it and incomplete combustion will result; about 7 inches of glowing fuel is usually sufficient if the coal is fed on to alternate sides of the fire-box, and the layer kept as level as possible. If a much thicker layer is used a semi-gas producer will be formed with all its resulting advantages.

The efficiency of the combustion can only be completely ascertained by a periodical analysis of the flue-gases (see 'Tests'), as carbon monoxide (the chief product of incompletely burnt coal) is invisible, and the absence of soot or smoke does not necessarily imply perfect combustion of the fuel. The presence of coloured smoke always indicates that some of the fuel has escaped burning, and is, to that extent, wasted, except in so far as a smoky atmosphere is essential to the colouring of the goods. To prevent this waste, the following conditions must be secured:—

1. A sufficient air-supply. If the fuel is not supplied with sufficient air, the gases will act as reducing agents, *i.e.* they will take oxygen from any coloured oxides present in the glaze and so spoil its colour, or the carbonaceous matter will not be burned out, owing to the lack of oxygen in the

gases, and any iron compounds will be more or less deprived of their oxygen, and will produce slag-spots.

2. Thorough admixture of the air and gases from the fuel.

3. A continuous high temperature in the fire-box so as to ensure the ignition of the gases.

4. As the solid portion of the fuel requires time for its combustion, sufficient grate area and flue space must be provided. The coal layer must be porous to allow the air to penetrate; yet no part of the grate must be left uncovered, and the fresh charges should be frequent and small, or the fuel on the bars will be cooled too much. For a similar reason, the fuel should be disturbed as little as possible, although with clinkering coals care must be taken that the supply of air through the grate-bars is not stopped.

5. The flame should be about 10 yards long with good coal; it should never be thin and short, nor wavering like a flag in the breeze, as this last implies that the grate is not evenly covered. It should be highly luminous, as, if dark and dull, an insufficiency of air is indicated. Whenever possible, sight-holes should be arranged so that the nature of the flame may be frequently observed.

6. Clinker must be removed before the bars are too much choked; but its removal requires care, or much smoke may be produced in addition to the cooling effect of masses of air passing through the uncovered bars. Clinker is sometimes a serious difficulty in firing, so that it is economical to pay a little extra for coal if by this means a better quality containing a less fusible ash can be obtained. Thus, with a coal having 12 per cent. ash, about one-eighth of the cost, including that of railway carriage, the cartage, transporting to the kiln, firing, and the removal of the clinker will be a dead loss as it will be expended wholly on worthless material. If a coal with only 6 per cent. ash is used, half of this expense will be saved, and this saving may more than pay for the extra cost of coal. It is, unfortunately, only possible to raise the fusing point of the clinker in a very few cases, so that the best way is to use coal with as small a percentage of ash as possible. The chief causes of clinker or slag are iron compounds, clay, and bases such as lime, soda, or potash in the coal. Where insufficient air is supplied to the fuel, the iron compounds are reduced to the ferrous state, and act as a powerful flux to any siliceous matter present, forming a fusible slag.

The two chief means of avoiding clinker are: (1) to keep the temperature of the fire sufficiently low to prevent the fusion of the slag, by injecting steam into the fuel, (2) to raise the fusing point of the slag by mixing sand or chalk (according to the composition of the coal ash) with the coal.

An excessive fire in a boiler is very wasteful in steam as well as in fuel, as the pressure of the steam is needlessly high. A sluggish fire is equally wasteful, as the steam is delivered at too low a pressure. It is, therefore, desirable to maintain a good, but not excessive, head of steam and to add coal to the fire in such a manner as to ensure this.

From the foregoing remarks, it will be seen that the operation of firing a kiln or boiler *efficiently* is a matter of some skill and care; and a manager who considers it a job to be given to any man who is strong enough to handle a shovel, will sooner or later find his mistake cost him dear in the deterioration in the quality of his goods or in a waste of fuel.

Draught may be produced by the difference in density of the air in the kiln and chimney and that outside (*natural draught*), or it may be produced artificially by means of an air-pump or fan.

In the case of a chimney, the velocity of the air passing through it is proportionate to its height and to the temperature of the air inside the chimney. It should not be below 5 feet per second. The air introduced artificially may be blown into the kiln or boiler furnace (*forced draught*) or it may be drawn through (*induced draught*). Induced draught is usually preferable where possible, as it produces a more regular distribution of the heat, and there is less wastage of power, but with old and leaky kilns forced draught is sometimes preferable; its use is the chief feature of the 'Boss system' of burning single kilns.

As the density of air decreases rapidly with increasing temperature, and as it is the weight of air passing through the chimney, and not its volume, that is of value, the drawing power of the chimney is greatest when its *mean* temperature inside is double the external temperature + 273, if the temperatures are measured in °C. This is calculated for three typical inside and outside temperatures in the following Table:—

TABLE OF MAXIMUM DRAWING POWER OF A CHIMNEY.

Inside temperature.		Outside temperature.	
°C.	°F.	°C.	°F.
323	613	25	77
305	581	16	60
273	523	0	32 (freezing)

The actual draught, measured in inches of water, may be calculated from the formula

$$d = h\left(\frac{7\cdot6}{a} - \frac{7\cdot9}{b}\right)$$

when d = draught in inches of water;
h = height of chimney in feet;
a = absolute temperature of external air (= °F. + 491);
b = absolute temperature of internal air (= °F. + 491).

If the internal gases are at a temperature of 600° F., and the external air at 60° F.,

$$d = h \times \cdot007.$$

The following table, due to Kershaw, shows the height of chimney required to produce a given draught:—

Height of chimney in feet.	Suction at base of chimney in inches of water, with exit gases at 600° F.
50	0·350
75	0·525
100	0·700
150	1·050
200	1·400
250	1·750
300	2·100

The effective draught at a boiler, kiln or furnace fire is always 35 per cent. to 40 per cent. less than the suction at the base of the chimney, and depends upon the length and area of the intervening flues and the state of the brickwork as regards leakage.

For a boiler, the area of the chimney above the level of the fire-bars is commonly taken as

$$\text{Area in square feet} = \frac{\cdot 06 \times \text{lbs. of coal burned per hour}}{\sqrt{\text{height of chimney}}},$$

but this must be taken as a minimum, and if the flues are over 100 feet in length, a greater area will be necessary to overcome the increased friction. For kilns, the results of this calculation must be at least doubled, as a much sharper draught is required, and the loss due to friction is much greater.

For kiln-firing, however, the height is usually of more importance than the area of the chimney. The construction of kilns varies so much that it does not seem possible at the present time to state definitely the minimum height permissible for a kiln chimney; 30–40 feet is customary for single kilns, and 90–160 for continuous ones.

A chimney which is too low or too wide will not produce a sufficient draught; it may often be remedied by placing an iron plate with a square or cross-shaped opening on the top of the chimney, the area of the opening being varied according to the draught required. If this does not prove to be satisfactory, auxiliary draught by means of a fan will probably have to be employed.

One great cause of loss of heat in the chimney is carelessly leaving open the furnace doors of boilers, and by allowing parts of the fire-bars to become uncovered with fuel both in boilers and kilns. It is almost impossible, even with the most carefully fired kilns, to avoid using one and a half, or even twice, the necessary (theoretical) quantity of air for the combustion of the fuel, and it frequently happens in practice that ten times the proper amount of air passes through the flues without the loss this entails being suspected. It cannot, in fact, be determined or controlled without frequent and periodical analyses of the flue-gases. The statement that "if the fires are properly managed, the flue-gases should contain 18 to 19 per cent. of carbon dioxide with traces only of the monoxide," whilst perfectly applicable to boilers, does not apply to many kilns. As mentioned on an earlier page, some goods require a large excess of air in order that, in burning, they may gain certain characteristics of colour, hardness, etc. Analyses of the flue-gases of kilns are not quite so necessary as those of boilers.

If the fireman has no means of getting his flue-gases regularly tested, he must take special care that the colour of his flame is right, and that it is never allowed to have a dull, smoky hue or show any other sign of an insufficient supply of air unless he is specially working under reducing conditions; on the other hand, he must keep a sharp lookout lest air rushes in through cracks and crevices in the masonry, impairing the draught and causing waste of fuel in the heating up of so much unnecessary air. For this purpose, a draught measurer is often employed. Very careful measurements with one of these instruments have shown that whilst the draught produced is proportional to the height and to the difference in temperature of the inside and outside of the chimney, yet the actual weight of gases passing up a chimney per minute is practically the same for all temperatures above 300° C., and there is, therefore, no advantage to be gained by exceeding that temperature.

In many forms of kiln it is essential that the goods should be 'set' in such a manner as to create an even draught throughout the kiln, as otherwise the temperatures attained will vary too greatly in different parts; it is here that skilful and careful setting is of importance, even for some common goods.

As leaky kilns cause loss of draught, all cracks should be stopped with clay,[1] and dampers should be kept in good condition. For a similar reason, the trial-holes should be opened as little as possible: a sheet of mica used as a window to the kiln will allow of the inside being seen without any cold air entering the kiln.

The regulation of the draught is chiefly made by dampers working in either a vertical or a horizontal direction (for some reasons the latter are to be preferred, as being better fitting). The proper use and value of dampers is not understood by far too many firemen, who look upon them simply as a means of closing the kilns when the firing has been finished (a curious idea!) or when a kiln is out of use. The chief uses of dampers are (1) to regulate the volume of gases passing through the kiln; (2) to control the temperature in the kiln; (3) to prevent unnecessary burning of the fuel; (4) to secure the proper admission of air to the fuel; (5) to prevent air entering into, or escaping from, the kiln in undesirable directions.

Without a draught-gauge it is extremely difficult to control the dampers properly, but if a suitable gauge is used the burner will soon see the advantages of correct regulation of the dampers. It is very important to have a man who thoroughly understands their working, or many ridiculous things may be done.

It is not always necessary to open a damper to increase the temperature in the kiln. At a late stage in the burning of some goods this is best secured by partially closing the damper, although as a general rule the wider the damper is open the greater the draught and the more intense the heat in the kiln.

When the goods are not too tender, or are well protected, a fairly high draught is a distinct advantage, as shorter time is required in burning and it is easier to ensure that the goods farthest from the fires are properly fired. There is, of course, more heat passing up the chimney, but in a continuous kiln, and sometimes in intermittent ones, this can be used effectively for drying. A high draught must be kept properly under control, or much damage may be done. For this reason, fans are more suitable than chimneys for creating a uniform, strong draught.

If too much draught is allowed the burner will have hard work to keep a sufficient heat in the kiln, as it flies to the chimney-shaft at once. It is not the heat in the fire-boxes, but that in the kilns, which effects the burning of the goods, and the burner must alter his dampers until the proper degree of temperature can be reached without unnecessary waste of labour and fuel.

Too little draught, on the other hand, will sometimes result in one part of the kiln being raised almost to white heat, whilst other parts are almost black. If cleaning the fire-bars does not mend matters, the damper should be raised, or, if it be already drawn out to its fullest extent, it probably means that the flues at the bottom of the kiln are filled with sand or are too small,

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[1] Or preferably with a mixture of equal quantities of fireclay and grog made into a paste with a mixture of equal quantities of water-glass and water.

or that the goods are set so closely together that no draught is possible between them. If the chimney-shaft is only short, it is often possible to increase it temporarily and so obtain a greater draught; but with a long shaft it is cheaper to allow the kiln to cool, examine it thoroughly, and, if necessary, re-set it. Sometimes the prolonged heating of the kiln will enable the goods to be as fully burned as if a higher temperature had been used.

It is not possible to give figures showing the actual air-pressure (draught) which should be maintained in all cases, as so much depends on the class of clay and goods in the kilns that the only way is for the clayworker to find out for himself by actual experiment how much air is necessary. About ½ inch of water column is very usual, but ¾ inch to 1 inch is better.

A similar remark applies to the temperatures to be reached in the burning. Seger has, however, given the following figures as approximately correct:—

Goods.	Seger cone.	Temperature in °C.
Porcelain colours and lustres, . . .	022 to 010*a*	600 to 900
Clays rich in lime and iron, . . .	015*a* to 01*a*	790 to 1080
Brick clays, clinkers, paviours, . . .	1*a* to 10	1100 to 1300
Stoneware with salt- or slip-glaze, . .	5*a* to 10	1180 to 1300
White-ware biscuit, ...	3*a* to 10	1140 to 1300
White-ware glost, ...	010*a* to 10	900 to 1300
Fireclay and porcelain, ...	7 to 20	1230 to 1530
For determining the refractoriness of clays,	26 to 39	1580 to 1880

The figures in the last column are only approximate, and it is always desirable to refer to the number of the cone rather than to the degree of temperature, especially with the higher numbers.

In most cases of clay-burning, the exact temperature reached is of less importance than the length of time the goods are exposed to a certain temperature—*e.g.* whether the maximum temperature is 1250° or 1300° C. matters less than the *time* of exposure at 1250°. The essential question is—"Has the heat been acting for a sufficiently long time?"

The Waste of Heat from the fuel may arise chiefly from: (*a*) Heat absorbed by the kiln structure. This depends on the amount of brickwork in the kiln or boiler setting, so that in a clamp or tunnel kiln very little heat will be absorbed, whilst in a down-draught kiln or Lancashire boiler the loss by absorption is usually 5 to 10 per cent. of the total heat.

(*b*) Loss of heat by radiation from the top and sides of the kiln or boiler. This loss is greatest when the kilns are built quite separately, and least when they are arranged *en bloc* as in a continuous kiln or a battery of boilers. The normal loss by radiation in single kilns varies between 40 and 65 per cent. of the total heat supplied. Some of this can be avoided by building thicker walls and crowns, or still better by the use of bricks made chiefly of kieselguhr between the interior and exterior of the kiln. The radiated heat may sometimes be used, instead of being wasted, by erecting a dryer round the kiln. The greater part of the radiation is from the crown, and it is advisable to have this covered with kieselguhr or to use some kieselguhr bricks in its construction. With well-covered boilers, it ought not to exceed 7 per cent. of the total heat. Loss of heat through cracks in the walls may also be included under this heading.

(*c*) Air entering the kiln through cracks or other defective brickwork cools the gases and so causes a loss of heat. This loss is very small in new, well-built structures, but increases rapidly if they are neglected, so that kilns and boiler settings should be thoroughly inspected periodically, and any defects such as cracks should be remedied.

(*d*) Loss of heat retained by the ashes and clinker, which is practically negligible so long as the ashes contain no unburnt fuel, as it seldom exceeds one-fifth of 1 per cent. of the total heating power of the coal. If, however, unburnt fuel finds its way into the ashes, the loss may be increased indefinitely —sometimes amounting, when very small coal is used and the fires badly cleaned, to nearly half the heating value of the coal. With continuous kilns, this may be due to stoking a new row of fire-holes before the kiln is hot enough, or to putting too much fuel into the fire-holes just before finishing, or to the use of too little air. In each of these cases, coke will be found among the ash.

(*e*) Loss of heat carried by the flue-gases up the chimney. This loss varies greatly according to the control of the firing, but with reasonable care it generally works out at 45 to 65 per cent. of the total heat in single kilns and 20 to 35 per cent. in continuous kilns.

As the efficiency of a chimney depends chiefly upon the difference in temperature and density of the flue-gases and that of the outside air, the flue-gases must be hotter than the air outside; the exact difference in temperature will depend on the temperature required in the furnace and on the amount of heat which is allowed to escape. As a general rule, it may be understood that a temperature of 250° to 300° C. is amply sufficient, with a well-constructed chimney, to secure a good draught, and any considerable excess of temperature over this should, if possible, have the attention of an expert, who will endeavour to make use of the heat thus being wasted. So much depends on the nature and state of the kilns and furnaces, and their positions relative to the chimney, that it is almost impossible to suggest the best means of utilizing this excess of heat without being on the spot; the heating of drying rooms or of the feed-water for the boilers are the commonest applications of the waste heat, but great care is required in the former that no leakage occurs, or the draught of the kiln may fail at a critical moment.

(*f*) Loss of heat retained in the fired goods is much less than is usually supposed. If the kiln is finished at 1130° C. (2060° F.), the heat in 1 ton of goods will be equal to that given out by about 64 lbs. of coal. The best use of this heat is in a continuous kiln or in a dryer.

For successful firing, it is necessary to consider what goes on inside the kilns, and to know something of the changes which take place in the constitution of the goods placed therein. These changes may be grouped under four main heads:—

1. Drying.
2. Eliminating volatile and combustible matter.
3. Burning proper or 'Full Fire.'
4. Glazing.

Drying.—The greater part of the water should, of course, have been dried out of the clay before the goods are placed in the kilns; but even when the goods are 'bone dry' they still yield up to 15 per cent. of water when they are heated for some time to a temperature above 500° C., *i.e.* approaching a dull red heat. This 'water' appears to be combined with the clay in some way, as after it has once been removed the clay can no longer be made plastic by the further addition of water, as is the case if the goods are merely dried in the ordinary way at a low temperature.

The ordinary fireman never seems to realize how much water there is in the goods in a kiln; 300 lbs. per ton of goods is by no means an uncommon quantity, and as each pound of water forms roughly 27 cubic feet of steam, this means that over 8100 cubic feet of steam must be driven out of each ton of goods before the firing proper can commence! Hence, the necessity for ample ventilation inside the kilns (especially with muffle kilns), and for sufficient time being allowed to effect the evaporation of the water without causing it to boil and so spoil the surface of the goods. It is on this account that a 'smoky' fire is used at the commencement of the firing.

Whilst, generally speaking, damp goods should never be placed in the kiln, it may sometimes be necessary to break this rule. In such a case, the damp goods should be placed as near the top of the kiln as possible. Even then there is considerable risk of the goods being spoiled.

It is not always easy to tell how long to keep on the 'smoking,' the usual English practice, of putting a cold bar of iron into the kiln and noticing whether any moisture condenses on it, being a very rough and by no means satisfactory test. When it can be managed, the temperature should be measured by means of a registering (maximum) thermometer attached to a light chain; it should increase steadily from the start, and the 'smoking' should not be stopped before the goods have reached a temperature of 120° C. (or 250° F.). If it is possible to draw a weighed 'trial' or two occasionally and to continue the drying until these cease to lose weight, more satisfactory results are likely to be obtained.

Much of the splitting of so-called delicate clays is due to a lack of sufficient care in the drying, or 'smoking,' so that the outside of the goods is dried too quickly, with the result that internal strains are set up in proportion to the 'closeness' or density of the clay, its thickness, and the rate of drying (see Chap. V.). The smoking stage is really a continuation of the drying, at a rather higher temperature, in order to remove the last traces of water from the goods.

In continuous kilns, especial care must be taken with the 'smoking,' as there is a tendency to unduly hurry this operation with such kilns. It is only in exceptional cases that goods can be efficiently dried (smoked) in less than forty-eight hours.

If the smoking is ineffectively carried out, the goods are apt to 'fly,' or unpleasant condensation products (*scum*) are formed on them, no matter how carefully they may be fired later. If the steam from the goods were to condense as pure water, no further damage would result than that caused by the softening of the goods; but, unfortunately, the water thus condensed is never pure, but is of a distinctly acid nature, chiefly owing to the sulphuric acid produced by the oxidation of the sulphur in the coal. (A test recently made showed that this condensed water contained nearly 30 grains of sulphuric acid per gallon.) Alkaline sulphates, hydrochloric acid, and ammonium chloride are also frequently present in the flue-gases and tend to cause discoloration or scum.

As it is the air passing through the kiln during the smoking which really carries off the steam and other volatile matters, it is necessary to allow it sufficient passage; the damper the goods the more air will be required. As soon as the goods have reached a dull red heat the draught may be adjusted to secure the most economical burning of the fuel.

It is scarcely necessary to point out that the increase in heat during the smoking should be as regular as possible. A thermometer attached to a light chain can be conveniently used to ascertain the temperature up to 300° C. (570° F.).

All 'patent' methods for carrying out the earlier stages of firing continuous kilns safely have the same objects, viz. the separation of the period of 'smoking' from that of true firing, and the removal of the water-vapour from the goods through special openings in the kiln. As the contraction of the air through loss of heat (due to the evaporation of this water) is greater than its expansion (due to the addition of the vapour), the air used for smoking becomes specifically heavier than it was when first introduced, and its natural way of travel is downwards, but it is usually expelled through pipes in the arch of the kiln. A detailed consideration of the advantages and disadvantages of removing steam from the upper and lower portions of a kiln respectively is beyond the scope of the present work.

Methods of smoking are very varied; they may, however, be classed in two main groups:—

(1) The use of a special stove ('stoving') or a wicket-fire.

(2) The use of pure air drawn over hot goods in the kilns with a view to cooling them.

The second method is preferable so far as it is applicable,[1] because the air is simply heated by contact with the hot goods, and therefore undergoes no contamination by flue-gases, etc. It is merely necessary to exercise care that the gases are not too hot when they are turned on to the newly set goods, or the latter would crack. The difficulty of applying this method lies in the fact that in many kilns the supply of clean, hot air is not sufficient for the proper heating of the new goods to 120° or 130° C., and it must, therefore, be supplemented by the first method or by air heated in flues above the arches or below the floor of the kiln.

Briefly, true 'stoving' consists of the use of a fire in the 'wicket,' or doorway, of a continuous kiln or in one or more fireplaces of an intermittent kiln, the heat from this fire being purposely kept low. Sometimes it is preferable to use a portable stove (of iron) burning coal or coke. In each case, the fuel is used to heat a large supply of air which can be drawn over it into the kiln. As already suggested, the objection to using this method is that the products of the combustion of the fuel in the stove are mixed with the hot air, and that, consequently, great care is required to prevent acid condensation products forming on the goods and discolouring them. This is one of the chief reasons why waste kiln-gases cannot be used at such an early stage of the burning; they contain too much water and too much acid. It has been calculated that a cubic yard of kiln-gases saturated at 212° F. and cooled to 194° F. will deposit no less than 6 oz. of water.

The advantages of a stove are that it may be so constructed that instead of all the air being heated by passing through the fuel, some of it is heated indirectly so as to keep it free from combustion products. The exact proportions of fuel and air required for the 'smoking' varies with the

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[1] Many clayworkers fail to appreciate the value of hot-air flues, and some go so far as to declare them useless!

temperature of the goods in the kiln when the 'stoving' is begun and with the skill of the fireman, for it must not be forgotten that this early stage of firing requires just as careful attention as the latter ones.

The following example will indicate how the *minimum* quantities of air and fuel may be calculated; but it must be borne in mind that the figures obtained by calculation are the very lowest possible, and that in practice they will probably have to be increased by at least half their value, and in most cases may, advantageously, be doubled.

Assuming that one chamber holds 10,000 bricks, each weighing 7 lbs. and containing ½ lb. of water, it will be necessary to heat 65,000 lbs. of clay and 5000 lbs. of water 212° F., a rise of 152° F., and also to evaporate this water. For driving off the water, two quantities of heat are necessary :—

(*a*) For raising its temperature to 212° F., 5000 × 152 = 760,000 B.T.U.; and

(*b*) For converting it into steam, 5000 × 967 = 4,835,000 B.T.U. (latent heat).

The bricks will require an additional 65,000 × 152 × 0·2 = 1,976,000 B.T.U. for heating the clay to 212° F. (the sp. heat of clay being 0·2), and the total amount of heat needed will be *at least* 7,571,000 B.T.U., which is equivalent to 5 cwt. of coal, or 56 lbs. of coal per thousand.

If, in passing through the chamber, the air falls 100° F. in temperature, the amount of air needed will be at least 7,571,000 ÷ (100 × 0·24) = 315,458 lbs. of air; which, if the smoking takes 48 hours, represents 6572 lbs. of air per hour, or nearly 1500 cubic feet per minute.

If the goods had been raised to 112° F. by hot air from the cooling kilns and a proportional quantity of water had been evaporated, only 350 lbs. of fuel would have been needed.

Eliminating Volatile Matter.—At the close of the 'smoking' stage the goods are dry and hot, but some water—the 'water of combination'—and most of the organic matter still remain. These must be removed by an increase in temperature, and this is accomplished in the 'burning,' where bright fires are used instead of dull, smoky ones.

It is convenient to consider the rise in temperature from the close of the 'smoking' (120° C.) to the attainment of a dark red heat (900° C.) as an independent stage in the firing, though there is no sharp line of demarcation. During this stage of burning the following reactions usually take place: (1) decomposition of the clay with the evolution of water; (2) decomposition of other minerals with the evolution of any volatile matter; (3) combustion of vegetable, animal, and other carbonaceous matter, with the evolution of water, various gases and volatile matter; (4) oxidation of the iron compounds to the ferric state; (5) evolution and oxidation of sulphur from pyrites causing the formation of sulphurous gases and ferric oxide: ferrous oxide may also be formed accidentally; (6) conversion of chalk, limestone and other calcium, magnesium and iron carbonates into oxides; (7) inversion of quartz and flint into crystobalite; (8) partial fusion of some of the more fusible constituents of the 'clay,' followed (as the temperature rises) by the corrosion of the refractory material.

The completion of this stage is accompanied by the removal of all the volatile matter and the loss of plasticity, resulting in the conversion of the 'clay' into a hard, partially petrified material.

At the commencement of the 'burning,' or even towards the end of the 'smoking,' the organic matter in the clay, together with any gelatin, or gum, which may have been used in the slips, will commence to burn, but these substances are usually present in such small proportions that no special care is needed. With clay containing much added sawdust, coal, or peaty matter, however, the case is different, and unless the kiln is very carefully managed the goods may 'catch fire' and get overheated. With such clays, it is necessary to keep the temperature as low as possible during the smoking, and to largely exclude air at the earlier stages of the burning, so as to keep the temperature well under control. With clays of this kind great care and experience are essential to success, as too little air-supply will cause loss of heat, whilst too much may result in over-firing.

The rise in temperature should be steady and only moderately rapid with unglazed goods; with glazed ware previously biscuited a more rapid heating is desirable. If a clay contains much organic matter, a prolonged heating between 800° to 900° C. is usually necessary in order that this matter may be removed before the firing is allowed to reach a further stage, as otherwise *black cores* will be obtained.

These cores are due to reduced iron compounds (ferrous silicates) and to carbon in the pores of the material, and if the heating is prolonged sufficiently, with an ample supply of air, they may be burned out at a dull red heat. If, on the contrary, the temperature rises sufficiently for vitrification or partial fusion to take place, it will be almost impossible to prevent the formation of these black cores (see pp. 8 and 182).

Most burners have learned to 'soak' their kilns, but many of them fail to understand the nature of the changes which occur, and so they 'soak' at too low or high a temperature. *Soaking* may have one or two purposes—it may be used to fully oxidize any reduced or organic matter in the goods (in which case the temperature should not be below 800° C. nor exceed 900° C.), or it may be used to effect certain changes, such as vitrification, which it would be risky to attempt by allowing the temperature of the kiln to continue to rise. It is well known that a prolonged heating at (say) Seger cone 5*a* will produce the same effect as a much shorter heating at cone 9, but the former method will require more fuel than the latter, as the time required is so much greater. It is seldom necessary to occupy more than 48 hours during this stage of burning: in fact, it may be completed in 8 hours with goods of open texture. If the clay is liable to form a core, several days may be required for this stage of burning.

No good purpose is served by very slow heating between the conclusion of the 'smoking' and a full red heat (1000° C.). On the contrary, the temperature should be raised as rapidly as the goods will stand to 800° and then raised very slowly to 900° C. It should not exceed this until trials drawn from the kiln and broken show no trace of a 'core.' After this, the temperature may be again raised rapidly until the point of incipient vitrification is reached. It depends upon the nature of the goods whether a second 'soaking' is desirable at this stage. Care must, however, be taken that this final 'soaking' does not damage the goods, and, in the case of goods baked and glazed in one firing, to deaden or dim the glaze seriously. During the elimination of organic matter, etc., the rapidity of the heating is also dependent on the amount of shrinkage undergone by the clay. This varies greatly, but is generally small at first and increases rapidly with increasing temperature until the point of vitrification has been reached. This may occur at as low as 700° C. if the proportion of alkalies in the clay is large, but, in the case of fireclays practically free from alkalies, a temperature of 1600° C. or over must be reached before any vitrification can be detected.

With the diminution of volume the clay increases in density; but these two changes are not directly connected with each other in every case, as the formation of air-spaces in the clay, whilst not appreciably affecting the volume, has a noticeable effect on the density, so that certain clays (kaolins, for example) at high temperatures lose both in volume and in density.

Full-Fire.—There should be no sudden rise in the heating of a kiln, yet the object of the firing changes somewhat as soon as the goods have reached a dull red heat and all the combustible and volatile matter have been removed from the clay. In this the last stage of firing, the nature of the gases inside the kiln becomes of importance, as some clays, particularly those rich in sulphur compounds, require to be first heated in a reducing and then in an oxidizing atmosphere; with others the operations of oxidizing and reduction must be carried out in the reverse order, whilst still other clays must be heated under oxidizing conditions throughout. This is obviously a matter which each manufacturer must determine for himself as the most suitable for his particular class of work; and, having once determined his best method of working, he should see that it is carried out.

Too many firemen fail in their work because they will insist on firing at too long intervals and putting on too much fuel at a time. By so doing, perfect control over the temperature of the kiln is lost, and trouble is sure to ensue sooner or later.

Regularity of heating and a careful regulation of the air-supply are likewise necessary if the best results are to be obtained. The stoking should be done very skilfully; many goods are spoiled through the fire-bars not being kept properly covered, especially with a caking coal on a windy day. It is always best to stoke lightly, frequently, and evenly, and the fireman should give his fires constant attention without wasting fuel by too much poking.

The final temperature to which goods must be heated in the kilns naturally varies with the different kinds of clay and glaze, but to obtain ware of the maximum strength and durability the clay must be heated until a certain proportion of the constituents have fused sufficiently to cement the more refractory particles together. The temperature, however, must not be so great as to allow the article to lose its shape, though it must be sufficient to cause the complete fusion of the glaze, which must remain fused sufficiently long for any bubbles which may have been formed in it to escape.

The rate at which the glassy mass forms depends on (1) the proportion and nature of the fluxes in the clay or body and the products formed at various temperatures; (2) the temperature of the ware; (3) the duration of heating; (4) the size of the individual grains; (5) the uniformity of the mixture and the distance of the grains from each other; (6) the nature of the atmosphere in the kiln.

Hence, the firing should be very carefully controlled, so as to melt the glassy matter and burn the body to the right state of vitrification at the same temperature. In order to determine the temperature to which a clay must be heated to attain its maximum durability, which is usually the point of incipient vitrification.

In most cases, the appearance of a freshly-broken piece of fired ware will enable the clayworker to judge of the correctness or otherwise of the firing. Bricks and fireclay ware should be porous, yet not too spongy; earthenware should give a fracture not unlike that of a piece of freshly-cut cheese, with a slight yet noticeable gloss; while porcelain and stoneware are not porous, and the glossiness of the fracture is more pronounced than that of earthenware.

In the *finishing* of the firing much skill is required. Some workers prefer to close all the mouths of the kiln completely as soon as the desired temperature has been reached or certain characteristics in the goods have been obtained, and to allow any subsequent increase in temperature to effect the maturing of the glaze and the cementation of the refractory particles of the biscuit. It will be seen that this method of working has a large element of chance in it, as the increase in temperature so obtained by closing up the kiln will vary with the amount of fuel on the bars, with the draught, and with the speed at which the temperature has been increasing prior to the closing. At the same time, this method has the advantage of allowing the kiln to be left at a much earlier time than with other methods of finishing, though it is obviously only suited for a somewhat rough class of work.

Other workers insist that all fires should be drawn as soon as the necessary temperature is attained, and argue that, by closing the fire-boxes whilst much fuel is in them, a reducing atmosphere, which is in some cases undesirable, is produced. On the other hand, too rapid a withdrawing of the fires may lead to cracking of the goods, so it is best to regulate the firing so that when the desired temperature has been obtained it may be kept up for as long as may be necessary for the maturing of the glaze or the cementation of the biscuit, as the case may be, and then to let the fires die down somewhat before the fire-boxes are closed. Overburning should be avoided, as it may cause the articles to be excessively dense or even to lose their shape. Underburning should also be avoided, or the articles will be very weak or deficient in density. Underburned clays containing lime are very troublesome, as the lime slakes on exposure to weather, causing the goods to 'burst' or spall. As such clays lose their shape very rapidly if slightly overheated, great care is needed in burning them.

Glazing.—Firing glazed goods may be carried out on either green or biscuit goods. One single firing is better than separate firings for biscuit and for glaze on account of its economy, and because it ensures the use of an engobe and glaze of such a nature as to make their union with the body of the ware more complete than where different firings are employed. The case of glazed bricks appears to be an exception to this general rule, as, owing to the difficulty of disposing of second and third qualities of these goods, it is necessary to select the bricks for glazing with great care, and this can in many cases be done more effectively after the bricks have been fired once, as bricks which are quite unsuitable for glazing owing to slightly chipped arrises, etc., find a ready market as fire-bricks or building bricks. Damaged glazed bricks, on the contrary, are usually unsaleable.

Considered apart from the firing of the ware itself, the burning of glazed goods requires little explanation. Its chief difficulties lie in the production of a steadily increasing temperature, in maintaining it for as long as may be necessary for the proper development or maturing of the glaze, and the retention of the correct atmosphere (reducing or oxidizing) inside the kiln. This question of the atmosphere is especially important in the case of coloured glazes, for many substances used as glaze-stains are profoundly modified in colour by the nature of the atmosphere in which they are heated. Thus, chromium compounds are green in a reducing atmosphere, but red or buff in an oxidizing one; lead glazes may be blackened in a reducing atmosphere, and manganese and cobalt compounds form bubbles of oxygen if the glaze is heated too long in an oxidizing one. Hence, it is impossible to fire all kinds of colours at one time in a kiln. Steady firing is essential for glazes, or the ware may be blistered or 'feathered.' Very slow firing is detrimental to glaze, so that the firing should be as rapid as possible without damaging the ware.

When the glaze is applied to ware which has previously been burned ('biscuit'), there is no risk of the formation of 'cores' (p. 182), so that 'soaking' is unnecessary except in so far as it is desirable to allow the glaze to mature. Prolonged heating of glazed goods should usually be avoided, as it does little good and may easily remove the glossiness and produce dull wares.

The remarks about the closing of the kilns apply equally to glost as to biscuit ovens, but the evil results of a bad 'finish' are far more noticeable in the former than in the latter.

As so much depends on the nature of the glazes used, no general details can be given as to the best way to fire a glost kiln, except that it is often well to follow Seger's advice when using coloured glazes, and to commence the firing with a reducing or smoky flame up to a temperature corresponding to cone 1*a*, and, in this way, to remove the evil effect of any sulphates which may be present, but to employ an oxidizing flame before the glaze begins to melt, and to continue this to the end of the firing. This rule will not, however, apply to all cases. It is also well to remember that in the majority of glazes the more rapidly they are fired the better will be the result, as prolonged heating dulls the lustre of the glaze.

The greater part of successful firing depends on the watchfulness, care, and skill of the fireman. A good burner is a treasure not lightly to be discharged; a bad one is an unmitigated evil. A first-class burner is one who is able to get his kiln heated evenly throughout, or who, in pottery kiln-firing, can get the different parts heated to just the right points; can detect any notable change in the draught or heat of the kiln by observation, and handle his fire accordingly; and, lastly, who knows when to stop firing and how to close down. Most burners would be assisted by the use of a sufficient number of trial pieces, Seger cones, or pyroscopes to enable them to judge the temperature and progress of the burning. Many burners will not use these aids for fear of being thought ignorant! It would be much better for all concerned if no firing was ever stopped until trials from all parts had shown satisfactory results.

Some of the results arising from improper firing will be found under the head of 'Defects' (p. 179 *et seq.*), and some of the principal characteristics of glazes and engobes will be found enumerated on pp. 17 to 20.

Cooling.—The essential point in cooling the goods in the kiln is to secure speed with safety. If too rapidly cooled, the goods will dunt or crack; if the cooling be unduly prolonged, time will be lost. It is for each clayworker to determine for himself what is the minimum time in which his kilns can be safely cooled. It is as necessary to take precautions for the regular cooling of the goods as it is for their regular heating; draughts are particularly to be avoided. Under normal circumstances, it is usually possible to cool the kiln very quickly between the finishing point and 900° C., but when the latter temperature is reached the cooling should be slower. Many workers cool their kilns carefully at first, but unduly hasten the later stages, with consequent loss of goods; for it is when the goods have cooled to below a bright red heat that cracking mostly occurs, sometimes, owing to opening the kiln too soon, and at others by withdrawing the goods before they are sufficiently cold. It is a good plan not to pull down all the doorway at once, but to take out the top quarter first, and leave the rest until the following day.

Where it is important to cool the kilns as rapidly as the contents will permit, it is desirable to use a recording pyrometer and a standard cooling chart (corresponding to the heating chart described on p. 307) and to insist on the men working to this. In some cases, cooling may be hastened by blowing air into the kiln, but this should only be used in connection with a definite schedule, or much damage may be done.

Some glazes require to be cooled rather rapidly at first and more slowly later, in order to prevent the formation of crystals. The 'danger zone' varies with different glazes, but if cooled rapidly to 1000° C. very few glazes will crystallize. From the temperature of solidifying to that of the atmosphere the glazed goods should be cooled more slowly, or they will crack or craze. The few investigations which have been made on the effect of cooling ware at different rates during various stages of cooling show that there is scope for a very careful study of this subject. At present there is not sufficient information for any precise statement to be made on the various rates which should be adopted; they appear to differ with each class of ware.

CHAPTER X.

DISCHARGING, SORTING, PACKING, AND DESPATCHING.

Discharging or emptying the kiln is the last operation in the manufacture of clay wares, and is one which presents no special difficulty to men used to the work. The bricks composing the doorway should be piled neatly on one side for future use.

As the goods from the kiln are in many cases 'finished articles,' the greatest care should be taken in discharging, as carelessness at this stage causes greater loss than at almost any other. This is particularly the case with glost goods which have been through two or more kilns, according to the colours they carry. In brick and tile manufacture, a lamentable degree of carelessness is often shown in handling the finished goods, and much loss is thereby sustained. The damaged arrises so frequently seen are often due to the bricks being discharged too hot for the men to handle them properly, but insufficient supervision is also a prominent source of loss in this department.

In many cases, the saggers containing ware are difficult to separate; it is better to give them a sharp blow with a hammer rather than to attempt to prise them asunder by means of a chisel. The latter may be usefully employed in removing small pieces of clay, etc., adhering to the goods. Before refilling, the kiln must be thoroughly cleaned out.

Sorting requires skill, so that the sorters should be carefully chosen and well paid, as carelessness on their part is often troublesome to remedy and a fertile cause of annoyance to customers.

The sorting-room should be of ample size and well lighted, preferably from the north.

The goods should be roughly sorted as they come from the kiln, and should be so arranged that the sorters may handle them as little as possible, for handling costs money. The defective goods should be placed in groups according to (*a*) their faults and (*b*) the men responsible for them. Articles with defects which can be remedied by grinding, re-glazing, etc., should be kept distinct from those which are worthless, but it is well to take all goods from the kiln to the sorting-room—unless exceptionally heavy,—so that an accurate check may be kept on the disposal of the goods.

Where sanitary ware and other large articles are made, it is convenient for a responsible sorter to stand at the kiln and direct the men emptying it as to the destination of the goods.

Bricks, tiles, and terra-cotta generally should be sorted with the aid of a gauge in order that articles of different sizes may not be sent to the same job. Coloured goods should be compared with a standard colour, so that, in the event of any inquiry, the sorter cannot plead 'misunderstanding of instructions.' In any case, the manager of the works should frequently visit the sorters to see that they are working properly, and should take care that they are not kept too long at one colour, or they are bound to work badly owing to their eyes becoming fatigued to that colour, and so less able to detect small variations from it.

Stacking requires forethought, judgment, and discretion so as to enable any goods which may be required to be obtained at once and without the removal of other goods. The nature of the site used as a stacking ground is important; it should not be damp[1] or exposed unduly to wind, especially if the goods are hot when discharged from the kiln.

Bricks, drain-pipes, and other building materials are usually stacked in the open air, but it is much better to keep them under cover. They should not be placed directly on the ground, as bricks which are saturated with moisture are less saleable than dry ones.

The goods may be laid on well-tarred planks, preferably raised a few inches above the ground level by supporting them on spoilt bricks. They may be set quite close together, though it is usually advisable to leave a little space between them. If they are not stacked in a shed they should be covered over with tarpaulin.

No goods must ever be allowed to rest on ashes or cinders. If they are glazed, they are too valuable to run the risk of scratching by pieces of clinker in the ash; whilst if unglazed, they are extremely likely to 'scum' if they absorb any salts from the ash.

Changes in the stock should be accurately noted as they occur, so that the stock sheet shows the actual goods on hand at the close of each day. An occasional checking by actual count is desirable, but it must only be a check, and must not take the place of accurate record-keeping.

Packing requires more or less skill according to the nature of the goods. The tendency to waste packing material should be strongly discouraged, but undue 'economy' will result in breakages in transit. Speed in packing and despatch is greatly facilitated by a well-constructed shed into which the carts or trucks can be run and loaded, the floor of the shed being at the most convenient elevation for this purpose. It pays to have this shed protected from the weather so that the packers are kept dry, and do not, as in some places, have to work in a mass of wet straw and slop.

Packers are paid on either time or piece; the latter is preferable where it can be arranged, though it is often difficult to fix a price which shall be equally fair to master and man.

When packing bricks, it is a good plan to lay the bottom course on end at an angle of about 45° to the bottom, but parallel to the sides of the cart. The next course is laid at right angles to the lower course, and rests on it. This alternate arrangement is continued until the vehicle is full.

In a railway truck or cart with vertical sides, the bricks should be laid with their length across the vehicle and should be kept tightly in position with a wedge or roll of straw forced into the end of each row of bricks. The object, in each case, is to enable the bricks to be piled into a solid mass without any fear of their being damaged by shaking whilst on their journey.

Despatching.—When a number of packages are sent regularly to any particular place it is advisable to make arrangements with the railway company with regard to the rates, otherwise the cost of despatching will be much greater than is necessary. Where a through rate is not paid for, a special charge is made at each exchange station, and these charges mount up

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[1] Goods stored on damp ground are very liable to 'scum.'

seriously, with consequent loss to the firm. A little ingenuity in the selection of a route, or of packing the goods for separate orders in such a way that they may travel over as much of their journey as possible as a single load, being afterwards subdivided by the railway company, will often make a great difference in competing for business at a considerable distance from the works.

The secret of successful despatching lies in a simple but sound planning system, whereby the various men concerned may know exactly how the goods they require are progressing and where they are to be found. The haphazard or expedient methods usually adopted in clayworks inevitably break down whenever there is a rush of orders.

CHAPTER XI.

DEFECTS.

THE following list contains, in alphabetical order, the different defects more commonly met with, but by the nature of the case it cannot be complete.

Absorption of glaze by the body of the goods being too porous is usually the result of insufficient firing in the biscuit kiln. If an insufficiently thick coating of glaze be applied, a similar result will be obtained. Excessively prolonged heating of the goods in the glost kiln will cause a partial volatilization of the glaze, whilst if the ware be placed too near unglazed pieces (*e.g.* the walls of the kiln) the glazed goods will be 'dry,' or, as is sometimes said, the body will have 'sucked in' the glaze.

Black portions on burned articles may be due to faulty firing (see 'Cores,' p. 182), to something falling on the goods and so discolouring them (see 'Discoloration,' p. 188).

Blinding of the glaze, though differing somewhat from mere turbidity, is largely produced by the same causes; the term, however, is usually confined to a peculiar turbidity brought about by the formation of minute crystals on the outer surface of the glaze, so that the latter has a curious 'matt' appearance. Certain leadless glazes containing a large proportion of chalk or whiting and a small proportion of alumina are especially liable to this defect if they are kept too long at a temperature above their melting point. The remedy consists in the addition of clay to the glaze, and a considerable shortening of the time of 'maturing' of the glaze. Where the blinding is due to reducing conditions a gentle current of air passed through the kiln from the end of the firing until the goods are at a dull red heat usually assists in preventing the defect, provided that the firing has not been too vigorous at the last.

The use of wet saggers, or of damp fuel after the glaze has begun to melt, will also tend to blind the glaze.

Blisters or **Blebs** are commonly the result of too high a temperature in the kilns, and, less frequently, of air confined in the clay (due to excessive or insufficient pugging), which expands with the heat and raises a small lump or blister. Glazes heavily charged with metallic oxides (for colouring), or with carbonates, will sometimes 'boil' or blister if placed near to a mass of unglazed ware. If, towards the end of the firing, the temperature of the kiln be allowed to drop and be then suddenly raised, blisters are often formed, especially in coloured ware. (See also 'Spitting,' p. 209.)

Blisters in pipes and terra-cotta are often due to the clay being insufficiently pugged or incompletely mixed in the pan mill, and especially to the use of clay which has been in contact with oil and soon afterwards put back into the pug mill instead of allowing the clay to dry thoroughly so that the oil may evaporate before using the clay. Blisters are also caused by insufficient care when a plastic clay is extruded through a steam or hydraulic pipe press. Thus, if the head is allowed to slap down on to the body of the clay in the cylinder, air is included in the clay and causes the surface to blister as it issues from the die. If this condition arises and it is desired to save a particular run, a man may be set to puncture the blisters and smooth them down, but this is too costly for all but special work.

Blistered bricks are but seldom the result of putting damp goods into the kiln, as is so often supposed, but are usually due to the fatty nature of the clay or to vegetable matter it may contain. The remedy is to clean the clay from roots, etc., more effectively, or to add grog or lean clay. Lean, short clays, when put into the kilns in a damp condition, do not blister, but crack or fall to pieces. It has been frequently found that the addition of leaner clay or grog in order to produce a more open body will usually remedy the evil.

Blistering may also occur at quite four distinct periods of the burning, viz. during the (1) water smoking, when too little time is allowed, (2) oxidation period when this is hurried, (3) period where sulphur gases are expelled, (4) incipient vitrification period.

In order to intelligently investigate these different periods, a pyrometer and draught gauge are essential. In order to prevent repetitions of errors in burning, fixed burning schedules are necessary.

Blotches of colour on the goods may be produced in a variety of ways. With *unglazed* goods, they are usually due to the use of a reducing fire, or to an insufficient supply of air to the kilns (see p. 171), or to an excessive proportion of iron pyrites in the clay. Highly carboniferous shales require prolonged heating, with an abundant supply of air, to prevent their discoloration and the formation of black 'cores' (p. 182). Copper or iron oxides, or similar compounds which have coloured silicates, will also discolour clay, as will various kinds of dirt introduced by the carelessness of the workmen. When iron compounds are heated with an ample supply of air they tend to be of a red colour (or pale cream in the presence of lime), but heated in a 'smoky' atmosphere they lose oxygen, often absorb sulphur, and produce dark grey or even black substances, which form a clinker-like mass on the surface of the goods. What is known technically as 'flashing' (*i.e.* the effect of flame on the goods) will often produce blotches of irregular colour, due to a similar cause, the flame itself being deficient in oxygen, reducing iron and other compounds to undesirably low states of oxidation, and in some cases causing a slight deposit of soot on the goods which the conditions of the subsequent firing fail to burn away.

With *glazed* goods, blotches of colour may also be produced by the reducing action of the fire, by insufficient oxidation of the iron in the clay, by the defective mixing of a coloured glaze, by the careless application of colour to the goods, or by perspiration (or oil) getting on to the goods, and preventing the even distribution of the glaze. In such cases, the cause having once been found, the remedy is obvious.

Gypsum in the clay will, under reducing conditions, lose oxygen, and form a black calcium sulphide, with some proportion of silica, and so may produce dark blotches.

Some colours are easily volatilized in the kilns; these should not be placed near to white ware or ware of very delicate colours, or the condensation products may form ugly blotches of colour on the goods. (See also 'Discoloration,' p. 188.)

Blowholes, in either baked clay without glaze or in glazed ware which has been glazed in the green state, are mainly the result of insufficient pugging or wedging of the clay, so that the air contained in the wet clay has not been expelled before the goods entered the kiln. In this case, the blowhole will be clean; if discoloured, it has probably been caused by carbonaceous matter in the clay (tiny particles of coal or dust are a common cause), which burns away, leaving a hollow place, the edges of which are often partially vitrified by the mineral matter present in the impurity. If the blowhole is almost black in colour, it is probable that the clay has been badly picked, so that the ironstone has not been completely removed. Metal filings caused by the men sharpening their tools at the bench will often produce a similar effect.

Another form of blowing is specially noticeable in clays containing gypsum, which tends to make the clays sinter easily, and to form a dense outer skin which holds in the gases formed during heating and later causes 'blowing.' By working the kiln when at a dull red heat, with very little air, the gypsum is reduced to sulphide; this removes the cause of the blowing action.

Too rapid heating of damp clay will sometimes cause blowholes by the sudden formation of steam in the interstices of the clay, and to its escape with explosive violence. Common clays, containing much iron as pyrites, unless heated sufficiently slowly, will occasionally show the same defect.

Blowholes forming in the finished goods on exposure are generally attributed to the formation of quicklime in the goods from the chalk contained in the clay. The simplest remedy is to increase the temperature of the kilns, so that the lime may combine with the clay; if this is not feasible, the fired goods may be dipped into water so as to completely slake the lime, or the clay may be washed free from some of its chalk before use; this latter method is, however, generally too expensive. (See 'Limey Clays,' p. 196.)

Blushing is a term used to denote two entirely different defects: it sometimes refers to a very slight discoloration suffused over a large part of the surface of the ware, usually due to an article of light colour being fired too close to others of much darker shade; but it is also used to denote peeling or scaling of the glaze, and in this case the causes will be found under these headings.

Brittleness in glazes, or in bodies of partially vitrified clay, is one of the results of too rapid a cooling of the kilns, especially at the commencement, whereby the material is not properly annealed.

Brittleness in fire-bricks is due to the formation of crystals[1] from some of the constituents of the bricks on repeated heating, and on cooling them slowly through their 'critical temperatures.' Firing in a kiln with a bad foundation and a damp sole will also cause all kinds of bricks to be brittle.

Another cause of brittleness is too rapid cooling from red heat downwards, especially with goods made of a very dense clay, which cannot stand rapid changes of temperature.

An excess of fluxing material in the clay will also cause brittleness if the goods are burned to a point of considerable vitrification, and other materials which do not possess a noticeable fluxing power appear to occasion the same defect. On the other hand, silica bricks which are composed of almost pure silica are notoriously brittle, and especially so under changing temperatures.

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[1] A sufficiently extensive and felted mass of lath-like crystals may produce exceptionally tough and strong bricks.

China ware containing an excessive proportion of bone ash is especially liable to be brittle.

Bubbles are often the result of too suddenly raising the temperature of the kiln to a point considerably above the melting point of the glaze, and allowing the glaze insufficient time to 'mature.' At the same time, excessively prolonged heating of the goods at the melting point of the glaze must be avoided, as it tends to cause a rearrangement of the molecules and to dull the glaze. No definite rule can be laid down, as the time required for the proper development of the glaze varies with the materials of which the latter is composed.

Certain materials used as glaze-stains evolve oxygen and other gases when heated, and if this takes place whilst the glaze is in a partially melted condition, the gases may be retained in the form of tiny bubbles. If maintaining the temperature of the kiln for a rather longer time does not cure this defect, it may be necessary to use a reducing fire for finishing the firing, or to discard the use of the bubble-forming material.

Air-bubbles are occasionally found as the result of the materials having been so finely ground that the air is imprisoned; this defect is a rare one, and the remedy is obviously to be found in the use of coarser materials. (See also 'Spitting,' p. 209.)

Chipping off the glaze or engobe is due to the same causes as 'peeling,' p. 198.

Cooling the kilns improperly is a fruitful source of many defects, especially 'crazing,' 'cracks,' 'dunts,' and 'feathering,' or crystallization, and the more important defects will be found treated under one or more of these heads.

Cores or 'hearts' are irregular discolorations which may be seen on the outside of bricks, but which are more commonly observed when a brick is broken and the fractured surface is examined. When the defect is very serious, it is usually accompanied by a spongy structure and by swelling. Investigations by Orton and Griffen, and by Hopwood and Jackson, have shown that these cores are due to carbon and to reduced iron compounds in the clay. If the supply of air within the pores of the article is not sufficient to burn out the carbon and to oxidize the iron compounds, a 'core' may be produced. Clays containing a large proportion of combustible and fusible matter are particularly subject to this defect. When the combustible matter commences to burn without sufficient air in contact with it, any red iron oxide is reduced to ferrous oxide, and the latter, with the unburned carbon, forms a dark core. If the temperature is then sufficiently high for partial fusion to occur, the core is covered with a film of fused material and it cannot then be fully oxidized.

The supply of air will depend on the atmospheric condition of the kiln and on the porosity of the goods. If the porosity is reduced by incipient vitrification, oxidation is rendered almost impossible. It is, therefore, necessary to burn out all the carbon and to oxidize the iron at a temperature so low that vitrification cannot occur. It is generally found that 900° C. (cone 010*a*) is the highest temperature which can be regarded as safe for this purpose.

Hence, when bricks with a tendency to 'core' are used, the temperature should be maintained between 800° and 900° C. until all the core-forming material has been oxidized. This may be determined by drawing trials and breaking them.

If this takes so long a time as to be unprofitable, the porosity of the material must be increased by the addition of grog, sand, or sawdust, and by grinding less finely. If this is undesirable, the goods should be set as openly as possible in the kiln.

As the porosity of burned clay is at a minimum in goods made by the semi-dry process (owing to the small amount of water used), the substitution of a method of formation using a more plastic paste will frequently prevent the formation of cores.

Surface clays seldom show this defect, but red-burning shales are particularly liable to it.

Cracks are of two main kinds—those in the clay or body of the ware, and those in the glaze. The former are sometimes known as 'dunts' (p. 186) and the latter as 'crazes' (p. 191).

Cracks in the goods before going to the kilns may be due to faulty designing, but this may, to some extent, be remedied by very careful attention to the manner in which the goods are supported, both in the drying-room and in the kiln. In the case of machine-pressed goods, what, from an engineer's point of view, may appear a trifling defect in the machine, will sometimes make it impossible to turn out sound goods: a little unevenness in the cutting table, a slight irregularity in the pressure, a slight misfit in a die, or even a slight roughness of the metal face will sometimes cause the goods to crack.

Another very common source of cracks during the drying of the goods is due to this process being carried out carelessly, so that certain parts are dried more rapidly than the rest, a dangerous process at any time, but especially so with jointed goods, or with those having great variations in the thickness of their various parts.

The use of too plastic a clay, or of one too finely ground, is a prominent source of cracks in ware, especially in large tanks and baths. The remedy consists in the use of a leaner (more sandy) clay, or in the addition of non-plastic material to the clay. Some clays which are not excessively plastic also crack because they are too rich in silica; such clays may be cured by admixture with an appropriate proportion of bauxite. Cracking in some clays may be due to a gelatinous matter in them which is decomposed by adding a little quicklime to the clay. Some clays can stand up to 12 per cent. of quicklime. The addition of a little common salt is also a good remedy in some cases.

Faulty pugging of the clay, whereby some portions of it are drier than others, will also cause cracks to appear, owing to the unequal contraction in drying.

Sometimes cracks are produced, in spite of the greatest care being taken to make the clay paste thoroughly homogeneous, if an unsuitable die is used, or, in the case of wire cuts, if the mouthpiece of the pug mill be not carefully adjusted to the clay in use. It is essential that the clay shall press equally against every part of the die or mouthpiece; especially must this be the case with regard to the corners, as otherwise the piece will have a soft place when it comes from the press, or the central portion of the clay strip will leave the pug-mill mouthpiece before the sides, and the strains thus set up will cause the clay strip to crack. In this latter case it sometimes happens that the narrower sides of the strip leave the mouthpiece before the broader ones, so that when cut the bricks have a tendency to curl slightly.

A frequent cause of circular cracks resembling the age marks in a tree, and occurring chiefly in the centre of the bricks, is an unequal forward movement of the clay in the mouthpiece. These cracks are usually due to a highly laminated clay or to the blades on the end of the pug-mill shaft nearest the mouthpiece being worn or of a wrong shape or to their being in a wrong position. They are often formed by the last blade being too near to the mouthpiece, so that the pieces of pugged clay have not time to reunite after passing the blade. In such cases, a longer collar should be inserted between the end of the pug mill and the mouthpiece, or it may be necessary to alter the design of the mouthpiece, in which case an expert should be consulted. Tension cracks, which are more common in hollow than in solid goods, are due to one part of the clay being subjected to a greater thrust or pull than the remainder. Such a defect is usually due to the imperfect lubrication or to the faulty design of the pug mill.

The friction in the mouthpiece depends on the slope of the inner surfaces of the latter (being least when the slope is least), and on the area of the sides of the strip of clay, so that the narrower sides have less friction than the wider ones. It is, therefore, advantageous to make the narrower sides of the mouthpiece slope rather more than the others in order that the different portions of the strip may all travel forward at precisely the same rate.

The most friction occurs at the corners of the mouthpiece, with the result that the edges are held fast whilst the remainder of the strip travels forward, and the edges, no longer able to withstand the strain, tear away in the form of the so-called 'dragon's teeth.' These 'teeth' are also formed when dry clay remains in the mouthpiece of the mill. If an alteration of the slope of the faces of the mouthpiece and a rounding of the corners does not effect the desired result, as may happen with an excessively 'short' clay, it is best, if the composition of the clay cannot be altered, to use a mouthpiece with water lubrication. The water forms a cushion between the clay and the metal, and so, by reducing friction, prevents the tearing of the former; but it has, at the same time, the tendency—owing to the 'slip' which the water forms with the clay—to cover up small surface cracks which would have been visible if no water had been used, and which, though covered, seriously lessen the strength of the bricks.

Press cracks are due to pressing bricks in an unsuitable condition or to the improper application of the pressure. The 'clot' should be as nearly as possible the size and shape of the finished brick, so that there is little deformation in the pressing.

Stones will make a brick crack if they are sufficiently near the surface.

Some cracks are really due to lamination in the clay paste; the 'S' cracks described on p. 195 are of this kind.

In the kilns, cracks may be produced by a variety of causes, such as faulty setting, kiln leakage, bad firing, or too rapid cooling. Under the first of these comes the cracks produced by the goods having been set without any regard to the strength of their relative parts or to their not having been set solidly, so that the movement resulting from their contraction causes them to fall, or at least to crack. Setting bricks on a floor on which there are fragments of brick which get under one end of the goods and tilt them slightly, this irregularity increasing as the courses rise, with the result that the bottom brick cannot stand the irregular strain and cracks, is a by no means uncommon experience. Goods which are too dry when set are often very brittle, and so crack in the setting.

Kiln leakage may be due to a faulty site, to the kiln not being drained, to faulty construction, or to lack of repairs. This latter may also cause cracks by allowing the kiln to 'leak air'; too much draught will do the same. In ordinary brick kilns, care should be taken that the 'screen' (when one is used) in the kiln is made of good materials, with as thin joints as possible, or the cement ('daub') used may shrink unduly and allow air which has not been properly warmed by the fire to leak in and crack the goods. For a similar reason, holes at the bottom of the screen are not always advisable, though they are frequently used with a view to inducing some of the fire to enter them and so save fuel. In muffle kilns, or those in which the goods are placed in saggers, the danger of cracks from cold air is reduced to a minimum.

Cracks due to the firing are often caused by raising the temperature too rapidly at the commencement; or sometimes, if the steam is allowed to remain too long in the kiln, it may condense on the goods, soften them, and then when the heat is raised rapidly it may crack them.

If a suitable thermometer cannot be used in the earlier stages of firing the kiln, some arrangement should be made whereby a trial may be withdrawn to see that it is free from steam: sometimes a large cold poker or crowbar is put through the trial hole and left for a few minutes; if it is damp on being withdrawn the kiln is not free from steam: the bar must be quite cold on insertion. Steamed goods are commonly the fault of a fireman who does not work his dampers properly.

Cracks may be also formed in certain classes of kilns by careless stoking, so that cold air is allowed to rush through holes made in the clinker and fuel; hence, it is not advisable to clean out all the fires at the same time. Some clays burned in continuous kilns show a particular tendency to crack; this is frequently due to the sudden rise in temperature immediately after a chamber has been taken into the round of the kiln. The hot gases enter the chamber suddenly, impinge on the goods, and cause cracking. The difficulty is increased by setting the goods too open and by the bricks being damp and insufficiently soaked. The avoidance of such cracking is very difficult if the dampers are badly arranged or the kiln is too short.

In cooling the kilns, goods may easily be cracked. They must be cooled slowly just as they are heated slowly. Especial care is required to prevent cold air from spoiling the goods directly after 'burning off,' as may easily happen if the closing of the fire-holes is proceeded with too leisurely. A good plan is to lower the damper *slightly* as soon as the last charge of coal has completely stopped flaming.

A prolific source of cracked goods is the too early opening of the kiln. This exposes the hot goods to irregular currents of cold air, and so causes them to crack. The temptation to 'draw' a kiln before it is cold should be resisted, as the disastrous effects produced do not show at once in all cases, but only after some weeks.

When goods are insufficiently fired and are not glazed, they are liable to crack on exposure to the weather; this is often the case with red bricks which are heated just sufficiently to develop the desired colour without any regard being paid to their durability.

Cracking of the Engobe is commonly due to its having a different expansibility or shrinkage from that of the clay of which the goods are made. If so, the remedy depends largely on which contracts or expands the most. This can only be accurately determined by actual measurement (Chap. XIII.), but much may be learned from an examination of the crack. If it be a clean one, with the engobe adhering well to the body on each side, the former will be improved by having its contractibility lessened by the addition of a little flint, quartz, or fine sand, unless the engobe is already very rich in silica, when rather less of this ingredient should be used. If, on the other hand, the engobe rises up from the body with a blister-like formation, a cure must be sought in the addition of a greater proportion of flux to the engobe, or in increasing its fusibility and contraction.

Sometimes, cracks in the engobe are due to the use of gum or other materials intended to make the slip adhere better to the goods; or to the use of acid salts or materials which coagulate or decompose the slip, such as alum, sulphate of copper, etc. These latter may often be cured by the addition of a sufficient quantity of soda solution to just neutralize their effects; this will not, in most cases, materially affect the fusibility of the engobe. For the rest, there is no cure except a discontinuance of their use.

The use of a too coarsely ground engobe will sometimes cause it to crack; in this case the remedy is obvious.

Crawling of a glaze (especially of a stoneware glaze of the Bristol class) may be due to too high a percentage of alumina or to excessive zinc oxide, but is more frequently due to too thick a coating of glaze. If the ware is dusty it is sure to crawl, and if the ware is glazed in the unfired state this dust is very difficult to remove, yet it may at any time cause crawling.

Another cause of this defect is the use of too much ball clay in the glaze.

Other causes are imperfect ventilation in the kilns, bad firing, and even careless setting. The addition of a little extra flux to the glaze will often cure it. (See also 'Peeling,' p. 198.)

Crazing, or cracking of the glaze, is exceedingly difficult to prevent, as it is almost, if not entirely, due to the glaze and clay expanding to different extents for the same change in temperature.[1] In coloured glazes especially it is difficult, when altering the expansibility of a glaze, to avoid changing the colour, and consequently many of the cheaper articles on the market craze badly as they grow older. It is, in fact, one of the difficulties in connection with this defect that it does not always show itself before the goods have been sold.

Crazing seldom occurs in glazes fired at a temperature above 1200° C. and carefully cooled, as the composition of such glazes bears a much closer resemblance to that of the clay on which they are fired. Easily fusible 'majolica' glazes, on the contrary, almost invariably craze when applied to a body made of fireclay or other 'natural' clay, particularly where the glaze is thick.

If crazing occurs suddenly in a glaze which is generally free from this defect, and the firing, and especially the cooling, of the kilns has been properly carried out, it is likely to be due to an unnoticed variation in the composition of the felspar or Cornwall stone used in the glaze. Thus a stoneware glaze which ordinarily is particularly free from crazing will often craze badly if 5 per cent. of soda be added to it; yet such a variation in the percentage of alkali in the felspar and stone is by no means uncommon.

Soluble salts, derived from Portland cement and other sources, may cause crazing.

Crazing may also be due to change in the methods of work, such as applying the glaze to green instead of to biscuit goods, and *vice versa*, or to applying

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[1] Purdy and Potts and Staley have disputed this explanation, but they appear to agree that "the practical use of these rules remains the same."

too thick a coating of glaze to the goods. As, however, the clay and glaze always tend to exchange some of their constituents, there is continually a chemical action going on whilst the goods are at a high temperature, with the result that on prolonged heating the glaze tends to become less fusible and the clay more so; and as the reaction is to a large extent dependent on the relative masses and surfaces of the two, it follows that the thinner the glaze the better chance will it have of attaining to a composition more like the body on which it is placed. For this reason a prolonged firing, or an increase in the temperature of the finishing point of the kiln, will often prove an efficient remedy for crazing if the effect be not too pronounced; in the former treatment the partial volatilization of the alkalies in the glaze may also help. When using a body with a high percentage of silica, great care should be taken not to over-fire it, as some glazes on such a body are very liable to craze.

The use of too much ball clay (added to toughen the glaze) will also cause crazing.

Seger has studied the causes of crazing exhaustively, and recommends the following as the best remedies:—

(*a*) Use a smaller proportion of plastic material in the body, and increase the proportion of flint or quartz.

(*b*) Grind the body more finely, especially the siliceous portion.

(*c*) In non-vitrified bodies increase the amount of fluxing materials; but if the bodies are vitrifiable, as in porcelain, use a smaller proportion of flux, especially of felspar.

(*d*) Prolong the heating of the kilns or raise the finishing temperature.

Instead of altering the composition of the body it is often easier to alter that of the glaze, in which case Seger recommends:—

(*e*) Increase the proportion of flint or quartz in the glaze, taking care that there are never more than three molecules of silica to each molecule of alkali in the glaze.

(*f*) Substitution of part or all the silica in the glaze by boric acid; this also lowers the melting point of the glaze.

(*g*) Replace some or all of the alkali in the glaze by others of a lower molecular weight (see Table of Molecular Weights). This is equivalent to increasing the proportion of silica. Thus, the use of zinc oxide as an 'anti-craze' depends on the fact that its power of combining with silica is to the power similarly possessed by lead oxide in the proportion of the molecular weights of these oxides, viz. 79 : 223; so that if a glaze containing 55 per cent. PbO and 45 per cent. SiO_2 were found to craze under certain conditions, it might perhaps be cured by the substitution of zinc oxide equivalent to half the lead oxide present. This would produce a glaze containing 33 per cent. PbO, 12 per cent. ZnO, and 54 per cent. silica; that is to say, the percentage of silica would be increased nearly 10 per cent. by this means. So great a change in composition would, however, seldom be made in actual practice.

When a glaze on a vitrifiable body crazes through the body being over-fired, it is really due to the glaze not being able to absorb sufficient silica from the body. The addition of a little flint to the glaze will often effect a cure.

Crazing is most likely to occur on bodies with low flint, high clay, and more than 30 per cent. of felspar. With some bodies, crazing is unavoidable.

Crooked Ware may be caused by lack of sufficient support in drying, by irregular drying, by careless placing of the goods in the kilns, by too great a heat in the kilns so that the ware is partly fused, or by an error in the mixing of the body so that too much fusible matter (or conversely, too little infusible matter) has been introduced into the mixing. From whatever cause, except in complex shapes or large thin slabs, the production of crooked or warped ware is preventable.

Crystals in glaze are due to the formation of silicates which are soluble in the remainder of the glaze, and which separate out in the form of crystals when the glaze is cooled sufficiently slowly or is kept sufficiently long in a 'half molten' condition. When regarded as a defect (see 'Blinding'), the formation of crystals may be prevented (*a*) by rapid cooling of the glaze past the temperature at which the rate of crystallization is greatest—usually above 1100° C., but sometimes as low as 900° C.; (*b*) by applying a thinner coating of the glaze to the goods; (*c*) by such an alteration in the composition of the glaze that mono- and bi-silicates and not tri-silicates are formed; (*d*) by the addition of alumina or boric acid; or (*e*) by reducing the proportion of zinc oxide in the glaze.

If the composition of the glaze is correct, crystallization will most probably be due to the glaze being kept too long at the 'best temperature for crystallization.' All glazes tend to crystallize more rapidly at certain temperatures than at others, and so must be cooled through this 'danger zone' as rapidly as possible. Variations in the rate of cooling at other temperatures appear to have no influence on the crystallization.

Crystals are sometimes produced purposely in glazes, beautiful 'star' effects being produced by (1) the addition of zinc oxide or rutile (titanium oxide) to the glaze; (2) finishing at a very high temperature, so as to carry the chemical reactions of the constituents further than usual, and cooling slowly; (3) applying a very thick layer of glaze; (4) very slow cooling; (5) adding a minute proportion of clay to some glazes, though a larger proportion will prevent the formation of crystals.

Crystals seldom form in ordinary glazes unless the glaze layer is of more than ordinary thickness.

See also 'Feathering.'

Curving or warping of the ware is treated under 'Crooked Ware.'

Dimness, or lack of lustre, in glazed ware is usually due to faulty firing of the kilns. Other causes are mentioned under 'Dullness.'

Dirt has been aptly defined as 'matter in the wrong place,' and its occurrence is generally due to carelessness or ignorance. Some remedies may be found under 'Spots,' 'Discoloration,' etc., according to the appearance given to the ware; in most other cases the nature of the dirt will give a clue to the best means of preventing its occurrence in future, such as greater cleanliness in the workshops, kilns, and yards, inspection of saggers for loose pieces of clay or dust, arrangements for preventing dust from blowing on to the goods, and so on, not omitting watchfulness over the men lest by the thoughtless sharpening of their tools at the working bench they introduce metallic filings into the clay, or by lack of personal cleanliness, especially when making coloured slips or glazes, they introduce other impurities.

Discoloration may occur on either the unbaked, the biscuit, or the glazed goods. In the first case it may be due to impurities in the clay forming a kind of 'scum,' or to dirty, careless workmanship or improper storage.

If the discoloration is formed on the baked ware it may be due, in addition to the causes just named, to (1) improper placing in the kilns, so that the flame licks the goods and so discolours them; (2) to insufficient air in the kilns, so that the combustible matter in the clay is not completely consumed, or (3) the iron compounds being incompletely oxidized. Some clays contain so much vegetable matter that, unless very slowly heated, the goods are drawn out black from the kiln. The only remedy is to limit the supply of air at the commencement of the heating, so that only a small proportion of the material can burn at once, and to prolong the heating at a dull red heat with more air until all the coal or other combustible matter in the clay has been completely removed. (See 'Cores.')

Brown discolorations are frequently due to pyrites in the clay being oxidized. The addition of barium will usually prevent this. Sometimes pyrites forms small spots, flat patches, or eruptions of black slag-like material which consists chiefly of ferrous silicate. This is caused by the reducing conditions of the kiln, and can only be avoided by removing the pyrites from the clay prior to using it. Pyrites cannot certainly be converted into red oxide by proper regulation of the firing.

A *grey* discoloration may be due to several causes, some of which are mentioned under 'Grey Bricks.'

In the manufacture of goods in which the colour of the baked clay plays an important part, as in red bricks and some terra-cotta, discoloration is commonly due to improper firing. This subject is a complex one, and many points in it are by no means fully understood as yet: some useful hints will, however, be found on pp. 22, 27, and 28.

A *green* discoloration may be due to vanadic acid. This may be prevented, according to Seger, by heating to cone 2 under reducing conditions. This must not be confused with the green 'scum' produced by rain washing the colouring matter off trees on to the goods, or with that due to vegetable growths (*algæ*).

Discoloration of glazed goods may be caused by the impurities in the clay or glazes used, or by 'dirt,' 'scum,' or 'steam,' or, in the case of certain coloured glazes, by the colouring materials volatilizing and condensing on other goods placed near. This is particularly the case with glazes containing copper or cobalt.

Where lead glazes are employed, a blackening of the goods in the kilns may often be due to the use of a 'smoky' or 'dirty' fire by which the lead compounds are reduced.

A peculiar *yellow* discoloration sometimes found on lead glazes is composed of a sulpho-silicate of lead and may be due to one of the following causes: (1) the glaze contains lead sulphate as an impurity; (2) the glaze contains a large proportion of galena; (3) the goods have been too damp when set into the kiln, and the sulphur in the coal has formed a decomposition product.

Blue and brown discolorations in china are sometimes due to the formation of ferrous phosphate by (1) reducing gases; (2) a deficiency of alkalies in the body; or (3) carbon in the bone ash.

A *brown* discoloration is occasionally produced by the action of chlorides in the body, which combine with the iron forming ferric chloride, which is volatile, but later redeposited on the cooler goods, and is eventually converted into red ferric oxide.

The *yellow* discoloration known as *la malade jaune* in hard porcelain is produced by oxidizing conditions in the first stages of the burning, followed by reducing conditions later, whereby some of the ferric compounds are reduced to ferrous oxide which readily fluxes. This defect is usually accompanied by blisters on the ware.

Where fires are badly supplied with air and the temperature of the kilns increases with great rapidity, black particles of soot or carbonaceous matter may be deposited on the goods and become surrounded by the molten glaze in such a way that the air is unable to burn out the carbon. For this there is no direct remedy other than prevention, which consists in raising the temperature more slowly.

Most coloured glazes are very sensitive to temperature-change when near their melting point, and still more so to the composition of the atmosphere in which they are heated: thus, copper in an alkaline glaze at a moderate temperature and with a plentiful air-supply, will produce a blue colour; with a siliceous glaze under similar conditions this will be turned to green; whilst if heated in a strongly reducing atmosphere so that cuprous compounds are formed, red glazes will result; or if the atmosphere varies and is at one time oxidizing and at another reducing, a combination of these colours may be formed. Chrome compounds under powerfully oxidizing conditions tend to form characteristic buff compounds instead of the usual green ones.

Discolorations due to uneven coating of the goods with a coloured glaze, or to not making a sufficient allowance for the run of the glazes, suggest their own remedies.

Iron spots (pyrites) may often be removed by a finer grinding of the clay whereby the blotches are converted into black 'pin-points,' but in many works it is more satisfactory to clean the grinding mill off twice daily and to throw away the sweepings; these will contain most of the pyrites, which, on account of its hardness, will not grind so easily as the clay.

Buff-burning bricks are often discoloured by faulty burning and also by defective preparation of the clay. In clays of this class containing both lime and iron, a red surface discoloration may be due to the sulphuric acid from the flue-gases decomposing the iron-lime compound, and so allowing the iron to give its natural red colour in places.

Much discoloration of unglazed goods is external and due to flue-gases, etc. This class of defect is referred to under 'Scum.' Other forms of discoloration are due to sulphur in the fuel, and these can often only be avoided by substituting wood for coal, when very sensitive colours are being fired, though for most purposes the use of a purer coal will bring about a cessation of the defect.

Some brickmakers are troubled every autumn by the appearance of discolorations of various kinds on their goods. Vegetational growths account for a small proportion of these discolorations, the washings from neighbouring trees for a few more, but most of them appear to be due to defects in firing. It is by no means clear why these discolorations should be more thought of at one time than at other seasons of the year—for they appear at all seasons—unless it is that with the rush of the summer season the discoloured bricks are sorted out, and by the time the summer is ended they have reached sufficiently large proportions to demand attention.

Other forms of discoloration are treated under the headings 'Blotches,' 'Spots,' 'Sulphur,' etc.

Dryer White is a scum formed by soluble salts in the clay rising to the surface as the clay dries. It cannot, usually, be seen until the goods are burned, and so is difficult to distinguish from 'kiln white.'

Dryness and **Dullness** of the glaze is generally due to one or more of the following :—

(*a*) Too little glaze on the goods.
(*b*) A too infusible glaze which does not mature properly at the temperature of the kilns.
(*c*) An error in the firing of the kilns. (See 'Starving,' p. 211.)
(*d*) Placing the goods too near unglazed surfaces, or to the use of unglazed saggers.
(*e*) To the biscuit being so hard fired that it does not absorb sufficient glaze when the goods are 'dipped.'

Dunting is a variety of 'cracking' of the clay goods due to either too rapid heating or too rapid or irregular cooling; but the expression is often used to denote cracks from other causes. If the crack shows an opening at the edge, too rapid firing at the commencement may be suspected; though carelessness in the making or in the placing may be the cause, as considerable experience is required in the allocation of such defects to their true sources.

If the dunt is produced in the cooling, it will usually show no opening at the edge of the crack, and if broken, the edges of the crack will be quite smooth; if the crack was in existence before firing commenced, the fracture will generally be much rougher.

Glazed ware which has been removed from the kilns before it was sufficiently cooled will often make a series of noises like small pistol shots; if the ware be then carefully examined, each of these reports will be found to be represented by a crack.

Efflorescence is a variety of 'scum' (p. 201) produced by salts in the material which gradually crystallize out on the surface of the goods. If this occurs during the drying of the goods in the clay state, it may sometimes be prevented by adding baryta or barium carbonate to the clay in the pug mill in quantity sufficient to decompose the salts present; this can only be done when these salts form insoluble compounds with the baryta. Painting the goods with starch- or flour-paste, oil or tar is often useful as a preventative, or in some cases, an increase in the temperature of the kilns will afford the desired freedom by causing the salts to combine with the clay. The deposit is generally white, but is sometimes yellow or green.

The chief causes of efflorescence are (1) the use of clay containing soluble salts; (2) the use of water containing soluble salts for tempering; (3) the formation of soluble salts in the kilns by oxidation of the impurities in the clay or in the kiln-gases; (4) the introduction of soluble salts into the goods when the latter are in use; the reacting salts being derived chiefly from the mortar or cement.

The salts most liable to form a scum are the sulphates, chlorides, and carbonates of potassium, sodium, aluminium, magnesium, and particularly lime; lime salts, though not very soluble, produce the most abundant efflorescences, and are least easily washed away by rain. The most satisfactory method of preventing scum formed from salts existent in the clay is to weather it thoroughly before use so as to wash out any soluble salts which may be present. Mechanical washing is sometimes even more effective.

If the lime in the mortar or cement used in laying the bricks contains magnesium sulphate or other soluble salts, these latter are dissolved when the mortar is made, and the solution penetrates the bricks and as they dry the soluble salts are left on the surface of the bricks. The storage of bricks on a foundation of ashes or other ground rich in salts may produce a scum in a similar manner, as in wet weather the rain becomes contaminated with salts which are drawn by capillary attraction to the surface of the bricks. In either case, a gentle sponging of the goods with very weak hydrochloric acid will often remove the deposit.

This subject is more fully dealt with under the general heading of 'Scum,' as well as under 'Dryer White' (p. 190), 'Kiln White' (p. 194), and 'Wall White' (p. 214).

Feathering is a species of superficial crystallization which sometimes occurs in glazed goods, and is due to unsteady heating or to draughts during the cooling of the kilns. Some glazes are more liable to this defect than others, especially if they are capable of forming a definite compound (silicate) with any constituent of the glaze which is soluble in the remaining portion of the glaze. Leadless glazes containing a large proportion of lime or zinc oxide often do so.

Feathering is also attributed to the action of sulphur in the fuel on the glaze. In this connection, J. W. Mellor has found that the defect is most pronounced if the sulphur gases reach the glaze when it is near its congealing point, such as when one part of a kiln is held back to get up the temperature in another part. A. Fielding has found that sulphuric acid in the borax used in some glazes produces the same effect, but others have found that the sulphates must be on the surface and not throughout the mass to cause this defect.

Other causes are described under 'Crystals' (p. 188).

Flakes on the surface of goods may be a form of 'Shelling' or 'Crazing,' but with unglazed articles they are not infrequently due to the use of defective plaster moulds. When soft moulds are used, the clay may draw away small portions of plaster which appear in the finished goods as flakes. The only remedy in this case is to use a better mould.

Where the flakes are, apparently, produced in the kiln they may be considered as 'scum' or as due to some form of 'lamination.' Further information will be found on pp. 195 and 201.

Flashing is a term used to denote the effect of a luminous flame on clay goods whereby the latter are changed in colour and 'scorched.' Goods so discoloured cannot as a rule be cleaned; it is therefore necessary to prevent the access of flame to the goods either by placing them in properly luted saggers, or, in the case of commoner goods, by placing them where the flame cannot reach them.

Flashing may also be produced by imperfect reduction or oxidation of some of the constituents of the clay, as in the formation of 'cores' (pp. 8 and 182).

Domestic fire-backs and some other articles are usually whitewashed before being sold, this defect being, thereby, covered.

Flowing is a process of glazing by vaporization, in which a volatile compound of the colouring matter is produced and deposited on the surface of the ware. Blue is the commonest colour applied in this way, though greens are produced from copper compounds. The usual material for producing the volatility is a chloride, the particular chloride selected being dependent on the nature of the ware; lead chloride or a mixture of salt and saltpetre or bleaching powder are frequently used, generally in the form of small pellets which are placed in the saggers along with the vessels to be decorated, the colour itself being applied to the ware. If the saggers are properly luted, and the other conditions suitable, the chlorinated atmosphere will cause the colour to spread from the design on to the surrounding white body in the form of a kind of halo, the extent to which this takes place depending on the amount of colouring matter on the goods and on the length of exposure to the chloride.

When flowing exists as a defect, it is usually due to the presence of a chloride and some metallic oxide with which the chloride can combine and volatilize. (See pp. 136 and 138.)

Frost is at once the great friend and enemy of the clayworker according as he uses, or misuses, its effect.

As a means of breaking up the raw clay no means devised by man have proved so effective as frost, and, in spite of the great advance in machinery, many of the most skilful clayworkers prefer to weather their materials, whilst many of the smaller works would be closed were it not for the beneficent influence of this agent.

Frost acts chiefly by converting the moisture of the clay into ice, which occupies a larger volume than the original water and so causes the disintegration of the mass.

Extensive experiments carried out at the Berlin Testing Station appear to show that the effect of frost cannot be predicted from a study of the porosity of sample bricks, as the disintegration of such bricks on repeated freezing and thawing is quite as much dependent upon the way in which the bricks have been made and the care and sufficiency with which the clay has been prepared as upon the ordinary physical characteristics of the bricks themselves.

These experiments have conclusively shown that *there is no relationship between the porosity of a brick and its resistance to frost.* It is generally found, however, that a vitrified brick is least affected by frost.

Pavers are excellent frost-resisters, and so are most fire-bricks, though the latter are generally fairly porous. Bricks which have been damaged by steam when in the kiln should, on no account, be exposed to frost, as they lack sufficient mechanical strength; they have a dense exterior caused by the condensation of the steam, and a porous interior—this combination being peculiarly unfavourable to resistance to frost. Bricks which are merely underburned and are equally porous throughout are more resistant, as the pressure of the freezing water is relieved by the pores.

All goods exposed to frost are liable to suffer damage, though many withstand its influence for a long time. Better-class goods should always be protected.

There is a curious and hitherto unexplained increase in the strength of some bricks after freezing, but this phenomenon only occurs with highly porous goods.

Glossiness in the glaze is sometimes difficult to obtain with leadless glazes. It appears to be in some way connected with the molecular weight of the fluxes used, but the exact relationship has not been determined. Ware which is kept too long in the kilns at the melting point of the glaze will often lose its gloss, which may, however, often be restored by a relatively rapid heating and cooling. Under-firing, or an insufficient thickness of glaze, will also cause a lack of lustre; whilst goods placed too near unglazed surfaces in the kilns will often suffer from the same defect. (See 'Dryness,' p. 191.)

Grey Bricks are sometimes caused by using clays through which water containing lime has percolated so that the clay is saturated with lime compounds. The body of the brick would otherwise burn to a good red colour, but in the presence of lime an unpleasant grey colour or even a white compound is produced. The following remedies are sometimes of use: (1) the faces of the bricks, prior to being burned, may be painted with tar or dropped in a mixture of starch paste and glue; (2) the clays may be mixed with sufficient baryta to render any sulphates insoluble and harmless.

Heating of the drying-rooms and kilns is to be considered as most important if successful manufacture is desired. The great point to be remembered is that all heat must be applied *steadily*, as irregular temperatures will prevent best work being done. It is, therefore, advisable to have some means of controlling the firemen in order to prevent their firing irregularly, especially at night, and various appliances for this purpose are described in Chapter XIII.

The effects of too much or too little heat are dealt with under the headings 'Over-firing,' and 'Under-firing,' but it must be borne in mind that goods may be spoiled by too slow or too rapid heating, although the actual temperature attained when the kiln is at its maximum may be correct. Too rapid heating will sometimes give a result similar to over-firing, whilst it is almost certain to crack the goods; too slow a heating, on the other hand, wastes fuel, and, especially near the finishing point of the glost kiln, is apt to produce goods insufficiently glossy or 'dry.'

Holes or Hollows in the surface of the goods are produced when a piece of combustible matter has got into the clay. When the goods come out of the kilns this matter has been burned out, and a hollow place results. This defect is most frequently due to carelessness, either on the part of the clay-picker, who has not done his work properly, or on the part of other workmen who have carelessly allowed pieces of paper, food, coal, or similar material to become mixed with the clay. Air imprisoned in the clay also 'blows' or 'blisters' in the kiln.

'Pin-holes' on the surface of the glaze are discussed on p. 199.

Lime, or chalk in moderate-sized pieces, sometimes produces holes, but may be prevented by a finer grinding of the clay (p. 181).

Iron causes various defects. See pp. 8, 9, 171, etc.

Irregularity in Size is usually due to the materials being imperfectly mixed, or to the use of a varying quantity of water in the clay paste. It may also be due to variations in the composition of the clays used.

A further cause of irregularity in size is the wearing of moulds and dies. This should be reduced to a minimum by careful inspection and frequent measurement, the moulds and dies being relined, or replaced by new ones, when necessary.

Kiln White is the term used to designate a white scum which appears on bricks, etc., whilst they are in the kiln. It is due to soluble salts in the water or clay, or to the condensation of the moisture and acid from kiln-gases on the goods, thereby causing soluble salts to be formed. Further particulars are given under the heading 'Scum' (p. 201).

Analyses of kiln white show it to be almost entirely calcium sulphate with small amounts of magnesium and alkaline sulphates, and occasionally alum.

Dryer white (p. 190) is difficult to distinguish from kiln white, but the former is almost always brought to the surface of the brick through the evaporation of the water, and so appears in small pimply crystals, while the kiln white is most often caused by the reaction of the kiln-gases and the lime in the brick, and appears as fluffy clusters. This is not a sure means of distinguishing the kiln and dryer whites, as kiln white may also come from evaporating water, and the dryer white may also be formed, in the case of a waste-heat dryer, by the reaction between the sulphur in the hot gases and the lime in the clay.

Lamination is the separation of the clay into thin plates, or layers, and these layers being smooth, do not bond as thoroughly as other parts of the clay.

Laminations are frequent in wares made by compression, and are often extremely difficult to avoid. They are commonly produced by a lack of pressure in the machine, by the pressure being unequally distributed, or by the action of the worm or auger.

Laminations in semi-dry pressed bricks are generally due to the material not being suitable for manufacture by the method used.

Shales, either in the raw state or in a partially weathered condition, are specially liable to this kind of defect, as their intensely laminated structure can only be destroyed by very thorough treatment in the preparation of the clay.

Some shales and laminated clays always give trouble unless they are ground in a dry condition so as to form a dry, or at most very slightly moist, powder. Passing them through crushing rolls is not sufficiently effective to destroy their original laminated structure, and a finer division—a more complete separation of the particles—is essential.

On the other hand, many materials will work admirably if treated in a sufficiently pasty condition, but if too little water is added, the material will be so imperfectly mixed that a satisfactory and homogeneous mixture is impossible. For this reason, many clays which are difficult to work by a semi-dry process will produce excellent bricks if more water is added and a softer paste ('stiff-plastic' or 'plastic process') is used.

Structure, or lamination in wire-cut bricks, is usually due to the auger being improperly placed or wrongly constructed, but if occurring chiefly at the edges they may be due to the die. Some clays adhere tenaciously to iron, and thus cause laminations, which must be prevented by altering the shape of the worm or auger, or by substituting steel, to which such clays sometimes adhere less strongly.

Many clays which laminate are of a soapy character, two surfaces not uniting properly together when pressed. The addition of grog will usually reduce the soapiness and will prevent lamination, as will any other method which breaks up the smooth layers and re-forms the material.

'S' Cracks.—When the material is in an expression (wire-cut) machine it is under great compression, and then, as it reaches the end of the shaft, the portion of clay which was above approaches that which was below the shaft, but unless the two unite firmly an intermediate space or crack may be formed, though this may not show until the brick has been dried, or even burned. These cracks, which not infrequently take the shape of a letter 'S,' are particularly troublesome. They are chiefly due to (*a*) insufficient breaking up and mixing; (*b*) the use of too fat a material, in which case sand or grog should be added; (*c*) imperfect construction of the auger or mouthpiece, so that the centre of the clay column is divided by the auger and is never properly united; (*d*) improper filling of the press box when semi-dry clay is used; and (*e*) use of an unsuitable method of manufacture.

Fortunately, the number of clays in this country which have a tendency to laminate in this manner is not large, though the complaints in this lirection are increasing as greater efforts are made to reduce the manipulation of the clay to the minimum amount. With the increased use of semi-dry processes they will still further increase if certain deposits are to be worked, so that a wise clayworker will ascertain, by the average of careful tests, whether any new clay he proposes to work will be liable to this defect.

The most troublesome clays in this respect are those of a naturally fatty nature, with a heavy shrinkage, and those containing both fat and lean clays in close proximity, the two being indifferently mixed together. Thus, a fat clay lying on a shale may easily cause much trouble in this respect, the process of manufacture suitable for the shale not being well adapted for the fat clay above it.

Fat clays have a tendency to laminate badly when passing through the die. If there is any unequal flow, these clays have a strong tendency to form smooth surfaces where the clay slips, and decided lines of cleavage are developed in the ware. This lamination usually can be broken up by the use of sand or better grog. In some cases, however, the addition of a small amount of plastic clay to a shale may prevent lamination.

'Shelling' is sometimes termed lamination, but it only affects the outside of the articles (see p. 207).

Owing to the nature of the causes of lamination it is wise, in case of difficulty, to requisition the services of an expert in clayworking, rather than to try an indefinite series of experiments.

Lifting of the glaze is one form of 'peeling' or 'shelling' (pp. 198 and 207), the defect being in one of its earlier stages.

Limey Clays, unless crushed very fine, will 'blow' (p. 181) when burned. Washing is preferable to crushing very fine, but is somewhat more expensive, and is difficult to carry out with rock clays and shales.

The use of a clay-cleaner is frequently found to be the most satisfactory means of removing limestone from the boulder clays, though only the coarser particles can be removed in this manner.

Limes differ greatly in their power of damaging bricks and in the speed with which they act. Magnesian limestones require a much longer time to produce 'blowing' than do pure calcium limes.

The 'blowing' of lime in clays is due to its being in a 'quick' state in the fired goods, and not combined with the clay; if the finishing temperature of the kiln be raised so as to bring about the latter combination, no 'blowing' can possibly take place. Unfortunately, the difference between the sintering point and the temperature at which the loss of shape occurs, in bricks containing much lime, is very small, and unless the firing is carefully managed overheating will take place. What is required is a long 'soaking' of the kiln just before the final finishing heat, so that the lime may have time to combine with the clay. This may take forty-eight hours or more, and often effects a change in the appearance of the bricks which does not please customers. Where this prolonged heating cannot be carried out, the only treatment for clays showing lime defects is to grind finely and to immerse the fired goods in water as soon as they come from the kiln, so as to quench all the lime.

Coarse particles of limestone are the worst offenders, those which will pass through a No. 40 sieve being usually harmless, though they may produce a whitish spotted appearance on red-burning clays. The particles of limestone should always be less than one-sixteenth of an inch in diameter; the smaller they are and the higher the firing temperature the less the liability to damage, as very small grains of lime combine with clay at high temperatures to form a vitrified material which is perfectly harmless.

Lumps on the surface of the goods as they come from the kilns may be due to the ironstone contained in the original clay, which has not been removed by the picker, or to pieces of material (sagger, dust, or ashes) falling on the goods whilst in them. If the goods are heated too rapidly, the contained moisture or gases produced from the combustible matter in the clay may not be able to escape without lifting up a portion of the surface of the goods, very much like a miniature volcano; in this case, the remedy is obviously to heat more slowly.

Moisture in the kilns is often unsuspected; yet, when present, is a source of great trouble to the clayworker. In some cases, the site of the kilns renders it extremely difficult to keep them dry, but this must be done if successful work is to be carried on.

Moisture in the goods can scarcely be termed a defect; its removal is described in the section on 'Drying.'

Moisture in raw materials, especially those used for glazes, is often excessive. The best firms of dealers will supply on a guaranteed basis of moisture (commonly 10 per cent.): but even then it is very desirable that each purchaser should test his own goods, or he may easily buy water at the price of felspar or lead. (See 'Moisture,' in Chap. XIII.)

Oil on goods will prevent them taking the glaze until it has been removed by firing. It is, therefore, important that all grease, oil and fatty foods as well as lubricants should be rigidly excluded from places where they can spoil the goods. Even where oil is legitimately used in a clayworks, care should be taken as to its quality; the author once had considerable difficulty in tracing the source of some very objectionable iron spots until the oil was found to be the cause. When oil is required for lubricating clay goods which are afterwards to be glazed without previous firing, paraffin may often be employed; care must, however, be taken that it is free from non-volatile oils, which would prevent the glaze from adhering to the goods.

Over-firing is one of the chief sources of loss in most clayworks; it is brought about by a variety of causes, of which the greater number are due to carelessness. Unless the fault be excessive, this defect is not of so much consequence in terra-cotta works or in those where only white or transparent glazed goods are produced; though the colour of the articles may often be ruined by the fireman's carelessness in this respect.

The chief characteristics of over-fired ware are distortion of shape or design, excessive running of the glaze, an unusually vitrified body, and improper colour of the goods. These can only be avoided by the clayworker determining exactly the conditions necessary for successful firing for his particular goods, and insisting on these being maintained, using such instruments as are available for the determination of the temperature, draught, etc., so as to afford an efficient control.

Paleness of colours may be due to faulty material, to the colouring matter being adulterated, or to the presence of interfering substances: these, however, are matters for the professional chemist and analyst. If the firing of the kilns be unduly prolonged, some colours, being more or less volatile, will become light; or through faults in the application of the colour to the goods, the latter may not receive sufficient colour. This is particularly the case where the colours are applied in the form of a slip in which the good are dipped, as the colouring matter, being often very 'heavy,' settles rapidly to the bottom of the dipping-tub. Attempts to give pale red-burning brick clays a better colour by the addition of iron oxide are seldom satisfactory.

Parting of the glaze is a common fault of leadless glazes which contain too large a proportion of felspar, but it also occurs in other glazes excessively rich in fluxes. Parting, like peeling and crazing, is due to the difference in the relative expansion and contraction of the body and glaze, so that an excess of either causes trouble. In the case of 'parting,' the surface tension of the melted glaze is so much greater than the force with which it adheres to the clay, that the glaze gathers itself into globules of varying size. A little dust on the ware will sometimes cause this defect, by preventing the glaze from adhering firmly to the body and so facilitating its running together into drops. An excess of felspar will also cause parting, as it prevents the glaze from being sufficiently fusible to flow well over the ware. As porcelain bodies have a composition much more nearly allied to that of the glaze than have other bodies, it follows that parting but seldom occurs in this branch of the trade, whilst it is not infrequently met with in the application of new glazes or colours to bodies of refractory clay. The most appropriate remedy consists in the addition of some infusible material, such as flint or clay, to the glaze; but where this is not practicable, the difficulty may often be overcome by adding lime, chalk, or other flux to the clay of which the goods are made. In the case of cheap or large goods, it is more economical to cover them with a slip composed of a flux, mixed with the clay of which the goods are made, and then to glaze in the usual way.

Peeling or 'scaling' of the engobe, or of the glaze from the body of the ware, is generally due to a difference in the relative expansibility of the materials used. In this respect, it may be regarded as the complement of 'crazing.' Seger has recommended that the following alterations be made in the *body*:—

(*a*) Reduce the proportion of silica (flint) and increase the proportion of plastic clay.
(*b*) Substitute kaolin or china clay for the more plastic clay.
(*c*) Increase the proportion of felspar.
(*d*) Use less finely ground materials, especially flint.
(*e*) Fire the kilns at a slightly lower temperature.

He also recommends that in the *glaze*—

(1) The proportion of alumina and silica be reduced or the fluxes increased.
(2) Part of the silica be replaced by boric acid.
(3) Part of the alkali or alkaline earth metals be replaced by others of higher atomic weight (see (*g*), p. 187); thus, sodium carbonate might be replaced by whiting (chalk), or whiting by barytes.
(4) A shorter time of exposure to the maximum temperature of the kiln, or heating the goods to a lower temperature, as over-firing tends to produce peeling. Thus, on firing a piece of glazed ware normally it may give a good result, yet if under-fired, may craze, and if over-fired, may peel.

It is, of course, to be understood that this alteration in either body or glaze is to be made systematically, and only one of the above suggestions carried out at once in order that its effect may be determined. The prevention of peeling and crazing is one of the greatest difficulties of the potter's art, and it can only be solved by careful and often prolonged trials.

Other causes of peeling are :—

(*a*) Oil or grease on the surface of the goods.
(*b*) Too high a polish on the surface of the clay if the goods are glazed in the green state.
(*c*) Dust on the goods; this and the superlative polish are best removed by passing a clean damp sponge lightly over the goods just before glazing.
(*d*) Stones in the clay of which the goods are made may cause peeling by irregular shrinkage on heating; in this case, the clay must be more finely ground before use. The same treatment must be used if the peeling is the result of an insufficiently homogeneous mixture—as when a fat and lean clay are mixed,—special attention being paid to the pugging or mixing of the clays.

Perspiration, being often of a greasy nature, acts very much like oil (p. 197) when it gets on the goods; special care must, therefore, be taken to prevent ware which is to be glazed from being fingered more than is necessary.

Pimples are not infrequently seen on salt-glazed pipes. They are most frequent when the clay is irregular in character and coarsely ground; material which passes through a No. 20 sieve seldom shows this defect. A. J. Aubrey has investigated this subject, and finds—

(*a*) That pimples are caused by the incipient fusion, bubbling, and swelling of small particles of shale, lying close to the surface of the pipe, which particles, it can be assumed, would act similarly to large particles of shale burned under similar conditions.

(*b*) That the size and frequency of the pimples depend upon the fineness of grinding, and consequently, homogeneity is the real solution of the problem.

(*c*) That these pimples appear between 2000° and 2060° F.

(*d*) That these pimples appear in greatest size and extent on pipes fired in fast-burning kilns, where it has been found that the temperature rises considerably after the start of the salting.

Pimples may also be caused in a manner similar to 'Blisters' (p. 179).

Pinched Ware. See 'Crooked Ware' and 'Warped Ware.'

Pin-holes are produced in various ways, the commonest of which is the use of too hard a glaze or of insufficient firing. Another frequent cause of pin-holes is dust of an organic nature on the ware before glazing, or falling on the goods whilst the glaze is sufficiently soft for the dust to adhere. If this dust can burn completely away, little harm can be done, but if, as is more usual, it leaves behind a certain amount of ash, pin-holes are likely to be formed where each particle of dust formerly rested. Sometimes, inorganic materials such as grains of sand prove equally detrimental. If the glaze gives off tiny bubbles of gas when near its fusing point, or after it has fused, these may rise to the surface and then break, leaving a small depression on the surface of the glaze.

Whilst the remedy must necessarily depend to a large extent on the cause of the pin-holes, it will generally be found that by softening the glaze somewhat, by the addition of a small proportion of flux, or by slightly increasing the temperature of firing, the defect may be prevented. Ware which is pin-holed may often be cured in this way by re-glazing with a somewhat softer glaze; but if the defect is due to dust of such a nature that it will not 'take' the glaze, this treatment will not be effective.

Pin-holing is often said to be due to air-bubbles in the glaze or glaze-slip, but experiments made by the author, in which air and various gases were purposely worked into the glaze before use, failed to produce this defect.

Pitting in unglazed ware is commonly due to the presence of organic or combustible matter in the clay, which burns out in the kilns and so leaves pit-marks. These may sometimes be removed by a polishing wheel of hard earthenware, or by filling them up with a paste of finely ground pitchers, clay and water, and passing the goods a second time through the kilns; but the only satisfactory remedy is to be found in a more careful preparation of the clay.

Pitting in glazed ware may be treated as described under the heading 'Pin-holes.'

When the base of the pitting is covered with a white powder, the defect is probably due to lime in the clay (see p. 196).

Plucked Ware, or ware which has had pieces pulled out of it in removing it from the stilts or from the kilns, is usually due to the use of improper supports, or to using them in an improper manner; but it may also be due to over glazing, so that the glaze runs down and cements the support to the ware itself. Inefficient cleaning of the glaze from the bottoms of the goods will produce the same defect. If goods are so badly placed that they fall over and so touch other pieces, or if the kiln is so over-fired that the same result happens, the placers or burners may be justly blamed, though with ware of entirely new and unaccustomed shape some little allowance may have to be made in this respect.

Porosity is a special characteristic rather than a defect in ware. It may be increased in dense-burning wares by mixing the clay, before use, with fine sawdust or other combustible material which will burn out in the kiln, by adding grog or by grinding less finely; or it may be diminished by adding a more easily fusible clay or some natural flux to the clay, but in this case it must be remembered that the total refractory power of the clay is reduced in proportion as its porosity is diminished. When it is desired to make clay goods entirely non-porous, they are usually glazed both inside and out, or are fired until they are vitrified.

Porosity may be reduced by mixing the clay with a low-melting clay, felspar, or stone, but this treatment often presents difficulties in the working of the clay.

The firing of clay which contains a notable proportion of coal, sawdust, or other combustible matter is often difficult, and requires the greatest care, or the kiln will catch fire and the goods be spoiled.

The determination of the relative porosity of different clays is described under 'Porosity' in Chapter XIII.

Roughness of the surface of goods coming out of the kilns may be due to lack of care or skill on the part of the maker, to an excessively rapid heating of the kiln in the earlier part of the firing, or to impurities, especially pyrites, in the clay if the goods are unglazed, whilst roughness of the glazed surface is one of the commonest signs of under-firing, though a particular kind of roughness (blisters) may be due to too much heat, or to placing the goods too near an unglazed surface.

Another variety of roughness may be attributed to iron spots caused by reducing conditions in the kiln. Sometimes, roughness is due to carbon which does not become intimately mixed with the clay in grinding. These particles remain on the surface of the ware and burn out eventually, leaving a cinder and very often a pitted surface. (See also 'Pin-holes.')

Roughness is a defect of so general a nature that it is almost impossible to treat it efficiently without seeing the goods; a little care and patience will, however, generally elicit the cause and discover a remedy.

Running of the glaze is most frequently, if not invariably, due to its being too fluid at the temperature of the kilns, so that if the latter cannot be altered, the glaze must be rendered less fusible by the addition of hardening materials, such as flint and clay. In coloured glazes, however, the shade is affected by this treatment, so that the clayworker is placed in a dilemma, the only feasible remedy then being to arrange the thickness of the glaze in such a way that as little of it as possible shall actually drop off the goods.

Where the colour of the glaze is of secondary importance, running may usually be prevented by a careful addition of alumina, either pure or in the form of clay, taking care to keep the ratio of acid oxides to basic oxides within the limits necessary for a satisfactory glaze.

Salts and **Saltpetre** show as a whitish incrustation or efflorescence on the surface of the goods either before or after firing. The term 'saltpetre' is generally incorrect when used in this connection, as the incrustation is not often due to this substance, but to sulphate of lime. For further particulars, see 'Efflorescence,' 'Scum,' and 'Wall White.'

Scaling is a term used to indicate defects described under 'Peeling' and 'Shelling.'

Scratches, chiefly on glazed goods, are not invariably preventable; they are caused by some hard substance coming in contact with the goods.

So long as the goods are in the manufacturer's premises they should not be seriously scratched, but many glazed bricks and pieces of sanitary ware are exposed to such rough treatment that it is almost impossible to prevent them being scratched.

Scum is a term used for a variety of defects on the surface of the goods. It is applied indifferently to the exudations from the goods and to various deposits which exist entirely on the surface, such as condensations of various kinds and crystalline deposits. It is, therefore, necessary to ascertain, as completely as possible, the nature of the scum; this can, to some extent, be accomplished by breaking the scummed article and endeavouring by means of a powerful lens to ascertain whether the 'scum' has penetrated below the surface. An examination of the physical state of the scum—as to whether it is amorphous or cystalline, its colour, etc.—is also important.

Broadly speaking, the causes of scum may be found in the materials employed, and in the absence of sufficient care in keeping the goods clean either in the drying-house or in the kilns, or, less frequently, in the faulty storage of the finished goods.

By the nature of the case, different branches of the clayworking industry suffer in very different ways from this defect: fine pottery, for example, is seldom or never troubled by scum due to the materials themselves; whilst in bricks and terra-cotta this is the most usual source of trouble, consequently, they may be considered first.

Scumming due to the materials used may show as a more or less white crystalline deposit, penetrating slightly into the article, and observable either when the goods are dry or when they have been fired and exposed to damp air. In the former case, the scum is almost invariably due to soluble salts in the clay or in the water used, the most important of these salts being the sulphates of sodium, magnesium, and calcium (lime). The corresponding chlorides and nitrates are only very occasionally the cause of scum, which is fortunate, as these latter are particularly difficult to remove. If the cause lies in the water used being impure, especially if it contains much oxidized sewage matter, the supply will probably have to be changed unless only low-class goods are being made. If, however, the water is merely contaminated with sulphates, it may be used, and the effects of the impurity neutralized by the addition of baryta, barium chloride, or barium carbonate.

In the majority of cases, the scum caused by salts is due to these impurities being in the clay and not in the water, though they are also occasionally formed during the firing, owing to the sulphur in the fuel combining with the bases in the clay to form sulphates. Various attempts have been made to remove these scum-forming salts from the clay by wintering or washing the clay before use; these methods have not, however, proved very successful, and in some cases, as in a clay containing pyrites, the proportion of soluble salts may actually be increased by this treatment.

The state of the goods when the scum is first observable must regulate the treatment most likely to effect a cure. Thus, if the scum is noticed on the goods in the drying-room, it may happen that it is due to sodium compounds, which will combine easily with the clay at the temperature of the kilns and so cause no further trouble. If, on the other hand, it is due to lime salts, these may not combine with the clay, and the goods will be scummed on drawing them from the kilns.

What is sometimes regarded as a *brown scum* is due to soluble iron salts, formed by the oxidation of pyrites in the clay; this is often very difficult to prevent, though the use of carbonate of barytes is frequently of service.

In the manufacture of bricks, the oil used not infrequently contains soap: this will occasionally produce an alkaline scum which leaves patches of glazed surface on the fired goods. It can only be prevented by the use of an oil free from this impurity.

There is a curious misconception on the part of many architects that grey or scummed bricks are harder than others. The production of scum has nothing whatever to do with the finishing temperature of the kiln, and a slight glossiness (due to the fusion of the scum-forming salts) is no indication of the real vitrification of the brick.

The following are the chief forms of white scum:—

1. *Efflorescence from the Clay.*—Most clays contain soluble salts, of which the chief scum-formers are, in order of their abundance, (1) calcium sulphate; (2) magnesium sulphate; (3) potassium sulphate; (4) sodium sulphate; (5) ferrous sulphates; (6) aluminium sulphates; (7) other soluble salts such as chlorides and nitrates.

All of these may occur in a single clay, especially if it has been weathered.

All of the above salts are very soluble except calcium sulphate, with a solubility of 1 : 400; this is great enough to completely spoil facing bricks in which it occurs. The sulphates of soda, potash, and magnesia will often cause scum when present in the most minute quantities. As little as 0·01 per cent. of any one of these salts has been known to spoil facing bricks. Surface clays are more likely to have a high content than the older deposits, but if the latter contain pyrites this is oxidized, on exposure, to iron sulphate. On further oxidation the ferrous sulphate is converted into a hydrated ferric oxide and sulphuric acid is set free.

$$FeSO_4 + O_2 + 7H_2O = 2Fe_2O_3 . 3H_2O + 4H_2SO_4.$$

This sulphuric acid reacts with the calcium, magnesium, aluminium, and other carbonates, silicates and chlorides, and forms sulphates, as gypsum, alum, etc.

Again, the iron sulphate may react directly with the calcium carbonate, which is nearly always present, and form iron carbonate and gypsum.

$$FeSO_4 + CaCO_3 = CaSO_4 + FeCO_3.$$

As the iron in an unoxidized clay is usually in the form of either the sulphide or carbonate, and since gypsum is also a common constituent, the reaction between the sulphate of iron and carbonate of lime is probably more common than that of mere oxidation and hydration. Both reactions are, however, initially due to oxidation.

Often materials are mixed with clays that carry soluble salts into them. Examples of this are the bricks made around London, in which ashes are used to reduce shrinkage, and bricks in which coal slack is used to aid in burning. In both of these cases, the soluble salts in the fuel are the chief cause of the scum.

When soluble sulphates are present in the clay, they appear on the surface of the green brick as it is drying. They are generally concealed by the similarity of their colour to that of the brick, but after burning they stand out as white specks on a darker background and the scum appears to be brought out in the kiln. The soluble salts are brought out in solution by the water, and the water evaporating leaves the salts concentrated on the surface. Trouble is encountered in all parts of the world from this source, and probably 75 per cent. of the scumming comes from this cause.

2. *Condensation Products from Kiln-Gases.*—Calcium carbonate is nearly always present in clay, often in large quantities. As this and magnesium carbonate are comparatively insoluble, they are not carried to the face of the brick during drying, but if they lie near the surface they are almost certain to form a scum by reaction with the acids in the kiln-gases, while that which lies in the interior, reacting with the kiln-gases, forms the sulphates which come out later as 'wall white.'

As before stated, nearly all shales and fireclays contain iron pyrites, which parts with half its sulphur quite readily at a comparatively low heat (400° C.). This sulphur is thus set free at a time when there is an abundance of water and oxygen in the kiln-gases, and as these pass over the lime and magnesium carbonates in the clay it reacts with them to form sulphates. These may appear as kiln white or they may remain unnoticed until the bricks are laid in the wall, when they appear as wall white. Guenther was the first to prove this in a positive manner.

The fuel used may act similarly, as it usually contains sulphur in the form of iron pyrites or marcasite, as well as free sulphur. Thus, it is possible for a clay that did not originally contain any sulphates to scum badly.

The colder the bricks the more they condense this water vapour containing sulphuric acid from the kiln-gases and absorb it. The absorbed acid acts on the lime, etc., forming sulphates which are left on the surface of the brick.

A brick set wet will scum because the moisture in it absorbs the acid vapours, and these react with the lime and magnesium carbonates as just described. As the acid may penetrate all parts of the brick through diffusion, sulphates will form and be carried to the surface of the brick as the moisture dries out.

The formation of soluble sulphates in the kiln is a very common trouble.

It is often encountered with clays that contain practically no troublesome ingredients before being fired. In many cases, there is really no excuse for trouble at this stage. It is simply due to ignorance on the part of the brickmaker or to poorly designed kilns and stacks. If good judgment is used and the smoking fires are kept at such a stage that only so much of the moisture is being driven off as the sluggish draught of a cool stack will carry, trouble is not likely to occur; but if the moisture is driven off more rapidly than the stack can handle it, it is precipitated on the ware again, when it absorbs acids from the gases and produces scum.

In a continuous kiln, this kind of scumming is due to the use of an insufficient number of chambers, or to the employment of wicket fires instead of pure hot air for 'smoking.'

Salt-glazed articles often have a coating of white crystalline scum, if the firing has not been carried out quite correctly. This deposit is usually caused by not cleaning the kiln at the end of the firing, so that on cooling some undecomposed salt is deposited on the surface of the goods and is embedded in the glaze. It may be sometimes removed by rubbing the article with a cloth moistened with dilute hydrochloric acid and then washing away the acid.

3. *Soluble Salts in the Water.*—The water used for mixing and tempering plastic clay often contains soluble salts. This, of course, produces the same effect as if the clays contained them. Many good clays are injured in this way.

If the salts notably exceed 35 grains per gallon, the water may be an important factor in causing efflorescence, since the principal salts, calcium and magnesium carbonates, combine with the sulphurous fumes of the kiln-gases, as already explained.

4. *Wall White.*—This is the scum which appears on walls some time after their erection. It may be due to soluble salts in the original clay, or formed during the burning, to the bricks standing on ashes or other unsuitable material, or to the use of unsuitable mortar. This form of scum is described separately under the caption 'Wall White.'

Methods of prevention are chiefly of three classes: those which attempt to remove the scum-forming materials; those which endeavour to convert the scum-forming salts into harmless substances; and those which consist in covering the goods with a colloid material which will absorb the salts, and will fall off when the goods are removed from the kiln.

Where the soluble salts are due to the weathering of pyrites, they may be largely avoided by using clay direct from the pit or quarry, though this will not, in all such cases, prevent the formation of scum in the kilns.

Clays containing soluble salts may be washed before using and most of the salts removed. This may be done by treating heaps of clay, after mining, with water, and then allowing them to dry. This method is only possible where high-priced ware is made. Clays are often allowed to stand in piles for from six months to a year, in which case the rain and snow do the same thing.

The removal of the salts is never complete under any commercial method of washing.

In some clays, the above methods will only increase the defect. This would be the case where a clay did not contain soluble salts originally, but upon exposure to the weather insoluble salts were converted into soluble salts, as with pyritiferous clays.

A much more satisfactory method of 'cure' is represented by the use of some baryta compound (usually the carbonate) which is added to the clay when it is being worked up with water into the plastic state. Barium *chloride* must not be used in presence of *much* sulphate, as the formation of the highly soluble calcium chloride actually increases the amount of scum. The baryta compound converts the greater part of the soluble sulphates into the insoluble barium sulphate, which cannot then rise to the surface of the goods, and hence can form no scum. It is often advisable, with some of the better-class goods, to use a little baryta or chloride of barium in addition to the carbonate, especially if soluble iron salts are present. In all cases, it is necessary to add the chemical in fairly accurate proportions, as an excess may produce the very defect it is sought to avoid. A method for determining how much baryta will be required is described later. This determination should be made at fairly frequent intervals, as the proportion of scum-forming salts in the clay is apt to vary considerably. The material is best added by making it into a cream with water and applying it to the clay by means of a watering-can or by a siphon of very small bore; the clay is then thoroughly well mixed, as it is essential that the baryta be as evenly distributed throughout the mass as possible.

If barium carbonate is used, it must be in the form of an exceedingly fine powder, the precipitated salt being very superior to the natural mineral (witherite) for this purpose.

Several clayworkers use both barium carbonate and chloride, adding enough of the chloride to overcome most of the scum and depending on the carbonate to take care of whatever whitewashing salts remain.

Baryta is, however, far less risky than the chloride, as the carbon dioxide formed in the clay during the burning usually renders it insoluble before it reaches the surface of the bricks.

A solution of barium carbonate in water containing carbonic acid gas is equally satisfactory, but is difficult to prepare.

It is often possible, when a clay shows a tendency to scum, to retain the salts inside the bricks by drying as quickly as possible.

Barium fluoride has been used to prevent dryer-scum, and according to H. F. Staley it has the following advantages:—(1) it is cheaper than other suitable salts; (2) it is more soluble than barium carbonate; (3) a smaller amount is required; (4) it has no effect on the natural colour of the goods; (5) an excess does not produce scum, as is the case with barium chloride, and (6) it promotes vitrification.

Where the clay is sufficiently refractory and a dark colour is no objection, the sulphates forming the scum may be made to combine with the clay by using a reducing fire at one stage of the burning. If the bricks can stand a still higher temperature, and the scum is composed of sodium and potassium salts, a simple raising of the finishing temperature of the kiln will be sufficient, but calcium sulphate can only be made to combine when reduced to sulphide.

Where the scumming is due to condensation products it may be avoided by heating the goods with pure air to such a temperature that the kiln-gases no longer condense upon them. For this purpose, a temperature of 120° C. is sufficient, but a somewhat higher temperature ensures all the bricks being sufficiently heated.

From this, it follows that care should be taken to see that there is a clear passage of pure hot air through the chambers undergoing 'smoking,' as only when this is the case can one be certain of the removal of the water from the goods, particularly when they are set in a very damp state.

The final class of 'cures' usually consists in painting the goods with tar, or with a starch or flour paste, or even with oil, the object being to cover the goods with a material which shall be sufficiently porous for the goods to dry rapidly and at the same time to allow the scum-forming material to be produced in or on this outer covering instead of on the surface of the goods. The advantage which such a coating also possesses is that it prevents, to some extent, flashing of the goods by the flame in the kilns; but its disadvantages are that the mass is apt to putrefy if made of starch or flour, and is in any case somewhat expensive in application. In this connection, it is interesting to note that M. Perkiewicz has patented the use of a mixture of flour and gelatin applied in a special manner, practically without cost, to the goods, which appears to overcome several of the greater disadvantages of this method of scum prevention. The method has been greatly praised in some parts of the Continent, but it has not been tried on any large scale in this country.

Some clayworkers employ sheets of paper for covering the exposed surfaces of their goods during the preliminary heating, but great care has to be taken not to use a paper with any considerable proportion of flux in its ash, or the goods will be vitrified in places. Though undoubtedly useful in a few cases, this method is not of any general application.

In those cases where the use of baryta in any form would be too expensive, it is usual to cover the scum-forming clay with an engobe of superior clay, which may or may not contain baryta compounds. The use of such an engobe is, however, attended with so many difficulties that its employment should be avoided whenever possible.

A. E. Williams states that the colour is greatly improved by spraying the column of clay with a 3 per cent. solution of ferric chloride. Some firms dip the bricks in a slip containing venetian red. Both these methods have the disadvantage that, in time, the colour wears off.

According to Dr Mackler's researches, it would appear that in the case of finished (fired) goods the amount of scum formed bears no definite relation to the proportion of soluble salts they contain, but that there is a pretty definite connection between the amount of magnesium and sodium sulphates and that of scum. The porosity of the material also seems to be of little influence, but the capillarity (or power of the material to lift liquids through its pores) is very marked. This capillarity is greater the smaller the diameter of each individual pore, hence, partially vitrified bricks seldom show any scum. The heating of the goods to the point of incipient vitrification is, in fact, the best remedy for scum, as in this way the salts combine with the alumina and silica of the clay. This is, however, impracticable in many cases, as the colour of the goods would be thereby spoiled.

There is no rapid method of determining whether a particular batch of goods will scum or not during use; but Dr Mäckler has found that the method described in Chapter XIII. gives excellent results, and is, in fact, so delicate that it will produce a noticeable scum in cases where the same goods, under less severe conditions, would be free.

Settling of the glaze-slip is to be strenuously avoided, as if it is allowed to occur, the fusibility of the glaze will be altered owing to the lighter constituents being removed in the dipping, whilst if the glaze is a stained or coloured one, the colouring material will be applied unevenly to the goods.

The only way to prevent this is to keep the glaze well stirred up whilst in use, though the addition of a very small quantity of finely powdered glue, previously dissolved in a little hot water, to the slip will sometimes be found to be of value in keeping the heavier particles of material longer in suspension.

Shelling or peeling of the engobe or of the glaze is due to the glaze and body not being properly adapted to each other, and so not expanding or contracting to the same extent when the temperature of the goods is changed. This lack of agreement may be owing to the use of a glaze of unsuitable composition, or of an engobe containing too much plastic clay; or it may be that the heating of the kilns has not been so arranged as to give the materials the desired composition; that is to say, the molecules may not have had an opportunity to arrange themselves in such a way as to produce the desired compound, even though the recipe has been closely followed in making up the engobe or glaze.

It may also be caused by the glaze coming into contact with a current of air during cooling either through opening the kiln too soon or through holes in the kiln walls. A thin film of dust on the articles previous to their being glazed will also cause them to peel or 'shell.' If the glaze is applied to the ware by a painting process and care is not taken to secure perfect adhesion between the glaze and the clay, shelling will be produced. This is particularly the case when the glaze-slip is solidified by the addition of gelatin.

Shelling is largely produced by causes of an opposite nature to those producing crazed ware; further information as to these causes will be found under 'Peeling.'

Occasionally, a piece of glazed ware will show both shelling and crazing. It will then be found that the latter precedes the former, of which it appears to constitute an earlier stage.

If the shelling begins during the drying, it is probable that the slip-clay is too plastic, and that the addition of a little flint would reduce its contraction and so make it adhere satisfactorily.

If, on the other hand, the shelling is not started in the drying but only in the kiln, the remedy is less easy to find.

What is sometimes known as 'shelling' in the case of unglazed goods is really a form of lamination (p. 195) due to lime particles immediately below the surface of the goods, or with a clay of a very close plastic nature, to careless drying before putting it into the kiln. The most simple and effective remedy for the latter is to thoroughly dry the goods before they go to the kiln.

Roofing tiles made in a hand-mould are seldom found to shell, whilst those made in a machine-press are seldom entirely free from this defect, unless fired at so high a temperature as to partially vitrify them. This is chiefly due to uneven pressure in different parts of a machine die. There are four methods by which this can be avoided: (*a*) by the use of suitable clay worked in a suitable manner; (*b*) by preparing the clay very thoroughly, and seeing that it is properly treated throughout the whole course of manufacture, as small defects in the presses will often cause serious shelling; (*c*) by firing the clay thoroughly: fully vitrified tiles seldom shell, whilst porous tiles, especially with a compressed or glazed face, usually do so: under-fired tiles should be re-fired; (*d*) the tiles must not be set in cement or hard-setting mortar, nor fixed so tightly in any other way that proper expansion is not allowed for.

Other forms of 'shelling' are described later under 'Spalling.

Shivering is a variety of 'peeling' which may be produced by adding flint which has been too finely ground or an excess of fine silica to a body. The addition of grog will not stop this defect, and only the removal or non-addition of the excess of silica is of any use.

Shrinkage of clay goods on firing is not in itself a defect, but when the change in volume takes place irregularly so that the goods lose their symmetrical shape and 'warp,' there is something abnormal. This will generally be found to be due to carelessness or lack of skill in the drying or placing of the goods in the kiln, or to attempts at mending damaged or incomplete pieces with clay of unsuitable stiffness. It is less frequently due to some other class of clay having become mixed with the bulk of clay used. Shrinkage may usually be reduced by adding a non-plastic material.

When the body is covered with a clay engobe, the latter, if it shrinks more than the former, will tear or peel, and this must be remedied by the addition of more siliceous matter in the form of sand, quartz, or flint, or by replacing some of the clay in the engobe by one of a more refractory nature.

Excessive over-firing will raise the temperature of the clay too near to its softening point and so cause the goods to shrink unduly (see also 'Irregularity,' p. 194).

Smoked Ware is really a misnomer, as the appearance which characterizes it is not due to smoke, but to the reduction of the lead in the glaze. The name is presumably derived from the curious discoloured appearance of the ware, sometimes resembling smoked glass. It is commonly caused by allowing the grate-bars to become choked with clinkers so that the kiln-fires are not supplied with sufficient air, though it may also, in some measure, be due to the use of inferior fuel. This latter may produce a large proportion of clinker, especially if it contain much pyrites, and so render it difficult for the fireman to keep his bars clear. The remedy is to use a fuel as free from fusible ash (clinker) as possible, and to allow the fires to burn quite clear before stoking and charging with fresh fuel, at the same time taking care that they do not burn so low as to actually lose heat in the kiln. Great care must also be taken that sufficient air is supplied to the fuel, particularly at the finishing of the firing, and on the introduction of each fresh charge of fuel. If, in spite of such precautions, the ware is still found to be smoked, the flue-gases from the kilns should be analysed to determine whether they contain reducing gases; if so, the air-supply will have to be still further increased. True 'smoking' cannot occur in leadless glazes, unless they contain colouring matters which form dark-coloured compounds when heated in a reducing atmosphere: defects of this kind are usually more of the nature of 'discolorations' (p. 188).

Soluble Glaze is a matter with which some potters have had difficulty. The solubility may apply to the glaze as a whole, or it may only refer to the presence of lead in a form in which it can be extracted by water or weak acids. This latter difficulty has been made prominent by the action of the Government in restricting the use of lead in glazing. It is, of course, important that pottery used for domestic purposes should not yield lead to the fruit juices or other substances used for food, and for certain technical purposes it is necessary that the glaze should be capable of resisting the action of relatively strong acids, such as vitriol. Professor Thorpe has found that if all the bases in the frit are calculated as PbO and all the acid radicles as SiO_2, and the ratio of these two results is not greater than $1{\cdot}45 : 1$, the frit will yield practically no lead to acid of the nature and strength proposed as a Government standard, consequently, frits can be made with a considerable proportion of lead (up to 59 per cent. PbO) and yet be quite insoluble under the conditions of the Government test (p. 275).

Lack of resisting power and solubility in a glaze are usually connected with its fusibility, the more highly refractory glazes being the most resistant. This is, to some extent, due to the fact that in these latter glazes silica (flint) takes the place of the borax used in the ordinary glazes; hence, the replacement of boric acid by silica, or of borax by soda (or lime) and silica, will usually bring about the desired insolubility, but at the same time the fusing point of the glaze is materially increased. In our present state of knowledge, it is not possible to combine high resisting power to chemicals with low melting point in a glaze.

Spalling or 'slabbing' in clay goods is usually a result of lamination, and is a very serious difficulty in the manufacture of drain-pipes and some other extruded articles. Some non-plastic materials spall badly when subjected to too sudden a change in temperature, silica and magnesia bricks being particularly subject to this defect. The defect is caused by the substance being in an unstable condition, and it can only be prevented by heating the materials long enough at a sufficiently high temperature that equilibrium is obtained. Thus, by heating the silica or magnesia at a sintering temperature until there is no further change in specific gravity, and using such 'shrunk' material instead of that calcined at a lower temperature, the spalling will, to a large extent, be avoided. The chief cause of spalling in clay ware is too stiff a paste in the extruding machine (*e.g.* pipe press), which causes undue friction at the mouthpiece, though its effect may not be noticeable until the action of heat in the kiln has produced spalling. The remedy, in such a case, is to ensure proper lubrication of the mouthpiece or to adjust the plasticity of the paste to suit the machine. Spalling may also be caused by the imperfect construction of the air-valve in a pipe machine, whereby air is 'locked' in the clay paste and cannot escape until, in the kiln, the heating of the air increases its pressure, which is eventually relieved by the spalling. Air entrapped in this manner may also cause blisters (p. 179)—a defect which frequently occurs simultaneously with the spalling. Another cause of spalling is the excessive plasticity or adhesiveness of the clay used. This may best be avoided by the addition of grog to the clay used for making the goods.

Spitting-out may, like blowholes, be caused by the goods being placed in the kiln whilst too damp, the result being that the steam produced by the evaporation of the moisture forms a miniature volcano as it leaves the clay. Pyrites and similar materials will also cause 'spitting'; they indicate that the clay has not been sufficiently carefully picked over before grinding. If the spitting is due to the presence of organic (combustible) matter on the surface of the clay, greater care must be exercised in the superintendence of the works in order to find at which stage this particular impurity is introduced. Air-bubbles in the clay due to insufficient pugging will also cause this defect. 'Spit-out' is most abundant when the atmosphere in the kiln is alternately reducing and oxidizing, the former producing hydrocarbon gases which are absorbed by the hot glaze and then oxidized, with the production of a still larger volume of gas later. Some hard glazes, fired at such high temperatures that it is almost impossible to avoid a certain amount of reduction, appear to absorb hydrocarbon and other gases whilst molten, and evolve them again in the cooling. The same phenomena is frequently observed in molten slags which have been cooled suddenly.

In the Potteries, the term known as 'spit-out' is used to denote the formation of bubbles and the consequent breaking up of the surface of the glaze on being re-fired in a kiln at a temperature inferior to that of the glost oven, provided the temperature of the kiln is high enough to soften the glaze and allow the bubble to form. If the fire be continued long enough, the bubble will burst, leaving the edges sharp. These do not heal, as the temperature reached is not sufficient to allow the glaze to flow.

This is a highly complex phenomenon, but Moore and Mellor have been able to trace it to a number of antecedents, some of which relate to the body of the ware and some to the glaze, though they attribute most 'spit-out' to the presence of moisture or organic matter in the body. This moisture or organic matter escapes by forcing a passage through the viscid glaze. Old ware spits much more than new because of the greater absorption of water. The chief remedy, therefore, appears to consist in ensuring complete oxidation of the organic matter in the first firing and the storage of ware under such conditions that it cannot absorb moisture.

Splitting of the body of the goods is generally due to lack of care or skill in the making of the goods, faulty jointing, etc., but it may also be caused by the goods being improperly dried (one part being allowed to dry too rapidly), to draughts, to too rapid changes in temperature, or to unsuitable placing in the kiln (not setting the goods level, not supporting them properly, or piling them too high upon each other). This last is one of the commonest causes of this defect.

Lack of sufficient support to projecting pieces during the drying of elaborately shaped articles, the use of too plastic a clay which is, consequently, dried too rapidly, and slight, yet important, defects in the mouthpieces of machine presses, are other frequent causes of this troublesome defect. (See alse 'Lamination.')

Spots may be due to a great variety of causes. If coloured, they may be a species of 'discoloration' (p. 188). They are chiefly of two kinds, according as they are due to impurities in the material itself or to external influences.

If the spots are on the terra-cotta, or biscuit, they may be caused by pyrites existing in a finely divided state in the clay, indicating imperfect sorting or 'picking' of the clay. *Iron* in other forms will also produce black or red-brown spots, the exact source of the iron being often very difficult to determine. Sometimes it may be traced to the workmen filing their tools at the bench where the clay goods are made; at other times, the cause of the spots may be found to exist in the oil used (for lubricating machinery) containing iron and getting into the clay or on to the goods; or, again, it may be traced to the use of dirty sand in the saggers, so that it gets on to the goods when the saggers are being placed in the kilns. The remedies in such cases are obvious, but the substitution of sawdust on the knocking-out block in the last case deserves special mention. White spots on unglazed ware are usually due to the crystallizable salts in the clay being carried to the surface of the clay during the drying, and showing themselves later in the form of white spots or 'scum' (p. 201).

Yellow spots are often due to soluble iron compounds in conjunction with lime in the clay.

Raised spots are usually the result of dust or sand falling on the goods in the kiln; sometimes this happens when one sagger is being placed on another.

Spots in the glaze may be due to the workman allowing tiny drops of slip to fall on to the ware, to the glaze not being completely melted, or to its being imperfectly mixed, or to its being insufficiently finely ground or sieved. Dust falling on the goods will also produce raised spots more or less covered with glaze, whilst most of the causes of 'spitting' will cause the formation of 'spots' of various sizes which are raised somewhat above the general level of the glaze. Coloured spots in the glaze are mostly due to accidental impurity, a few grains of some 'stain' having got into the glaze (see 'Discoloration' and 'Pin-holing').

Stains may be in masses or in spots. (See 'Discoloration' and 'Spots.')

Starred Glazes are due to crystallization (p. 188), the forms of the 'stars' frequently indicating the constituents of the glaze of which they are formed.

Starving may be caused by stopping up the mouths of the kilns with fuel, thus lessening, or even stopping, the draught. As a result of the insufficiency of air thus caused, the fires at the back of the mouths may almost die out, and so may admit cold air into the flues and make successful firing impossible. 'Starving' is also a result of not pushing the firebars well on to the brickwork supports at the back of the fire-boxes; air can, therefore, leak into the flues behind the bars without being properly heated by the fuel, and so will not only diminish the draught but may also keep certain parts of the kiln constantly at a very low temperature, so that the glaze is never properly fluxed.

'Starving,' in other words, is almost invariably due to lack of sufficient air at the fire-grate, and it may, consequently, be remedied by arranging for a better or larger air-supply to the fuel.

Sticking of goods to each other is usually due to a partial vitrification or to their coming into contact whilst the glaze on one of them is still fluid. It is usually a sign of careless setting in the kiln, or of over-firing.

Sometimes trouble is caused by unfired articles adhering to each other, as when roofing tiles are made by the wire-cut process, and are piled on each other. The use of a little grog, flint, or sand will often assist in preventing adhesion; sometimes the use of a leaner clay paste will give an improved material and will reduce the sticking.

Careless handling during transport to the dryers and kilns is responsible for many 'stuck' tiles, for each time that one is laid suddenly or rapidly on another the tendency to adhere is increased. Just as a brickmaker secures perfect adhesion of the different pieces of clay by bringing them sharply down on to each other, so dropping a tile suddenly on another, or on a pile of tiles, will almost certainly cause some of the lower ones to become fastened to each other, though this may not be discovered until after the kiln has been drawn.

It not infrequently happens that the burner is blamed for over-firing and causing goods (especially tiles) to adhere to each other when the real fault is with the setters, who have not placed them with sufficient care.

Streakiness in glazed goods may be caused by the fineness or coarseness of the glaze itself, or by unskilful application. In vessels with very uneven surfaces the glaze is apt to collect more thickly in the hollows and to run off the higher portions. When this is the case, the glaze will have to be 'touched up' before the goods are placed in the kiln, so that these tendencies may be counteracted. In some cases, very pretty effects are produced by allowing the glaze to run in certain directions. As a general rule, when ware is dipped it is best to have the glaze finely ground, as it dries more slowly in this condition, and so allows a more even distribution of the glaze on the surface of the goods.

Stripping-off of the glaze or engobe is due to these not having a similar contractibility to the body of the ware. It is a special difficulty in the case of white enamels which contain tin as an opacifying medium, particularly when this substance is present in large proportions, *e.g.* over 20 per cent. Being due to the oxide of tin itself, this defect can only be remedied by a series of extremely careful experiments in altering the composition of the enamel without losing its opacity and gloss.

In glazes free from tin, it may generally be remedied as described under 'Peeling.'

Stunting. See 'Cracks.'

Sulphates, whether in the clay or in the water used, are apt to cause the formation of an efflorescence or scum on the goods. This is best prevented by the use of baryta compounds or by covering the goods with an engobe (see 'Efflorescence' and 'Scum').

Sulphates are also apt to cause turbidity in the glaze, as they may, under certain conditions, liberate free silica.

It is commonly understood that sulphates in glaze will produce bubbles, black spots, and 'spit out' under certain conditions which are, at present, but imperfectly understood.

By the use of a reducing fire at an early stage of the firing, the sulphates may be, to some extent, decomposed and their defect-producing power destroyed.

Sulphur compounds occur to a notable extent in many coals and produce characteristic effects. This effect can only occur when there is insufficient air in the kilns and fires, as, except in the case of the very worst fuels, the sulphur dioxide produced from fuel should be carried off before it can affect the goods. Sulphurous gases—derived chiefly from the coal and from the decomposition of gypsum in some clays—may easily form 'kiln white' or 'scum' on moist, unfired clay, and in contact with a molten glaze may produce a dullness technically known as 'blinding' (p. 179). 'Feathering' is also caused by the action of sulphur (oxidized to sulphuric acid) on glazed ware. As it does not usually pay to attempt to purify the fuel, care should be taken that the coal used is reasonably free from sulphur compounds.

Sweating of the glaze is referred to under 'Running' (p. 201).

Swelling of the glaze is often noticed when a kiln has been seriously under-fired, so that the glaze has just begun to melt but still remains porous and dull; on further heating to the necessary temperature the swelling will disappear and a normal result will be obtained, provided that the glaze has not lost too much of its more volatile constituents by prolonged exposure to heat.

Swelling of unglazed goods is usually due to their having been placed in the kiln in a very damp condition, and then having been so rapidly heated that the moisture or burning organic matter could not escape without the exercise of considerable force.

If clays containing much organic matter are rapidly heated, this matter will not burn properly and may cause swelling and the formation of a 'core' (pp. 9, 171, and 182). Other causes of the swelling of unglazed goods are:—

(*a*) insufficient pugging of the clay; (*b*) not giving the goods sufficient time for drying before putting in the kiln; (*c*) rushing the fire too much while 'smoking' (pp. 169, 170).

Temperature being of the highest importance in the firing of the kilns, as well as in the drying of the goods, great care should be taken in regard to its measurement and regulation, as errors in the temperature of the goods at various stages of the manufacture may prove to be a source of enormous loss.

Thinness of the goods is a matter for which the designer and maker are responsible. As goods alter in shape in the kilns in proportion to their thinness, care is required to adjust this to the purposes for which the articles are required.

Thinness in the glaze on the surface of the goods drawn from the kiln is due to an insufficiently thick coating of glaze. This may be caused by the glaze-slip being too watery, to its having settled somewhat, to its not having been properly stirred up before use, or to the dipping having been done too rapidly. When other methods of applying the glaze are in use, the defect will be found in the majority of cases to be due to an insufficient coating of glaze material on the goods.

It occasionally happens that if a piece of glazed ware is placed too near to an unglazed surface in the kiln, the latter will 'rob' the former without getting glossy itself. The cause of this curious action is by no means fully understood.

Turbidity in a glaze is most frequently the result of under-firing, the glaze not being properly fused. Sometimes, the accidental admixture of some infusible matter, particularly clay-slip, will be the cause, and, less frequently, an error in the proportions of the different materials used in the compounding of the glaze. When the defect is very pronounced, a curious egg-shell appearance is produced which, on re-firing at a somewhat higher temperature, will be converted into an ordinary transparent glaze.

Minute bubbles of air or gas which have not been able to escape, owing to insufficient time being allowed for the glaze to mature, are occasionally observed, particularly when the glaze contains compounds which evolve oxygen at high temperatures.

Prolonged heating of the glaze at temperatures below its melting point is apt to produce turbidity owing to some of the alkali (flux) in the glaze being volatilized. This may be remedied by a more rapid heating at the earlier stages, or by the addition of as much more alkali to the glaze before use as will counteract that lost in the kiln; great care is, however, necessary, as too much alkali will make the glaze 'trickle' or 'run,' and will often be the cause of its crazing.

When the turbidity of a glaze is due to sulphur compounds, the quality of the coal used needs attention; but even with good coal and a highly reducing atmosphere, insufficient air-supply to the fires will cause turbidity. When large proportions of sulphates are present in the glaze, free silica will sometimes be formed and so cause turbidity; this may be prevented by the use of a slightly reducing atmosphere in the kilns up to just past dull red heat, and an oxidizing one for the remainder of the firing. In this way, the sulphates will be decomposed before they have time to liberate the silica. Great care is required with reducing fires that no soot is formed on the surface of the goods, as this would, later, become surrounded by the melted glaze, and no amount of heating would then cause its oxidation. (See 'Blinding,' p. 179.)

Twisted Ware. See 'Crooked Ware' and 'Warped Ware.'

Under-firing is one of the great troubles of the clayworker. As a general rule, it is far better to over-fire than to underdo it, as in the former case probably only a few goods will be spoiled, whilst in the latter case none of the goods will be worth much. The whole question of firing requires careful study on the part of both masters and men. Some further details will be found on pp. 160 to 175.

Unevenness in the glaze or engobe may be due to careless application, but it is not infrequently due to the running of the glaze. This latter is especially the case with ornamental ware in high relief. If the glaze is too soft or fusible, it will tend to collect in depressions on the surfaces of the goods, whilst if it be too hard and infusible it will not flow evenly over the surface.

Raw glazes containing soluble matters will usually produce an uneven surface, as these matters are carried to the surface in the drying of the glaze. The remedy is to frit such glazes (p. 25).

Some glazes settle rapidly, and so that an even mixture of their components cannot be applied to the goods. In such a case, the addition of a little powdered alum is sometimes useful, or the addition of 2 or 3 per cent. of gelatin[1] to the slip (the gelatin being previously dissolved in about four times its weight of nearly boiling water) will convert the slip into a stiff blancmange-like mass, which can be applied to the goods like a paint. Being solid, the material has the advantage that colouring materials can be added to the glaze with the certainty that, so long as the gelatin does not melt, the colour must be applied evenly, no matter what is its relative density (p. 135).

Unevenness in colour is chiefly due to 'settling' of the colouring matter in the glaze, to careless application, or to bad firing. In the first case, the use of some denser medium for carrying the colour is necessary (the use of gelatin, as just described, being suitable in stained glazes, or, where this is impracticable, fritting (p. 25) may be employed), whilst in the two latter more careful superintendence of the workers is necessary. If it is important to have a number of goods of exactly the same shade, it is desirable not only to have them coloured at the same time and with one mixing of material, but to fire them in approximately the same positions and all in one kiln. If this is not done, the many factors which can influence the shade of ware will render it almost impossible to obtain a perfect match.

Vitrified Ware, in the sense of defective ware, is the result of fluxing material in or on the goods. It is sometimes produced when non-porous, unglazed ware is made of clay which has been very badly mixed, so that the flux occurs in pieces instead of being properly distributed throughout the mass.

Patches of vitrified matter are generally the result of drops or splashes of glaze falling on to the goods, or if the goods are fired at too high a temperature the material may partially melt or vitrify. Attempts have been made to utilize this effect in the production of self-glazed articles.

If the finishing temperature of a kiln is sufficiently high, the 'scum' on the surface of the goods (p. 201) may fuse and produce an appearance of vitrification, though in reality only an extremely small portion of the surface is affected.

To determine whether a brick is partially vitrified, it is not sufficient to see that the surface is non-absorbent; the brick must be broken so as to expose a portion of the interior, and this must be examined before a definite opinion can be rightly expressed.

Wall White is a whitish scum or efflorescence which forms on goods after they have been erected. This scum is simply a film of soluble salts carried from the interior of the article to the surface by the water which they absorb,

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[1] Powdered glue of good quality may usually be employed instead of the more costly gelatin.

and left there after it evaporates. It is always worst near the eaves, spouts, window-sills, and water tables of buildings. The composition of wall white is somewhat more varied than 'kiln white,' as several additional factors enter the production. Magnesium and calcium sulphates are the most constant constituents, though sodium and potassium sulphates and chlorides may be present.

The scum is not always white, but may be tinted with green, probably due to either iridium or chromium, but care must then be taken not to confuse it with the tiny green plants (algæ) which frequently occur on walls.

Wall white is produced from salts occurring naturally in the clay or water used in manufacture (p. 204), from salts formed during the burning (kiln white, p. 194), and from the absorption of water containing salts after the goods have been made.

The prevention of the two first-mentioned forms is the responsibility of the manufacturer; the last named is commonly due to stacking the bricks on ashes or on some other unsuitable foundation. It may, however, be due to the mortar used.

If the scum is due to the goods drawing up moisture partially saturated with salts, the only preventative is to take care that this absorption of salts cannot take place in future by altering the material on which the goods are laid.

If mortar containing a considerable proportion of soluble matter is the cause, the scum will be more evenly distributed over the surface of the wall, instead of only a few feet from the ground. Scrubbing the scummed surface with hydrochloric acid diluted with about ten times its volume of water will often effectually remove this class of scum, but care must be taken not to allow the acid to come in contact with the mortar.

If goods scum during use, owing to improper firing, they cannot, of course, be cured, except by altering the firing or some other part of the manufacture, so as to prevent the formation or to secure the destruction of the scum-forming salts in the interior of the brick (p. 201 *et seq.*).

E. Cramer has pointed out that a reducing fire is often helpful in such cases, as the sulphates are decomposed by this means; but great care is required, or the use of a reducing fire will be found productive of almost innumerable difficulties.

Many bricks contain sufficient salts to produce wall white under certain conditions, but this defect chiefly manifests itself where there is an ample supply of water in the brick, but not sufficient rain to wash the salts off the surface. Hence, the portions which are scummed the worst are on the less exposed parts of the structure.

Pressed bricks are especially liable to show this defect on account of their dense, smooth surface. Sand-faced bricks dry more readily, and do not so easily show any scum which may rise to their surface.

Warped Ware (see also 'Crooked Ware') is chiefly due to bad placing in the drying shops or kilns, to over-firing, whereby the materials are partially melted, or to faulty workmanship on the part of the maker or designer. Warped ware may also be caused by working the clay too wet or through not pugging it enough. If the clay is laminated or not uniform in composition, the goods made from it may warp badly.

With articles made of complicated mixtures of clay, spar, etc., warping may be due to an error in mixing the body, though the other causes are by far the most frequent. Warped ware is usually preventable, though in the case of large tanks with thin walls, and vessels or articles of peculiar shape, it may not be possible to prevent some alteration of shape. Much may, however, be done by the addition of non-plastic material to the body, by the skilful use of props and supports for the portions of the articles most likely to warp, and by the exercise of special care with slow drying and firing.

White Patches or spots on coloured ware are usually due to accidental splashes of clay or engobe, or to the glaze being only partially fused. In the former case, the defect is scarcely to be removed, though it may perhaps be painted over; in the latter, re-firing, possibly at a slightly higher temperature, will often effect a cure. (See also 'Turbidity' and 'Scum.')

White patches on brick walls are known as 'wall white' (p. 214).

Whitewash is a term sometimes used in place of 'efflorescence' (p. 191), 'scum' (p. 201), or 'wall white' (p. 214).

Wrinkled Faces on bricks have sometimes been met with in cases where the firing of the kiln has been erratic, and where a strong reducing atmosphere has made it possible for some silica to volatilize and to be deposited on the goods. This siliceous deposit may, apparently, be formed at a comparatively low temperature, and as it will not shrink with the contraction of the clay, wrinkles are formed. This is only a suggestion as to the cause: the cure consists in keeping a watch on the air-supply to the fuel. Wrinkled bricks may also be produced by excessive condensation of moisture on the goods owing to setting them too damp into the kiln, or to using a kiln with a bad foundation. The bricks become soaked with water, and any uncovered surfaces may thereby be spoiled. Greater care in the earlier stages of burning will prevent this defect.

Wrinkled portions of glazed surfaces are an early stage of 'shelling' or 'peeling.'

CHAPTER XII.

WASTE.

THE subject of waste, though treated separately here, is only dealt with briefly, because many defects of working and management which produce waste have been pointed out in other sections, and the subject is too complicated to be compressed into a few words.

Waste may be considered in relation to goods, materials, power, and management, but, in whichever department of the works or offices it occurs, it is invariably included in the profit and loss account, though its identity is often hidden. In other words, it is the money value of waste which must be judged, for if this is not taken into account a more serious loss of money may result from the 'cure' than was caused by the 'disease.'

Waste of Goods may be due to (1) over-production, so that the goods spoil, get damaged, or become out-of-date and, therefore, valueless; (2) carelessness in handling, whereby the goods become damaged, or broken or dirty. Under this heading must be included faulty picking of the clay, or carelessness of the workmen in allowing food, paper, or other foreign matter to become mixed with the clay, and of the dippers, artists, etc., who get colour or glaze on the wrong parts; (3) so-called 'unforeseen' damage due to defective warehousing, draughty or leaky workshops, resulting in warped, cracked, or spoilt goods.

Most of the above defects and loss may be remedied by careful and thorough foremanship and management, ever remembering that 'a patch in time saves nine' when a tile comes off the roof or a window-pane is broken.

The question of dirt getting into the goods is a more serious difficulty in some works. It is generally imagined that the cost of keeping the works clean is so much waste money, yet this is by no means always the case. In how many works, for instance, is the clay allowed to be trodden under the feet of the makers until the parts of the floor not actually used for goods become noticeably higher than the rest? This clay is cleaned out when it becomes too much of a nuisance, and, being so dirty, it must be thrown away, whereas the use of boxes or tubs in which the workmen might throw the scraps of clay would entirely prevent this waste by enabling the clay to be returned to the mill and worked in with the fresh clay. In addition to this, it is always found that the workers do more and better work when the place is kept clean, and the management is rendered easier, for in a clean works untidiness and dirt are readily detected and stopped. There is also their influence on the customers who now and again wish to glance through the works, and who are more likely to place their orders in a clean and tidy works with a business-like appearance than with one of the tumble-down affairs so frequently seen, in which an architect fears to enter a building lest he breaks his neck, or risks spraining his ankle in the yard. In the more delicate branches of clayworking this cleanliness is more adequately observed, but a visit to some of the Continental brickyards would astonish some of our British foremen and owners.

One effective way of keeping the clayhouse clean is to have one man to do all the transport, instead of a lot of boys or girls larking around the clayhouse, as is often the case at present. The difficulty that 'the makers provide these young people' can be easily got over with a little tact, and the additional cleanliness of the clayhouse or sliphouse will rapidly repay the trouble of making the change.

Intimately connected with the question of dirt in the works is the question of drainage, for, if this is not properly arranged and maintained in order, the works can never be really clean. In most works, the difficulty is not so much how to obtain water, as how to get rid of it when it has entered the works in the form of rain or snow. Yet on the successful solution of this problem depends one of the first means of clean (and to this extent economical) working. The clayworker should, therefore, see that the drains are attended to at fairly frequent intervals, especially during the wet season.

Carelessness with regard to the proportion of the various constituents in a body is a frequent cause of waste. Closely related to this is the addition of water in irregular or unsuitable proportions to the clay or body; the loss from this source may be largely reduced by the use of two taps on the water-supply, one of these being adjusted to give the right quantity of water and the other to turn the supply on or off as desired without altering the adjustment of the second tap.

Waste due to careless handling of the goods should be thoroughly investigated, and the offender charged with some or all of the loss. (Care must be taken not to break the Truck Acts in making these deductions from the men's wages.)

Inaccurate and damaged work is often produced by wrong methods of handling the goods, particularly when they are in a tender state. Bricks, and many other articles made of a delicate clay, should be carried on pallet boards and not in the hands, as the latter exert too much local pressure. With forethought and a little practice, the use of pallet boards is no slower than any other method of handling ware, and the cost of the boards is more than compensated by the reduction in the number of goods damaged. In many brickworks, the setters or placers are the chief cause of damage by carelessness; if they space the goods or saggers irregularly in the kiln, the ware can never be evenly burned. Greater care in this respect would usually prove remunerative, but it is difficult to secure unless the men are paid a bonus for good ware.

Much loss by carelessness may be avoided and most of the waste due to breakage in handling prevented by keeping a strict record of the stage of manufacture at which each article was broken, and by making each man responsible for the ware under his charge until it has been definitely removed by another who then assumes the responsibility. The stock in charge of each man should be checked weekly, and suitable reports made with respect to all damaged goods.

Waste of Materials is a more difficult matter to control than the loss of goods made in the works. Under this heading are included raw and finished materials (clays, fuel, glaze materials, colours, etc., as well as tools and machinery). Wastage of materials is chiefly due to improper use, to improper materials or slow and out-of-date machinery, or to a direct 'throwing away' of the materials.

Under 'improper use' is to be included the ignorant or careless waste of fuel in the kilns or boilers; the employment of a needlessly expensive glaze, clay, or fuel comes under the term 'improper materials,' as does also the use of needlessly heavy machinery or of blunt tools. At the same time, the opposite extreme must be avoided, for if, *e.g.*, an excessively cheap fuel is purchased, its heating value may be so small that it may prove dearer in the long-run than a more expensive one. The only correct way of valuing fuels is to determine their composition and calorific power, or, if a less accurate criterion is sufficient, the amount of combustible material per pound of fuel, and to calculate the costs of such weights of the fuel as will furnish a given number of heat units or of pounds of combustible matter. Tests of this kind will rapidly show the best kind of fuel for the purposes of the clay-worker, and will also show the necessity of proper storage, for the calorific power of wet fuel is much lower than that of the same fuel when dry.

The chief waste of fuel occurs in the firing of boilers and kilns, for if too much or too little air be supplied to the fuel, loss will occur (see pp. 61, 160 *et seq.*).

The chief loss of heat in kilns is due to the defective supply of air, resulting in unburned fuel passing up the chimney and to the absence of any means of using the surplus heat. The formation of soot and smoke are also important sources of loss of heat, whilst irregular or improper attention to the fires may result in unnecessary burning of large quantities of coal. A careful comparison of the fuel used each time a kiln is burned will, eventually, enable a standard to be determined for that kiln, and this should not be exceeded without a very special reason.

Much fuel is wasted in stoking boilers and in admission of air to the flues through leaks in the walls. Most boilers are fitted with grates which are 25 to 40 per cent. too long. If one-quarter to one-half of such grates are covered with a fireclay slab so as to decrease their length, less coal would be used, but it would be burned more efficiently and would produce just as much steam as before. The following precautions should be taken to secure the maximum amount of steam with a minimum of fuel:—(1) don't use more air than is required; (2) keep the furnace temperature high; (3) keep the fire grate completely covered with fuel; (4) do not remove unburned fuel with the clinker; (5) do not allow the temperature of waste gases in the chimney to exceed 400° F.; (6) keep the brickwork in good condition and well tarred or painted so as to avoid leaks; (7) keep pipes well covered with insulating material; (8) re-use all condensed steam; (9) do not use cold water to feed the boilers; (10) repair all steam leaks immediately.

Wastage of clay and glazing materials, when not due to carelessness on the part of the users or makers, is often difficult to detect. In many works, difficulties and loss arise through the desire to economize by buying 'cheap' lines, which are seldom satisfactory unless there is someone on the works who can thoroughly test the materials and ascertain their correct strength and value. Felspar, to take only one instance, is frequently sold with a very different composition from that of normal spar, and yet the price is but little lower than that of the best felspar.

The composition of glazes and engobes is a matter about which the proprietor knows little, as a rule; but care should always be taken, when a change is made on the score of economy, that a real saving is effected and not a loss incurred, as in a recent case, where a minute proportion of zinc oxide in a glaze rich in Cornish stone being considered extravagant, a glaze containing over 50 per cent. of felspar was substituted, with the result that the cost was increased by 30 per cent.

If sufficient material can be stocked at one time, or if the composition of the material may be relied on, considerable sums may often be saved by the use of substitutes for some of the ordinary glaze materials; but, the use of these being to some extent experimental, and the composition of the raw materials being subject to considerable variation, it is useless to attempt this kind of economy unless a new supply may be thoroughly tested before the old is finished. With the better-known glaze materials, this testing is not nearly so essential, though it is always advisable.

By far the larger proportion of waste in clay and glaze is due to carelessness, or to want of proper provision for scraps. The result of this is that in the course of a year an amount of material is thrown away as dirty or useless which might, in the majority of cases, have been utilized for a cheaper line of goods or for some portion of the goods less readily seen; whilst much of the clay now allowed to pass away as dirty might, with suitable provision on the part of the management, have been kept clean, so that it only requires working up again to be fit for use. This is especially the case in the sanitary (fireclay) trade.

In a pottery using, say, three kinds of clay in the same workshop, much liability to confusion may be easily avoided by staining two kinds with aniline dyes, such as methylene blue or magenta, or one of the stronger greens. These colours will burn out completely in the kiln, and the amount added need be so small that the porosity of the clay is not affected. This method is particularly applicable to clay made up from scraps, in order to distinguish it from that to be used for best work. The much-used method of distinguishing various clays by setting bits of coal, clay, or stilts on special boards of special ware is far from satisfactory, as these bits are so liable to be lost.

The utilization of *waste products*, such as broken pots (sherds) and old plaster moulds, is a more difficult problem. Beyond mixing a certain proportion of the finely ground sherds with the raw clay in order to lessen its rate of contraction and make it firmer in the kiln, or to reduce the plasticity when the clay is too strong, there are but few uses for the sherds. Some experiments in the bacterial purification of sewage would lead one to suppose them to be superior to coke for filling the beds, but the cost of carriage would probably prevent their extensive use outside the Potteries. Attempts to use ground potsherds and cement in the preparation of artificial stone have not been commercially successful, as sand has proved cheaper owing to its being already in a powdered state.

Many attempts have been made to re-burn old plaster moulds, but this has never been commercially successful; and endeavours to include ground moulds in the plaster mixture used for new ones have resulted in a loss rather than a gain, as the moulds thus made wear out more rapidly and deliver less easily than those of new plaster. These two sources of loss, serious though they are, are at present unavoidable. This does not mean that they will ever remain thus, for a fortune awaits the man who can find a profitable use for them on a large scale.

Saggers are another item in which a considerable waste occurs, part of which is certainly avoidable, being due to making the saggers of improperly ground clay. In saggers and other goods which have to withstand repeated heating and cooling, the sizes of the grains are both very numerous and highly variable in their relative proportions; and manufacturers would be wise in experimenting in this direction. The proportions differ so greatly with the different kilns used, as well as with the sizes of the saggers, that general details would be useless. Suffice it to say that a satisfactory, or reasonably satisfactory, sagger-clay having once been obtained as the result of careful experiments and trials, this clay should be carefully sifted (before firing) through sieves of various sizes and the proportion remaining on each carefully noted for future use. As a rule, the greater the proportion of fine clay in the sagger the shorter will be its life; a certain proportion is, however, necessary in order to bind the larger particles together.

The waste in products (goods) due to damage in manufacture is, unfortunately, usually great, but it may be kept within exceedingly narrow limits by a wise yet vigilant and strict oversight. The difficulty mainly lies in ascertaining who is responsible for the damage, and in many instances the men must be given the benefit of the doubt. If, however, the sense of responsibility is maintained at a sufficiently high standard, this difficulty will be to a very considerable extent removed by sufficient and impartial inspection. Broken, over-burned, or misshapen bricks usually find a ready sale for concrete and foundations and to a less extent for road metal, especially if they are crushed and screened to suitably sized pieces. Whilst such sales cannot be profitable, it is necessary to keep the quantity of damaged goods as low as possible, and, as their production cannot be entirely avoided, it is important to convert them into some form which will sell readily and so regain some of the loss.

Firebricks should not be treated in this way, but should be ground and used as grog for the production of new bricks.

The Waste of Tools, machinery, barrows, timber, etc., through their not being properly put away or cared for, is one which should be avoided. There is no excuse for tools (in the fullest sense of the word) lying about to rot or rust when a little care on the part of the users might secure their maintenance in good condition. The same remark applies to crates, bags, barrels, and other objects used in the conveyance of goods into the factory. 'A place for everything, and everything in its place,' is the best waste-preventer yet discovered.

Waste of Lubricants is very common in clayworking. Very few potteries or brickworks take the trouble to collect and filter their oil so that it may be used over again, yet an oil-filter is not an expensive appliance, and its use makes the workman less anxious to reduce the lubricant to danger point, for he knows that any excess will be collected and re-used with the addition of a little fresh oil to make up for loss.

As all lubricants clarify more easily when warm, it is a good plan to have in the oil-purifier a spiral tube through which a little exhaust steam may be passed; or, as this is apt to put some back-pressure on to the engine, the discharge of the steam traps may be allowed to pass through the spiral pipe.

A rough-and-ready oil-filter consists of two pails, one of which is used to contain the unpurified oil, while the other has a pad of flannel placed over it through which the oil skimmed off the contents of the first bucket is allowed to filter. Meat-cloths or waste may be used instead of the flannel. It is often convenient to fit them on to a coarse metal sieve, which keeps the cloth or waste flat and so enables the filtration to proceed more rapidly.

In collecting the oil, care must be taken not to mix different kinds together. Separate tanks should be used, and, where there is a danger of splashing, baffle plates should be used to prevent two or more kinds of lubricants from becoming mixed.

Serious damage and loss may occur through over-economy in the re-using of lubricants. The quality as well as the quantity of a lubricant is of immense importance, and if too little oil is supplied, the bearings, etc., may be spoilt by overheating, whilst if oil which has been used previously has deteriorated in quality, it will not effectively serve its purpose and may even cause abrasion or corrosion! Great care, therefore, should be taken in using filtered oil; it should be quite clean, free from grit, acid, and water, otherwise it should not be used.

Waste in Machinery, both running and standing, is often very much greater than is usually supposed, and the ordinary allowance of 10 per cent. per annum for depreciation by no means always covers the loss. In most clayworking machinery an allowance of 15 per cent. would be more correct. Many clayworkers appear to regard the allowance made by income-tax officials as sufficient, but actually this amount is much too low. Brick- and tile-making machinery, and most other machinery used in clayworking, should be written off at such a rate that the whole of the capital cost is recovered in ten years or less. The sums so 'written off' should not be left in the business, but placed in a separate account.

A large amount of waste may be caused through machinery being improperly placed with respect to the source of power. They should be as near to this as possible, as much loss is occasioned by driving machines at the end of a long line of shafting. Large machines at some distance from the main engine should be driven separately by another engine or an electric motor.

The actual daily expense of machinery is made up of four parts: (1) depreciation and interest charges; (2) cost of power; (3) cost of repairs; (4) cost of labour for attention and working the machinery.

Of these the first is also expected to include, either directly or indirectly, a proportionate charge for rent of space occupied by the machinery, but this is a matter which will depend on the way in which rent and rates are distributed amongst the different departments of the works. Suffice it to say that three of these charges remain constant whether the machinery is running or disused; it is, therefore, a 'waste' or dead charge whenever the machinery is unnecessarily idle.

The cost of power to a machine will depend on four conditions: (*a*) the machinery is not in use and is motionless; (*b*) the machinery is not in use, but is running on the loose pulley or clutch; (*c*) the machinery is running, but not at full power; (*d*) the machinery is running at full (but not excessive) power and quite satisfactorily.

If the machinery is not in use and is not moving, as in (*a*), the expense of power may be *nil*, except in so far as the boiler or other source of power may have to be kept in readiness for an immediate demand, when the cost of this must be included, just as in the more wasteful (though often with present plant unavoidable) machinery of class (*b*). The only way in which the waste in these sections can be avoided is to keep the machinery constantly at work; or, if it is not intended to use it further, to write it off the books. Where the nature of the machine is such that it cannot be continually kept at work (as in the case of a hauling engine or a pump), the times of idleness must be reduced as much as possible or the expenses of this particular part of the plant will be excessive. The mistake is often made in supposing that when a machine is not moving, no expense is being incurred, whereas there is always the loss of income due to the money spent in purchasing and fitting the machine and earning no interest, whilst the selling value of the machinery diminishes every year.

If the machinery is not running at full speed (class *c*), it is important to find out the reason for this defect. If the plant is too powerful for the amount of work it has to do, it is a question as to whether more work cannot be given it by a rearrangement of plans, as clayworking machinery works more smoothly and satisfactorily when at its proper load than when running light, and the wear and tear is proportionately less. If the cause of waste of power is due to defects in the adjustment of the plant, or to actual defects in construction, it will generally be found that repairs and adjustment will rapidly repay their cost. Antiquated plant (as, for instance, an old boiler which the insurance company will not allow to be worked at full pressure) should be replaced by more efficient machinery.

It is only when machinery is working at normal speed, with normal output and full time, that it can be regarded as satisfactory.

The sight of some machinery running 'loose' is so common in clayworking that little or no notice is taken of it; it is considered to be on a level with 'breakages,' 'bad kilns,' etc.—that is, as a loss which cannot be avoided. Needless to say, a little study on the part of the manager will rapidly convince him that this is by no means the whole truth.

Much loss is frequently occasioned by the use of shafting which runs too slowly. Whenever the substitution is practicable, it is much more satisfactory to use two shafts 2 inches in diameter running at 300 r.p.m., than one shaft 3 inches in diameter running at 150 r.p.m., as smaller pulleys can be used, the weights will be correspondingly reduced, the belts shorter, and less power will be required.

Waste of Power in Transport is another serious loss in many clayworks, few engines used for this purpose being worked at anything like their greatest efficiency. In most cases, it is the result of bad management, by which a succession of small loads at fairly frequent intervals occurs instead of larger ones at longer intervals. The waste here is not only in the power, but also in the labour involved in driving the engine (or ponies), which might, under better arrangement, be employed on other jobs. This does not mean that a cheese-paring policy will be successful, but that in many clayworks a rearrangement of the transport will often result in one man's or lad's labour being available for other work during a considerable portion of the day. This is clearly not a case where generalities will be of use: each works must be considered in the light of its own circumstances and conditions.

Waste of Steam.—The amount of steam wasted in most clayworks is simply astounding. Not only are obvious leaks allowed to continue unheeded, but a general lack of skill is only too often shown in the design and arrangement of the dryers, pumps, engines, and other appliances in which steam is used. No simple rules will suffice for the prevention of such waste; the whole of the appliances should be examined periodically, with a view to prevent such wastage. At such examinations, care should be taken not to mistake useful arrangements (such as uncovered overhead steam pipes in a drying shed) for steam wasters—a mistake often made by over-zealous but ignorant engineers.

The chief causes of waste steam in clayworks are: (1) improper control of steam cocks; (2) use of more steam than is required (*i.e.* in drying sheds); (3) allowing machines to run when not working; (4) failure to use exhaust steam for heating feed-water or drying sheds. Feed-water heaters are unusual in brickworks, yet their use will save 1 per cent. of the fuel for every 10° C. rise in temperature of the feed-water. The heater must, however, be kept in good condition, or the saving will be neutralized. (5) waste of condensed steam; when free from oil, all water produced by the condensation of steam should be returned to the boiler, as such water is quite soft and free from deleterious substances, and being warm, will require less fuel to convert it into steam. If oil is present in condensed steam, it may usually be removed by filtration, but oily water should on no account enter the boiler, as it may cause an explosion.

The prevention of most of these sources of waste is obvious, but, as a matter of convenience, it is very desirable that the control of all steam-cocks should be in the hands of the foremen only, and not in those of the individual workers. Leaks in the piping or in the engine, boiler, or other part of the machinery should be under the responsibility of the engineer, and some means should be adopted to see that he keeps the plant under his charge in efficient condition. This may readily be done by means of occasional indicator readings of the engines and dynamometer readings of the machines. In fact, it is a good investment to attach some simple form of register to each machine of which the output is not paid for by the piece, in order to ascertain how many hours per day it runs idly or with only partial work.

A convenient form of steam-meter, shown in fig. 6, is made by George Kent, Ltd., of London. In this instrument, the variable steam-pressure actuates a pivoted lever in such a manner that a small variation in the pressure of the steam causes a relatively large deflection of the lever which is fitted, at its extremity, with a pen, so that a permanent record of its fluctuations is made on a sheet of paper stretched on a cylinder revolved by clockwork. By this means, any carelessness on the part of the fireman, leaks, or other causes of waste, can readily be detected.

Steam-pipes should be continually under inspection, as a comparatively small leak will in the course of a few weeks lead to a notable waste of fuel, especially where the steam is used both day and night for drying, etc. It has been stated that a leaky pipe or blow-cock may easily waste 2 per cent. of the steam, and an open cock may waste half the steam produced.

Steam-pipes should always be kept as free as possible from water, and drain-cocks fitted wherever necessary, as, should any accumulation of water occur in a long horizontal pipe, not only is there a considerable loss of heat, but there is also a great danger of fracture of the pipe. Long pipes which have become water-logged should never be emptied when under pressure; the connection with the boiler must first be cut off.

If satisfactorily arranged, each foot-run of 4-inch pipe should heat 150 to 200 cubic feet of air 1° F. per minute.

As steam-pipes expand about 1 inch in 40 feet when in use, some allowance for this movement should always be made, preferably by springy lengths of curved pipe, though expansion sockets may be used on occasion.

Where passing through the open air, or where not required for heating purposes, steam-pipes should always be covered so as to reduce the loss of heat as much as possible. On an average, there is a loss of ¾ lb. of steam per square foot of bare pipe per hour where steam at a pressure of 100 lbs. per square inch is passed through an uncovered pipe. This loss is increased to 1¾ lbs. at a pressure of 250 lbs. per square inch. The cost of wasted steam, with coal at 24s. per ton, at 100 lbs. per square inch, amounts to 2s. 9d. per square foot of piping per annum, and at 250 lbs. pressure it reaches 6s. 2d. per square foot per annum. Properly covered pipes lose only about one-sixth to one-twentieth of this amount of steam.

Of the various materials used for coating pipes the best are kieselguhr, slag wool, asbestos, mica flakes, and magnesia. Most of these materials are sold for the purpose under fancy names. It is usual to coat the pipes to a thickness of about 1½ inch with the insulating material and to cover this with tar to render it waterproof. The tar coating should be renewed periodically.

Joints for steam, and water-pipes, unless well made, will require almost constant attention and will be an endless source of trouble and expense. Although this class of work belongs to the engineer or plumber, yet a clay-works' proprietor or manager will often save himself much trouble and expense if he knows the best kind of joints for different kinds of work. This is especially the case with steam-joints in pipes, for the changes in temperature to which these pipes are subject renders them far more likely to leak than water- or gas-pipes, where the temperature and pressure are more uniform.

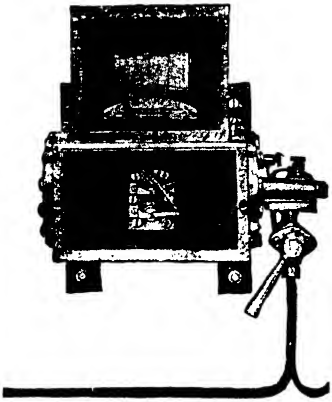

FIG. 6.—KENT'S RECORDING STEAM-METER.

The usual form of steam-joint consists of screwed pipe-end fitting into a screwed socket. As the screw-cutting appliances become worn or broken with use, an imperfect thread is cut and some filling material must be used to prevent a leak. Red or white lead is frequently employed for this purpose; but, although it fills up the interstices well and hardens rapidly, the pipes on which it is used cannot be taken apart without fracture; it is, therefore, considered better practice to use a paste made of graphite and a high-grade cylinder oil or a mixture of 15 parts of chalk and 50 parts of graphite made into a paste with 15 parts of linseed oil and 20 parts of ground litharge. A mixture of very thin tar with sufficient flowers of sulphur to make a plastic paste is excellent for pipe joints, and has the advantage of being not readily broken if a sudden strain is applied to the joints. A number of other substances, such as flint powder, are not suitable for mixing with tar as they do not give the requisite elasticity to the mixture.

The flanged joint (fig. 7) is also in common use, especially for larger pipes. This flange may be cast in one piece with the pipe, or it may be fastened to it with a screw-joint. In the latter case, it is advisable to rivet over the end to secure additional tightness and to avoid possible stripping of the flange. As the faces of the flanges are seldom so well fitted as to make a good joint, some yielding material must be placed between them to form a gasket and fill up any unevenness. Although sheet rubber is largely used, the heat causes the rubber to harden, and the expansion and contraction due to the changes in temperature of the pipes when the heat is on or off causes it to crack; asbestos should, therefore, be employed. Instead of using rubber or asbestos alone, a triple gasket consisting of two plates of copper or zinc with a sheet of asbestos between may be used; if the metal is corrugated parallel to its circumference (fig. 8) the joint will be still better. In cases of emergency, several sheets of tough packing paper, each covered with a coating of cylinder oil, have often been found of service, and sometimes have lasted as long as a rubber gasket under similar conditions, especially when protected by thin copper or zinc gaskets. Plain gaskets of soft metal should be avoided in steam-pipes where the steam pressure is lower at nights and in pipes not in constant use, as the expansion of the softer metal differs from that of the flange and so is apt to cause leaks. Where trouble is experienced through the asbestos absorbing water from the steam, a deeply grooved ring of thin sheet copper may be inserted in such a way that the steam and asbestos are kept out of contact with each other.

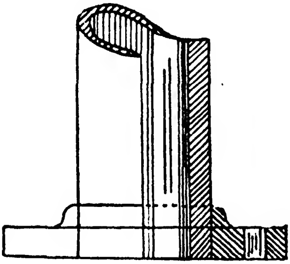

FIG. 7.

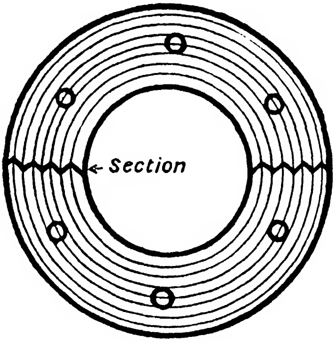

FIG. 8.

A continual supervision of gas- and water-meters is necessary in order to ensure that no serious leakage is taking place; steam leaks generally show themselves readily.

One of the great advantages of *electricity* as a source of power is the readiness with which it may be measured, as a simple watt-meter on each machine will register the total power consumed, and a careful study of these records ensures such electrically-driven machinery being worked to the fullest advantage. This information is not so readily obtained for steam-driven plant, but where it can be obtained it almost invariably results in more economical working and reduced running expenses. Unfortunately, so long as steam is so useful and economical a heat-transporter, it is hardly likely that electricity will make much headway in many classes of clayworking; but there is little doubt that where heat can be economically obtained from fuel directly, or in those parts of the works where power, but not steam, is required, that electricity will sooner or later be adopted, not only on account of the advantages it possesses as a form of energy, but also from the ease of measurement which enables its exact cost to be so readily obtained. This factor of cost is likely to become still more important in the future owing to increasing competition.

Waste at the *boiler* may usually be checked by a careful watch on the coal-book, or by a small bonus to the fireman if he can reduce the amount of fuel burned and yet keep up the steam. At the presses and mills it may usually be reduced by a system of piecework, accompanied with various encouragements to the men to work as rapidly as possible consistent with good work. This will ensure the full use of the machines when in use, but will not always prevent their running 'loose' unless there is abundant work for the men. A study of the lines of shafting will also indicate whether greater economy cannot be secured by using clutches so as to minimize the amount of idle shafting in motion.

Some machines are so clumsy, and require so much unnecessary power to drive them compared with the work they have to do, that their use involves a continual waste of power. Sometimes this waste cannot be avoided, because two or more classes of goods are made on the same machine; but even then it will often be more economical to obtain a smaller machine for the lighter work, the increased output being utilized in selling the goods at a slightly cheaper rate and still making a greater profit per annum. It is a matter of relative cost.

A very common source of loss in clayworks is the short life of boilers, etc., through lack of care in use. Much may be done to ensure a proper supply of good water, free from scale-producing salts, good fuel, as free as possible from corrosive ash, and proper attendance, but the real responsibility for such accidents as leaks, the boiler running dry, the safety valve blowing frequently, and so on, must necessarily lie with the stoker. As an indication of what may be expected under normal conditions, it may be stated that a boiler working 12 hours per day should last 20 years; a steam engine working 10 hours per day should last equally as long, unless it is of the high-speed type, when it will only last 15 years. Fuel economizers depend on the respective temperatures of the flue-gases and water, but should last from 10 to 20 years. If the appliances have to be replaced within these periods, there is presumably a serious defect in the manner in which they have been used.

Waste of Heat is, in some respects, the most serious and most difficult to prevent of any waste in a clayworks. Whether the heat is lost in the form of steam or actual heat from fuel matters little; in either case, the amount of money it absorbs per annum is immense.

Waste heat from kilns and furnaces (including boilers and dryer and shed fires) is a serious matter, yet but little real attention is paid to it. Some aspects of this question have been dealt with in the chapter on 'Firing' (p. 160), and need not be repeated here.

The chief loss is undoubtedly due to unskilled stoking, and to the resultant use of too much or too little air. As a consequence of this, either a large amount of heat is wasted in heating air to no purpose, or the combustion of the fuel is incomplete and the full amount of heat is not obtained from it. If only three times the correct amount of air is used in firing (a by no means uncommon proportion), not less than 40 per cent. of the fuel used will be wasted in heating this unnecessary excess of air.[1]

In practice, however, it is found that if less than twice the amount of air theoretically necessary is supplied to the coal in a boiler, the amount of steam is reduced. In practice, the best yields of steam are obtained with 2¼ to 2½ the theoretical amount of air.

The rate of firing must be suited to the fuel used, but with a good coal it will be found that for maximum economy the rate should be 620 to 640 B.T.U. per 1 lb. of air employed, and for maximum output of heat (or steam) the rate should be 750 to 780 B.T.U. per 1 lb. of air supplied.

The only true control of the stoking which can in any way be regarded as complete is that which results from a study of the composition of the flue-gases (p. 258) and the temperature at which they enter the chimney. For many purposes, it is sufficient to determine how much coal is required per gallon of water evaporated per day, and, as the results of tests made when the boiler is worked under the best conditions, to insist on the fireman not using more than (say) 10 per cent. above this in order to avoid the trouble and expense of testing the flue-gases regularly; but for kiln-firing this cannot so readily be done, since, whilst a careful study of the amount of coal consumed by each chamber or kiln is of value, variations in climate, etc., have much more influence on kilns than on boilers, so that a hard-and-fast rule as to the amount of coal to be consumed in the kilns cannot well be laid down. With sufficient care, however, the amounts can be fixed very closely without any hardship to the firemen.

Faulty construction of the kilns is often a source of loss of heat, as it allows the gases to enter the chimney too soon and at too high a temperature. With a continuous kiln, this may be remedied by increasing the number of chambers; but with single kilns it is to a large extent unavoidable, though, in some cases, by leading the flues through a drying shed the heat may be better utilized. In this case, care must be taken not to unduly lessen the draught; if the chimney is too small, the substitution of a fan will often effect an economy. These fans require but little power to run them, and in most cases are cheaper than a chimney of the same capacity.

The utilization of waste heat from kilns is a matter requiring considerable special knowledge. The flue-gases can seldom be turned directly into a shed containing bricks or other goods to be dried, partly because the temperature is too high, and partly because of the impurities (notably sulphur compounds) which they contain. As a rule, they are passed into a flue under the floor of the dryer, this floor being frequently made of iron so as to conduct the heat more readily to the bricks or goods, which are placed on waggons or cars to keep them from actual contact with the hot metal. These cars also serve as a convenient means of transport for the goods through the dryers, which are preferably of a tunnel form (p. 130).

Further particulars regarding the prevention of waste, or of reducing it when it cannot be entirely prevented, will be found in the chapters on 'Tests' and 'Defects,' and under the various operations under which waste may occur.

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[1] In endeavouring to prevent a waste of this kind, it is essential to remember that some goods require a large excess of air in order that they may have the desired colour or texture. The air needed for this purpose is not wasted; it is necessary.

CHAPTER XIII.

TESTS, ANALYSIS, AND CONTROL.

THE following suggestions for tests, and other means of controlling an economical and efficient production, are intended for the manufacturer and for the practical clayworker, and not for the clayworks expert. Detailed descriptions of complex methods which have, of necessity, to be employed in the more accurate testing made by the latter are, therefore, omitted, and the reader is referred to the standard works on the subject when such information is required. For convenience of reference the headings are arranged alphabetically.

Absorption.—The power of unglazed articles to absorb water is of great importance for certain purposes, including the probable resistance to weather and to the corrosive influence of gases, slags, and various chemicals.

The absorption test is usually carried out by accurately weighing one or more of the articles, immersing them almost, but not quite completely, in water for a short time, and, when partially saturated in this manner with water, completing the immersion by covering them with the water and allowing them to remain covered for some hours. They are then taken out, their surface wiped dry, and the articles re-weighed. The increase in weight gives their absorption capacity. Thus, if a brick weighing 120 oz. when dry was found to weigh 132 oz. after immersion and wiping dry, as just described, its absorption capacity would be $132 - 120 = 12$, which $\div$ 120 (the dry weight of the brick) gives 10 per cent. The reason for not immersing the article completely at first is to allow the air contained in the pores to escape; if the article is completely covered from the first, the water surrounding it prevents the escape of some of the air and so gives too low a result.

For rapid determinations of the porosity and absorption, it is usually sufficient to boil the sample in water for 45 to 60 minutes, and to measure the increase in weight after this period. A still more effective, but slower, method is to immerse the samples in boiling water and to subject them to a vacuum of 29 inches of mercury for three hours and then immerse them in water at room temperature for 96 hours.

A different, but sometimes useful, test of absorption is described under 'Permeability.'

It is also advantageous to state the absorption capacity in terms of volume and not of weight. (See also 'Porosity,' p. 280.)

It is thought by many clayworkers that the more water a brick will absorb the more easily will it be damaged by frost, but experiments at the Royal Testing Station, Berlin, have disproved this.

Air in Clay Paste is very objectionable, and a source of defective ware. It may be determined (as suggested by H. Spurrier) by placing a known weight or volume of the clay paste, such as a disc shaped in a brass mould and ejected by a brass piston, in a vessel similar to that shown diagrammatically in fig. 9, which has previously been filled with air-free water, by applying suction to the tube above the stop-cock. The sample must be inserted carefully so as to avoid the introduction of air into the apparatus. The water in the outer vessel is then boiled and the clay disintegrates, the air liberated rising to the top of the inner vessel. When the clay is completely disintegrated, the apparatus is allowed to cool, and when quite cold the volume of air liberated is measured. The air-free water may be prepared by boiling ordinary water for about 15 minutes and allowing it to cool in a covered vessel.

Analysis.—The details of the various methods of analysis of the materials employed by clayworkers are of so complicated a nature, and require so high a degree of manipulative skill in their execution, that they cannot profitably be dealt with here. Readers who wish to experiment in this direction cannot do better than study the little work, *How to Analyse Clay*, by H. M. Ashby, or *Treatise on Quantitative Inorganic Analysis*, by J. W. Mellor; but they must not be disappointed if, even after many attempts, they do not obtain such accurate results as they desire. At the same time it is important that those responsible for the production of the goods should be able to understand and make use of the information contained in an analytical report, and the following notes may be of use in this connection.

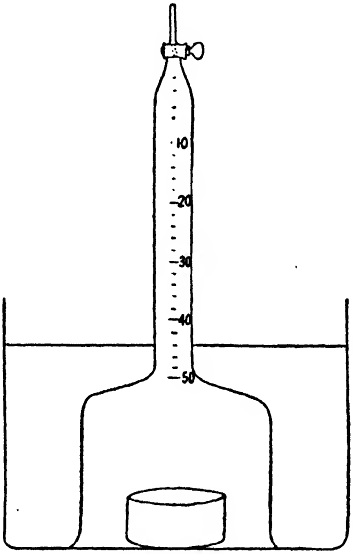

FIG. 9.

Clays are reported as consisting of silica, alumina, and water, together with various substances such as soda, potash, lime, iron oxide, etc., and the percentage of each of these constituents is set out in the results of analysis, which, if quite correct and complete, would total up to exactly 100. As, however, there are usually slight errors, and sometimes trifling amounts of substances present which have not been determined, it is seldom that the results add up to 100·00 exactly. In analyses which total exactly 100·00 the amount of one or more constituents have not usually been determined directly, but 'by difference.' Analytical reports on clays in which this mode of obtaining a result has been adopted should be avoided, as they are more liable to contain serious errors than those in which the figures add up *nearly* but not exactly to 100·00.

It is not, however, sufficient to know the total amount of each constituent of a clay. Information is required as to the various combinations in which these constituents occur, the fusing point of the clay, its contraction on heating, etc. It is, therefore, desirable to have a 'mechanical analysis' of the clay showing the proportions of 'clay,' 'silt,' 'dust sand,' 'fine sand,' and 'coarse particles' in the clay. These are obtained by washing the clay with great care first through sieves and then passing it through an elutriating apparatus such as that devised by Schoene.

It is also desirable to ascertain the nature of the different minerals in the clay, and especially the proportion of 'clay substance,' 'felspar,' 'mica,' and quartz or sand, in the sample.

Clay substance was a term devised by Seger to represent the nearest approach to 'pure clay' obtainable from clays of different kinds. Its amount is ascertained by collecting the finest particles that can be separated by washing the clay and removing mica, felspar, and free silica by treatment with hot sulphuric acid. As the result of many such 'rational analyses' of different clays, Seger found that they contained a substance of varying composition, yet approximately corresponding to $Al_2O_3 2SiO_2 + 2H_2O$, which is also the formula for the typical kaolins or china clay. Various modifications of this method have been suggested by other chemists.

Unfortunately, the 'rational analysis' of many clays gives results which are obviously erroneous, so that it is of very limited value. Where its results are compatible with those of an ordinary chemical analysis, the additional information is often of great value. In place of a 'rational analysis,' it is often convenient to mix a sample of clay with water and pass as much as possible through a No. 200 sieve. This portion may then be analysed in the ordinary manner, and from the results obtained from this and from an analysis of the whole material a 'proximate analysis' showing the 'true clay' or clay substance, felspar or mica, and free silica (quartz or sand) may be calculated. This calculation is necessarily based on arbitrary assumptions, —such as attributing the whole of the lime, magnesia, and alkali oxides to 'mica' or 'felspar'—which are not always correct, yet several observers have found that its results are at least as reliable as, and frequently more so than, those of a 'rational analysis.'[1]

It must always be remembered that 'felspar' in this sense is not a single chemical compound, but is a type of mineral with many varieties of similar mineralogical composition. Thus, the ordinary felspar of the clayworker is a potassium felspar known as 'orthoclase,' but the potassium may be partially, or entirely, replaced by one of several other metals such as sodium, calcium, etc., and in each case the new mineral retains its family name of felspar. Such felspars have, however, this in common, that their composition may be represented by the formula $RO,Al_2O_3 6SiO_2$, where Al_2O_3 represents one molecule of alumina, $6SiO_2$ represents six molecules of silica, and RO represents one molecule of any oxide similar to potash, soda, or lime, or any proportions of such oxides as will together make up exactly one molecule. As 'felspar' is a flux and yet contains nearly two-thirds of its weight of silica, it does not follow that a clay with a high silica content must necessarily be refractory. As stated on p. 15, the whole question turns upon the state in which the silica exists. If it is combined with an RO base, or if it is so finely divided that it can readily combine with the kaolin in the clay, it will act as a flux; if, on the other hand, it is in comparatively coarse particles, it will make the clay refractory. As an ordinary analysis does not show this difference of state, the importance of a mechanical and a rational or proximate analysis is obvious.

For more accurate determinations, some of the substances may be separated according to their specific gravities by means of a heavy liquid such as bromoform, which has a specific gravity of 2·9, so that finely ground silica, felspar, mica, and clay remain in suspension, whilst impurities of

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[1] Still less accurate results are obtained when the 'proximate analysis' of an impure clay is calculated from an ordinary chemical analysis.

greater specific gravity, such as pyrites, rutile, etc., settle out. Unfortunately, the specific gravities of the commoner impurities in clays are so nearly alike that these impurities cannot be separated in this manner.

B. Zschokke prefers to separate the coarser and finer particles by elutriation, and to determine the solubility of each fraction in hydrochloric acid as well as making an analysis of each. This method is good but very tedious, and is by no means as accurate as desired.

In order that the distinctions between these different analyses may be made clear, it should be noted that the chief value of ordinary chemical analysis is to indicate the presence or absence of deleterious substances, such as iron compounds in a china clay, or of soluble salts in brick clay, or a large proportion of alkalies in fireclay. A 'rational' or 'proximate' analysis shows rather more clearly how the different constituents are combined into the three constituent minerals of clay, felspar, and quartz, while a 'mechanical' analysis indicates the state of fineness of the sample, and, if the different portions into which the clay has been separated by this means are analysed, a further series of clues as to the advantages to be gained by washing the clay before use is obtained. Thus, the free silica (quartz or sand) present in clays only acts as a flux when it is in so fine a state that it will pass through a sieve with at least 600 meshes per linear inch, and is then so fine that it cannot be separated from the clay itself by washing. The presence of notable quantities of alkalies or of metallic compounds will, however, modify this condition in proportion to the amount of such fluxes, which (in the rational analysis) will be found under the head of 'Felspar.' Coarser particles of silica act as refractory agents in the clay. This accounts for the curious results sometimes noticed on the addition of quartz or flint to clay; sometimes the clay is rendered more refractory, and at others it is rendered more fusible. Seger, who has studied this subject thoroughly, found that if finely divided silica is added, in gradually increasing quantities, to pure kaolin (which he regards as typical 'clay substance'), the fusing point of the mixture is gradually lowered until the mixture containing one molecule of kaolin to seventeen molecules of silica is reached; after this, the addition of more silica increases the refractory nature of the mixture until pure quartz is reached, when it is found to have practically the same fusing point as pure clay (kaolin). Hence, if the analysis be made on a clay which has been passed through a No. 200 sieve, the higher the percentage of 'clay substance' the more refractory the clay. (See also p. 243.)

Plasticity apparently depends more on the state of division of the clay than on the chemical composition.[1] Usually, 'clay substance' is highly refractory (cone 36); its presence in large proportions indicates, therefore, a refractory clay. If much felspar, mica, or quartz is also present, the fusion point of the clay will be lowered correspondingly, as already explained. The exact fusion point must be determined experimentally (see p. 263).

Glazes may be regarded as clays containing an inordinately large proportion of flux or base. They are analysed in a similar manner to clays, and the results of the analyses are best stated in the same way. Further information on the composition of glazes and other engobes will be found on p. 19.

Flue-gases should be analysed at frequent intervals in order to ensure that fuel is not being wasted (see p. 258).

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[1] Schurecht has found that English ball clays contain 95 per cent. of particles less than 0·0026 mm. diameter, whilst china clay contains only 40 per cent., and he attributes the greater plasticity of the ball clays to their greater fineness.

The *water*, *oil*, *store materials* such as bone dust, etc., used in a clayworks should be constantly tested. Usually a complete analysis is unnecessary, although advisable when buying fresh lots of clay or glazing materials. Certain tests as to the purity of the materials in use should, however, never be omitted from the works routine. If carefully attended to, many pounds might be saved during the year.

Special questions arise from time to time which can only be answered after various analyses have been made. As a general rule, in such cases it is best to secure the services of an expert accustomed to these materials, as the results of analyses obtained by amateurs or even by public analysts are not often worth the time spent in obtaining them.

Anemometer.—An instrument for measuring the volume of air passing through a chimney or flue. It consists of a small wheel with relatively large vanes attached, and is so constructed that the slightest movement of the air sets it in motion. A counter is attached in order to register the number of revolutions per minute. This number indicates the velocity of the air, and if multiplied by the area of the opening of the flue or chimney through which the air passes gives the volume (cubic feet) of air passing per minute.

Another type of anemometer, known as the Pitot tube, consists of two thin tubes, one straight with holes down one side, and the other bent at right angles so that its end is opposite that of the straight tube. Both tubes project into the flue, so that the mouth of each tube is in the centre, the bent tube facing the draught and the other facing in the opposite direction. The outer ends of these tubes are fitted, by means of rubber connections, to a U tube or other form of draught gauge shown on p. 250, containing a mixture of two volumes of ether and one of chloroform. The gases blown down the curved tube press on the surface of the liquid and 'draw' at the straight tube, thereby creating a difference in the level of the liquid in the gauge. The heights are read off and the speed calculated from the formula

$$V = 46{\cdot}67\sqrt{H},$$

where H = the difference in the height of the liquid in the gauge (in inches).
V = the velocity of the gases in feet per second.

Baryta has, for some years past, been successfully used to prevent certain varieties of 'scum,' due to the presence of soluble sulphates in clay. In order to determine the quantity of baryta or of barium carbonate to be added, the following experiment should be made and repeated with every fresh batch of clay, as the proportions of soluble sulphates vary considerably, and a large excess of the baryta compound is to be avoided.

Into each of half a dozen bottles, provided with glass stoppers, exactly 4 oz. of the dry clay in the form of fine powder is placed, together with about half a pint of water. The bottles should then be about three-quarters full. The clay and water are well shaken, any lumps of clay carefully broken up, and measured volumes of a 1 per cent. solution of barium chloride solution added. This is usually done by means of a burette, graduated in cubic centimetres, and obtainable from any scientific apparatus dealer. One cubic centimetre is placed in the first bottle, 2 in the second, and so on up to the last, which would receive 6 cubic centimetres. The bottles are shaken up vigorously at intervals of an hour for twelve hours, after which about 4 oz. of the clear liquid (filtered, if not quite clear, through filter-paper) is placed in a clear glass and a few drops of dilute sulphuric acid added. If sufficient barium chloride solution to precipitate the soluble sulphates has not been added, the solution will remain clear; but if too much has been added, the sulphuric acid will produce a white turbidity. The bottle containing the liquid with which the least turbidity is produced is the one which contains the most correct proportions of baryta and clay. Suppose it was No. 4 (No. 3 bottle remaining clear may have exactly the correct amount added, or it may not have had sufficient, so that it is best to take the one showing a slight turbidity as correct). Then No. 4 will have had (say) 4 cubic centimetres of the barium solution to 4 oz. of clay. As this solution contains 1 per cent. of its weight of barium chloride (cryst.), each 4 oz. of clay will need the addition of $4 \times \cdot 01$ grammes of barium chloride, or each ton of clay will need $4 \times 3\frac{1}{4} = 13$ oz. of barium chloride; or as 1 lb. of the chloride corresponds to $\frac{5}{8}$th lb. of the carbonate, 11 oz. of the latter may be substituted. If 100 grammes of clay be used instead of 4 oz., each cubic centimetre of barium chloride solution will correspond to 100 grammes of the solid barium chloride, or 81 grammes of barium carbonate or 62 grammes of baryta per ton of clay. If a clay should contain so large a proportion of sulphate that 6 cubic centimetres of the barium solution are not sufficient to precipitate it, a fresh test must be made, using more of the solution for each bottle.

Binding-power of clay is often determined as a check on the correct working of the mixing and pugging machines. Although a skilled worker can usually tell by the 'feel' of the clay whether it has been properly worked, it is often handy when special mixtures are in use to determine the force required to pull a strip of the plastic clay apart. The test cannot be usefully made on the dry clay, as it is often so brittle as to be untrustworthy. It is best carried out while the clay is still damp, but after the contraction has largely ceased, though tests of the clay straight from the mill are of great value. The test is most conveniently made with an apparatus similar to that used for the testing of Portland cement by tension: a piece of the plastic clay being formed into a rough resemblance to a figure 8 in a brass mould, a light scale-pan attached, and the whole hung from a convenient beam or stand. Shot is then allowed to trickle at a standard rate into the scale-pan until rupture takes place, when the combined weight of shot and pan is determined. The result is expressed in lbs. per square inch of section at the point of fracture, which should be as nearly as possible at the centre of the test-piece.

It is useful to mark two small dots exactly 2 inches apart on the test-piece before breaking, and to measure the percentage of increase in length brought about by the tension of the weight (shot). The results obtained vary greatly for different kinds of clay; a very plastic clay will have a breaking strain of some 50 lbs. per square inch, whilst other clays will break under a strain of a few ounces. (Eight lbs. is a fair average for ordinary brick clay.)

It is also useful to observe the length of a piece of clay which can be pressed through a $\frac{3}{8}$-inch hole in a vertical plate attached to a small horizontal cylinder or 'wad mill' before appreciable bending of the clay takes place.

In order to determine how much lean clay or other non-plastic material can be added to a clay without unduly destroying its value for moulding into shape, Bischof's method is generally used. In this, the two materials are mixed in various proportions, and the same measured quantity of water added to each. The pastes are then rolled into small balls as equal in size as possible and allowed to dry. They are then rubbed gently between the finger and thumb or with a small 'camel-hair' brush. The mixture which just resists the action of the rubbing may be taken as the standard. Some authorities make up small balls of mixture in this way, and then notice to what length a cylinder can be rolled from each without cracking.

Boilers (see p. 56).—The actual testing of boilers is usually, and most satisfactorily, carried out by the inspectors appointed by the various Boiler Insurance Companies; their reports and suggestions should be carefully attended to.

The efficiency of a boiler may be calculated from the following formula:

$$\text{Efficiency per cent.} = \frac{100A(T - t + 32)}{c},$$

c = calorific power in B.T.U. of coal used.
A = actual water (in pounds) evaporated per pound of coal.
T = total heat in 1 lb. of steam at the boiler pressure.
t = initial temperature (in °F.) of the feed water.

If superheated steam is used, the formula becomes

$$\frac{110A[T - t + 32 + s(t_2 - t_1)]}{c},$$

where s = specific heat of superheated steam (usually taken as 0·55).
t_1 = temperature of saturated steam.
t_2 = observed temperature of superheated steam (°F).

Bone, or, more correctly, *bone ash*, is the residue left on calcining the bones of animals until all the combustible matter has been driven off. It consists chiefly of calcium phosphate, and is used in clayworking partly as a flux and partly for rendering the body more transparent and translucent. It is also used in the manufacture of china to prevent crazing, to increase the whiteness of the material, and to prevent distortion through over-firing.

As calcium phosphate is the chief ingredient, the material should be assayed for this substance, and samples containing less than 75 per cent. should not, as a rule, be used. The assay of phosphate should be made by a properly trained chemist. The chief impurity in bone ash is chalk or calcium carbonate, which occurs naturally to the extent of about 15 per cent., but it is also occasionally added as 'filling.' It is a particularly unprofitable adulterant to the potter, as it unduly softens his bodies. It may be determined by the method described in the assay of chalk (p. 240.)

Burners, or firemen, require constant supervision if the very best results are to be obtained, as their work is hard and the temptations to shirk it are exceedingly great. On this account it is good practice to pay the firemen partly by wage and partly by bonus on the articles 'from kiln.' Various means now exist for checking the firemen's work, such as pyrometers, etc., which register the temperature of the kilns, and various kinds of 'watchman's clocks' are also in use to ensure that the fireman does not fall asleep at his work. The great defect of most of these appliances, however, is that they do not give the warning until it is too late to repair the damage which has been done through the fireman's neglect of his work. What is really wanted for this purpose is an arrangement which shall inform the burner when it is time to put on more fuel or to attend to his fires, and if he does not attend to his work, to warn the foreman, manager, or some other responsible person. To a limited extent this is accomplished by the Stöcker clock, which rings an electric bell at the kiln every fifteen minutes or so; if a press-button is not pressed within, say, three minutes, another bell in the foreman's or manager's room (or bedroom, if at night) is set ringing. In this way, a suitable person is warned immediately the burner neglects his work, whether from illness or other cause, and little or no harm is done to the goods in the kilns.

A somewhat cheaper, though less satisfactory, warner consists of a telephone at which the manager can listen and so hear the noise made by the fireman when firing; this plan, however, is tedious for the manager, and is of but little use if he has gone to bed and the fireman has gone to sleep at his post.

One of the most promising 'warners' is an attachment to an electric pyrometer (p. 298) whereby, the instrument having been set to certain limits of temperature, any increase above or decrease below these limits causes a bell to ring at the kiln and so warns the fireman; whilst if this warning is not attended to, and the temperature brought within the proper limits within a reasonable time, a second bell in the manager's or foreman's bedroom is set ringing. Unfortunately, electrical pyrometers are not very durable at the high temperatures used in most clayworks, and require such frequent standardizing as to be unsuitable for general use except by a specially trained man. Optical pyrometers (especially those in which the light radiated from the hot body is compared with that of the filament of an electric lamp—Holborn-Karlbaum type—or of the Féry type) are more easily managed, but to ensure accurate results they should be standardized frequently.

Calorimeters are instruments for determining the amount of heat held, given up, or gained by any substance. They differ from thermometers and pyrometers in that they measure actual heat and not changes in temperature. The unit of heat is the amount required to bring about a change of temperature of one degree in a unit weight of water at a given temperature. There are three units at present in general use, viz. the 'caloric,' which is the amount of heat expended in raising the temperature of one gramme of water 1° C. (strictly, from 4° C. to 5° C.). As, however, the 'calorie' is too small for ordinary purposes, it is usual to employ a unit one thousand times as large—*i.e.* the amount of heat required to raise the temperature of one kilogramme of water 1° C. This larger unit is termed the 'major Calorie,' but in writing it is usual to term it 'Calorie,' distinguishing it from the smaller unit by writing its name with a capital C.

The third unit is the British thermal unit (B.T.U.), which is the quantity of heat required to raise the temperature of one avoirdupois pound of water from 60° to 61° F.

Calorimeters are chiefly of use in clayworks in testing the *calorific power* of fuel. Two forms of calorimeter are most in demand: one a comparatively simple instrument, devised by Lewis Thompson; and the other a more complicated and somewhat more accurate instrument, known as the 'bomb' calorimeter.

The Thompson calorimeter (fig. 10), which is quite simple but not very accurate, consists of (*a*) a large glass cylinder marked to contain, when rather more than half-full, 29,010 grains of water at 60° F.; (*b*) a copper tube, or 'furnace,' fitting into a recess of a perforated stand, over the spring clips of which fits a combustion vessel consisting of a copper cylinder perforated round its lower edge, and provided with a long pipe and stopcock at its upper end. There is also a thermometer (*c*) which must be capable of being read to at least $\frac{1}{5}$° F. The test is carried out by mixing 30 grains of the dry and finely powdered fuel with about 300 grains of a 'combustion mixture,' composed of 3 parts by weight of pure potassium chlorate and 1 part of pure nitre. Both these substances must be finely powdered, dry, and well mixed before use. Sodium peroxide is sometimes used in place of the chlorate and nitre. It is usual to compress the mixture of potassium chlorate and fuel into a little briquette, since if it be used in the powdered form low results are obtained on account of particles of fuel being blown upon the metal base of the bell and being consequently not burnt. The dryness of all materials used in calorimetry is important, and it is best to dry them *separately* at 110° C. for at least four hours immediately before use. The mixture of fuel and combustion mixture is placed in the copper furnace-tube, and a small fuse, made by soaking a couple of strands of thick cotton in a strong solution of nitre and allowing them to dry thoroughly, placed halfway into the mixture. The fuse should be about 1 inch in length, leaving ½ inch protruding from the powder or briquette. It is an advantage if the top of the apparatus is covered over with an asbestos board with holes for the insertion of the thermometer and stirrer, so as to prevent the exchange of heat with the outside air. The glass vessel having been filled to the mark with water, the temperature of which has been accurately ascertained by the thermometer, the fuse is lighted, the 'combustion vessel' fitted into the clips, the stopcock closed, and the whole arrangement lowered carefully into the water with as little delay as possible. If the combustion mixture has been properly made and the materials are dry, the fuel will be set on fire and will take up the oxygen necessary for its combustion from the mixture; white smoke will be given off through the perforations in the copper vessel, and bubbles of carbon dioxide and other gases will rise through the water with such violence as to upset the apparatus unless the copper vessel is held in place. As soon as the bubbles have ceased and it is judged that the combustion is over, the stopcock is opened and the copper vessel used to stir the water and so render it of an even temperature throughout. When this is accomplished the temperature of the water is again read by means of the thermometer, and the rise in temperature is noted. It is usual to add one-tenth of the increase in temperature to the result in order to compensate for losses by radiation, etc., and heat absorbed by the instrument. As the latent heat of steam is 967, and 30 grains of fuel are used, the rise in temperature in °F. plus 10 per cent. gives directly the number of pounds of water which will be evaporated by one pound of fuel: thus, if the rise in temperature was found to be 11° F., the number of pounds of water at 212° F. which would be converted into steam by one pound of the fuel would be $11 + 1{\cdot}1 = 12{\cdot}1$ lbs.

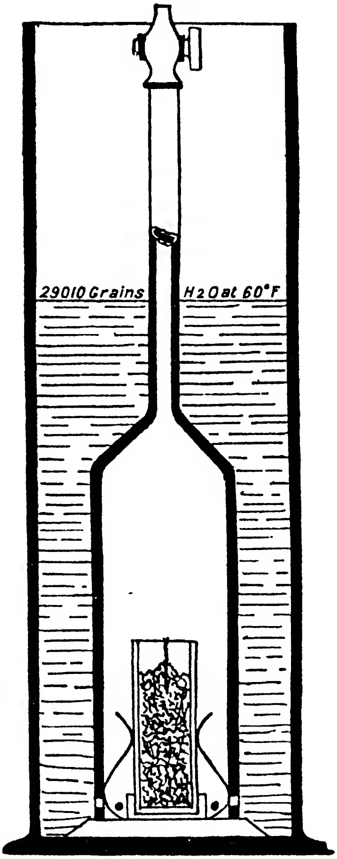

FIG. 10.

The 'calorific power' may be found by multiplying the rise in temperature (duly corrected as above) by 967. Thus, in the example given, $12{\cdot}1 \times 967 = 11{,}700$ B.T.U.

If a different volume of water or other weight of fuel is used, the calorific power may also be found from the following formula:

$$V = \frac{(W+E) \times (R+c)}{F},$$

where E = grammes (or grains) of water equivalent to the apparatus.
R = rise in temperature (°F.).
F = weight of fuel in grammes (or grains).
c = cooling correction.
W = weight of water in grammes (or grains).

There are two disadvantages to this method: (1) some of the heat is lost through the walls; (2) the combustion is not so perfect as is required. An improvement has been devised by Rosenhain in which the vessel containing the water is placed in a wooden shield, and the combustion chamber consists of a glass cylinder closed at the top and bottom by brass plates, the upper plate carrying the electric ignition apparatus, a holder for the sample of fuel, and a small tube through which oxygen can be passed through the apparatus. A ball-valve permits the oxygen and gaseous products of combustion to escape and bubble through the water, but prevents any water entering the combustion chamber. Exactly two grammes of the sample are placed in a small silica dish in the holder, the combustion chamber is lowered into the water, and oxygen is passed through the apparatus. The fuel is ignited electrically, and when combustion is complete the passage of gas is continued until a maximum temperature has been reached in the water. No stirring of the water is needed, as the mixing is effected by the gases bubbling through it. The temperature reached by the water is then used to calculate the amount of heat developed in the combustion of the given weight of fuel. The loss of heat due to that absorbed by the instrument, escaping gas, etc., is determined by burning a standard fuel which has been tested under stringent conditions.

In the Roland Wild calorimeter the combustion of the coal is effected by mixing the fuel with sodium peroxide and starting the combustion by means of an electrically heated wire.

The 'bomb' calorimeter works on a similar principle to the above, the fuel being burned in a 'bomb' containing oxygen, usually at a pressure of 20–27 atmospheres or 280–400 lbs. per square inch. The bomb consists of a block of cast steel in which a suitable cavity, fitted with a screw cap, has been bored. The sample is placed in a small platinum crucible which is suspended in the bomb. A special platinum wire surrounds the sample, the ignition is effected electrically, and with the oxygen under such a high pressure that combustion is almost instantaneous, a temperature sufficiently high to fuse the platinum wire used for ignition purposes being momentarily attained. A lining of thin asbestos board may be placed in the crucible to prevent the latter being affected. The bomb is immersed in a known quantity of water, the temperature of which is ascertained with a thermometer reading to one-hundredth of a degree before igniting the sample, and again after combustion is completed and the temperature of the water and bomb has been rendered uniform by constant stirring. The weight of the bomb and water being known, the amount of heat evolved is found by multiplying these by their respective specific heats and by the rise in the temperature of the water. Corrections are required for the amount of nitric acid formed and for the fact that the total rise in temperature is greater than that indicated by the thermometer, owing to the loss of heat by radiation. The Thompson, Rosenhain, and Wild calorimeters are cheaper and last longer than the bomb calorimeter, but for very accurate determinations the latter should be used, as the results obtained by the others are always somewhat uncertain. Liquid fuels should always be tested in a bomb calorimeter.

In every case, it is necessary to examine the contents of the apparatus on completion of the test, in order to ascertain that no particles of unburnt fuel still remain.

Although this test is one which can be carried out quite satisfactorily with ordinary care and attention to details, there are numerous sources of error, and it is always advisable to repeat the test several times, and to take the average of the results obtained. Special training is necessary before good results are reached.

As the value of any fuel depends almost entirely on its calorific power, the use of this test in making choice of a fuel is obvious, and that fuel is most economical as regards heating power which gives the highest number when the calorific power in B.T.U. is divided by the cost of the fuel in pence per ton; thus, a fuel with a calorific power of 12,000 at 10s. per ton is more economical than another with 10,000 at 8s. 6d. In comparing the values of fuels of low calorific power, however, some consideration must be given to the ash and other constituents, as a coal giving a large proportion of easily fusible clinker is less desirable than one at a slightly higher price per B.T.U. with a more dusty residue on combustion.

It is obvious that, no matter how accurately the determination is made, the result obtained can supply no information as to the useful value of the coal in an ordinary boiler or furnace where the conditions of its combustion are entirely different. In fact, the calorific power of a coal merely shows the maximum heat which can be developed by its combustion under the most favourable conditions. It is not surprising, therefore, that some coals valued by this method do not agree with the results of actual experience when the same coals are burnt in boilers or furnaces of standard design, and unfortunately, there is no means of correlating the two.

It must also be remembered that the manner in which a fuel is burned may be of great importance. Some fire-boxes are unsuitable for burning certain kinds of coal, and it may, therefore, happen that a fuel with low calorific power, but suited to the fire-box used, may give better results than a coal with a higher calorific power for which the furnace is unsuitable.

The *calorific intensity*, or maximum temperature producible from a unit weight of the fuel, is obtained by dividing the number of sensible heat units produced by its combustion (= cal. power) by the product of the weight and specific heats of the combustion products. With a good coal this will give a temperature of about 2500° F.; but this temperature is seldom attained in practice because of incomplete combustion, excess of air, heat losses due to radiation, and by absorption through the chimney and brickwork. In addition to this, the temperature attained depends on the rate of combustion, and so can never approach the theoretical figure when large quantities of fuel are used. The calculation of the calorific intensity is, therefore, of academic, rather than of practical, interest.

Chalk is a necessary constituent of or addition to clays used for certain purposes, and, like all other naturally occurring minerals, it varies greatly in quality. It is, therefore, very desirable that it should be tested on the receipt of each new batch. If in a sufficiently finely divided state, chalk is often a welcome constituent of the clay, since in burning it promotes vitrification, reduces drying troubles, and improves the colour of the product; but, on the other hand, when it appears in larger pieces, as in the case of clays containing limestone, it sometimes renders them quite unsuitable for the purposes of brickmaking unless the clay be previously washed or so treated as to remove the pieces and concretions of chalky matter, or to crush them to so fine a powder that they are harmless. Apparently 25 per cent. is the limit that a clay can stand without spoiling in the firing, and for this proportion, the material must be in the form of the finest possible powder, as, unless it combines with the silica of the clay on firing, the articles will disintegrate on exposure to the air.

Chalk, with its allied compounds limestone and Paris white or whiting, is a more or less pure form of calcium carbonate, and when absolutely pure consists of—lime, 56 per cent.; carbon dioxide, 44 per cent. The most frequent impurities are silica, iron oxide, alumina, gypsum (sulphate of lime), and other sulphates. Some varieties of limestone contain magnesium carbonate as well. The characteristic constituent of chalk and of its congeners is, however, the carbon dioxide, and its valuation is commonly confined to a determination of the proportion of this constituent in the material. The carbon dioxide is most conveniently estimated by measuring the volume of gas liberated when the sample is mixed with an excess of dilute sulphuric acid. One of the most satisfactory appliances for this purpose is a Lunge's 'nitrometer,' or 'gas-volumeter,' as the instrument in its modified form is called. This consists of a graduated glass tube, at one end of which is a glass stopcock and at the other end a strong rubber tube connected to another glass tube (the 'pressure tube), as shown in fig. 11.

The apparatus is filled with mercury, or with strong brine made by shaking clean water repeatedly with table salt in larger proportion than the water can dissolve and allowing it to stand for some hours so that the water may become saturated with the salt, the clear liquid being then used for filling the instrument. Care must be taken that the graduated tube, A, is completely filled to the exclusion of all air; but the liquid should only reach a few inches above the lower end in the pressure tube, B, at the commencement of the test.

About 0·4 gramme of the sample to be tested is to be accurately weighed into a small flask, D, this being best accomplished by first weighing the empty flask, putting into it a small quantity of the powdered sample, and again weighing carefully. If the increase in weight is about 0·4 gramme, the exact increase is carefully noted; if much over or under this amount, some of the powder must be taken out or more must be added to the contents of the tube until the correct quantity is obtained. The reason for this is that if too much is used, the apparatus will not hold the volume of gas produced, whilst if too little is taken the result will be less accurate owing to the larger number by which it must be multiplied in order to ascertain the percentage. About 50 drops (5 c.c.) of strong sulphuric acid previously mixed with three or four times its volume of water is placed in the little tube, C, which, with its contents, is carefully lowered into position as shown, the greatest care being taken that none of the acid gets out of it, and the cork is then inserted tightly in the flask. The pressure tube, B, is lowered somewhat in its clamp, the glass stopcock opened cautiously to connect A and D, and the pressure tube raised so that the mercury or brine fills the graduated tube exactly to the top of the stopcock; the pressure tube is then clamped securely, the stopcock being left open. In making these final adjustments, it is generally advisable to lower the pressure tube some 6 inches or so in order to see that the apparatus does not leak. If all seems satisfactory, the flask, D, is cautiously tilted so as to allow the acid to run out of the tube and thoroughly wet the sample. Chemical action will commence almost immediately, and the evolution of gas will continue until almost the whole of the sample has been dissolved. The flask and its contents should be gently shaken round and round so as to secure the thorough admixture of acid and sample, and, when all action appears to be over, the flask should be warmed gently to about blood heat in order to dispel any carbonic acid gas which may have dissolved in the acid liquid. The apparatus is allowed to stand until cold, after which the pressure tube is again released and is raised or lowered until the liquid is at exactly the same level in both it and the graduated tube; the volume of gas is then read off in c.c. As all gases change their volume very considerably with comparatively small changes of temperature, it is necessary to find the temperature of the carbonic acid gas. This may be done with sufficient accuracy by hanging a delicate thermometer near the apparatus and allowing some time to elapse between making the test and measuring the volume of the gas. As the pressure of the air has an effect on the volume of the gas, it is best to have a compensating tube, E ('volupensator'), attached to the instrument. This tube is arranged so as to hold exactly 100 c.c. at normal temperature and pressure;[1] under other conditions, the volume shown by it will be different, but the ratio of apparent volume to 100 c.c. will be the same as that of the gas which is being measured: thus, if the compensating tube reading were 115 c.c. and the gas measured 23 c.c., the true volume of gas at normal temperature and pressure would be 20 c.c., for 115 : 100 = 23 : 20. In this way, all the complicated reduction and correction for temperature and pressure is reduced to a simple proportion sum, and the reading of the thermometer and barometer eliminated.

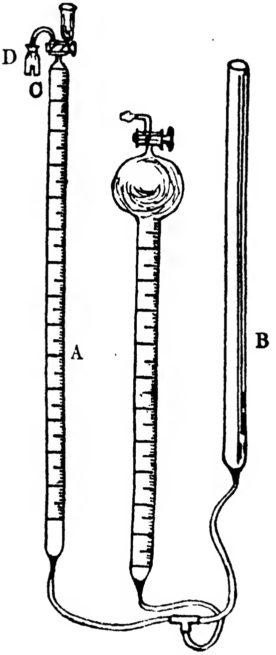

FIG. 11.

As 1 gramme of pure calcium carbonate will liberate 222 c.c. of carbon dioxide at normal temperature and pressure, the percentage of pure calcium carbonate in the sample is found by multiplying the volume of gas measured by 100 and dividing the result by the product of 222 and the weight of sample used. Thus, in an actual experiment 0·375 gramme of whiting gave

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[1] A gas is at normal temperature and pressure when it has a temperature of 0° C. or 32° F. and is under a pressure of 760 mm. or 30 inches. If the level of the fluid is the same in both the measuring tube, A, and the pressure tube, B, the gas will be under the same pressure as the atmosphere, and the latter can be ascertained by reading a barometer.

79·5 c.c. carbonic acid gas at normal temperature and pressure; hence 79·5 × 100 = 7950, and this divided by 222 × 0·375 (= 83·25) gives 95·5 per cent. of pure calcium carbonate in the sample.

If magnesium limestones are being tested in this way, the calculation does not apply, as magnesia has a different combining weight from lime, but the percentage of carbon dioxide present can be calculated by remembering that 1 c.c. of that gas at normal temperature and pressure weighs 0·00198 gramme. A typical dolomite contains about 48 per cent. of carbon dioxide.

Lime and magnesia may be determined, when required, by precipitating them respectively as oxalate and phosphate, as described in any standard text-book on gravimetric analysis. Care is needed to ensure a complete separation of the magnesia from the lime precipitate, or wholly erroneous results may be obtained.

An alternative method for the assay of calcium carbonate samples consists in determining the amount of acid which a given weight of the sample will neutralize. For this purpose about half a gramme of the sample (or more, if a low-grade material is being tested) is accurately weighed in a watch-glass, transferred with water to a small flask of about 4-oz. capacity, a couple of drops of methyl orange solution added, and then a standard solution of decinormal sulphuric or hydrochloric acid (obtainable from most large chemists) run in, drop by drop, from a burette until the colour of the liquid is changed from yellow to a yellowish pink, when the volume of decinormal acid used is read off. As 1 c.c. of this standard acid represents 0·005 gramme of pure calcium carbonate, the number of c.c. of acid used divided by twice the weight of sample taken for the test will give the percentage of calcium carbonate present. This is, however, only true when calcium is the only carbonate present. For all ordinary purposes the test is, however, sufficiently reliable, if care be taken to stir the liquid efficiently whilst adding the acid, and if, after the test is considered finished and the volume of acid used has been read off, a further quantity of acid is added in order to produce a decided pink and to ensure that the end point of the reaction has really been reached.

Iron in chalk, whiting, limestone, etc., must be determined by the usual methods given in the standard text-books on analysis. A rough idea of the proportion present may be gained by dissolving about 1 gramme of the sample in dilute hydrochloric acid and adding to it a few c.c. of a solution of ammonium thiocyanate. This will produce a dark red colour, the intensity of which will depend upon the proportion of iron present. It may be compared with a solution containing a known quantity of iron (see p. 265).

Checking is an important operation which is often neglected in small factories. A systematic examination should be made of the weight of goods delivered, and their quality and price. It has more than once happened that a firm, unable to supply goods at the price offered and unwilling to stock an inferior quality, have systematically watered the materials sent out so that they might weigh correctly when received by the customer, who unsuspectingly paid for water in the belief that he was buying felspar or some other glaze material. A determination of the percentage of moisture in such materials should, therefore, always be made as soon as possible after receipt of the goods. (See 'Moisture.')

Tests for checking the quality of goods in other ways will be found under the headings of the goods or materials themselves.

Clay testing is a subject of considerable complexity, as so little, comparatively speaking, is known of the true internal constitution of clay. As already explained (p. 230), an analysis of a clay carried out by ordinary methods is of trifling value to the clayworker, as it does not give him the information he requires.

To be of value, the examination of a clay must deal exhaustively with the following particulars at least:—

1. General composition, with especial attention to the presence and effects of certain small quantities of organic and mineral impurities, particularly iron compounds, with suggestions for their removal. This information should be supplemented by a physical examination made in order to determine the proportion of stones, sand, and other foreign materials in the clay. These are separated from the clay by a process of careful sieving and washing, the different materials being then identified by other tests (see p. 270).

2. Ease of working is an important characteristic in a clay, and though the final tests for this property must be made on a comparatively large scale, much information as to the ease or otherwise with which a clay may be ground, mixed with water, pugged, and made into goods, may be ascertained by careful working on fair-sized samples.

3. The behaviour of the clay at high temperatures is of great importance, and though this can often be predicted from the results of a rational analysis, the true test consists in an actual determination of the refractoriness of the clay (see p. 263).

4. The amount of contraction on drying and on burning must also be determined (p. 245), and attention paid to the ease and rapidity with which the drying may be allowed to take place. Some clays can be dried almost 'anyhow,' others require the greatest care and attention to prevent their cracking.

5. The appearance of the finished goods when fired at various temperatures, as regards colour, surface, soundness, and capability of taking a good glaze or engobe must be ascertained. The most suitable conditions of burning should also be determined.

6. The porosity and power of absorbing water, and the tendency to produce scum on standing exposed to the air (due to the presence of soluble salts), must also be tested when these are of importance, as in the brick trade (pp. 229 and 280).

7. The changes in the porosity of the clay when burned at different temperatures are important in many cases, as they give valuable information, *e.g.* the effect of heat on the material, and often indicate the most suitable finishing temperature as well as suggesting the limits of usefulness of the clay for various purposes.

When it is simply desired to establish the presence or absence of some particular constituent of the clay, so complete an investigation as that described above is not necessary; thus the percentage of *chalk* in a calcareous (or 'limey') clay may be readily determined by either of the two methods described for the assay of chalk on p. 240, except that not less than 1 gramme of the clay should be used in making the assay. The first method is more accurate than the second for clay, as the insoluble matter present makes it difficult to observe the change in colour.

Iron may usually be estimated in unburned clays by boiling about 5 grammes (accurately weighed) for some hours with about 4 oz. of concentrated sulphuric acid to which a few drops of nitric acid have been added, allowing the solution to cool, diluting with water to about ten times its volume, and carefully adding a slight excess of ammonia so that the liquid is slightly alkaline after vigorous stirring. If iron is present, the precipitate which is formed will be brown. In order to estimate the iron present in the clay the precipitate must be filtered off, washed well with water, and the residue on the filter treated by some standard method (see p. 265; also Ashby's *How to Analyse Clay*, or Mellor's *Quantitative Analysis*).

As this method is unreliable with burned clays, these should be fused with sodium carbonate or, preferably, potassium bisulphate, the fused material dissolved in water, acidulated and made up to a convenient, definite volume. Definite portions of this solution are then treated with ammonium thiocyanate solution, and the red colour produced is compared with the colour produced by a standard solution of iron (see p. 265).

Mellor has found that, when extremely small quantities of iron are present, it is better to use ether and amyl alcohol, as the colour is then more intense. A description of his method is given in *Trans. Eng. Cer. Soc.*, viii. 129.

Water in clay may be determined by the method described under 'Moisture' (p. 276).

Alkalies (potash and soda) are important fluxes, and must therefore be practically absent from fireclay and other refractory clays; their peculiar characteristics render their estimation difficult, and it is better to entrust this work to a skilled analyst.

When in the form of slip, it is desirable to make frequent tests of the fineness of the clay; and in order to ensure that it is well mixed, it is wise to dry small samples of the clay as rapidly as possible and to pass them through the kilns; an examination of the fired pieces will show whether the clay has been properly prepared before the bulk is used. This, of course, applies chiefly to the higher classes of goods, though a frequent inspection of the plant and clay in all branches of clayworking is essential to success.

Clay paste from pug mills, etc., should be tested for homogeneity, variation in composition and in air- and water-content. A microscopical examination will often show variations in composition; the air-content may be determined as described on p. 229, and the water-content as described under 'Moisture' (p. 276).

Coal testing is an operation requiring considerable skill if the true value of the fuel is to be ascertained. It is too often assumed that the calorific power (p. 236) or heating value of the coal is the sole criterion by which it should be judged, but in practice it is found that the nature of the ash is also of considerable importance. A further difficulty often arises from the circumstance that when a change in the source of supply is made, the kilns almost invariably go wrong if the firemen are aware of the change! The explanation of this curious result is not always easy, but in practice it is always best to bring about such changes gradually, so that they shall not be discovered.

It is advisable to make frequent tests of the amount of *ash* in the coal. This is easily accomplished by heating about 2 grammes of the sample in a tared porcelain crucible at a red heat until all the combustible matter has been burnt off and the residue is white, or, at most, reddish or grey. Care must be taken that the heat is not applied too rapidly at first, or some of the material may be projected out of the crucible. A good bunsen burner is the most suitable heater, the crucible being supported on a pipeclay triangle on an iron stand. The percentage of ash in coal varies greatly with different qualities; for firing kilns it should not exceed 8 per cent.

When considering the question of obtaining coal from a fresh source it is advisable to calcine several pounds of the coal in a crucible, to form the resulting ash into a 'cone' (p. 263) by mixing it with a little gum-water, and to determine the fusing point in a similar manner to that of clay (p. 263). Coals which give an easily fusible ash should be avoided for kiln purposes, as they render the cleaning of the fire-boxes difficult. Occasionally, the admixture of a small proportion of 'grog' or sand will prevent coal ash from clinkering, but with some kinds of ash this will only increase the fusibility. It is also advisable to determine the moisture in the coal, as this may largely influence the heating power.

In collecting samples of coal for testing, considerable care and skill are required if a fair, average sample is to be obtained. It is not sufficient to pick up any odd lump. The sampling must be done thoroughly and properly, or it had far better not be done at all. When sampling coal in the pit, portions should be taken from several parts of the face, freshly exposed pieces being the best. A suitable proportion is 5 to 6 lbs. of coal for each foot thickness of the seam. When sampling from a stack of coal, pieces should be taken haphazard from different parts of the stack, at least one-hundredth of the total weight being withdrawn. In each case, the large sample so obtained should be reduced to pieces not more than 1 inch in diameter, well mixed, and made into a heap. One quarter of the heap should be removed, crushed still finer, and one quarter again separated. This procedure is continued until 6 to 10 lbs. of sample is obtained. This should be taken to the laboratory for further investigation.

Compression tests are especially important to those branches of the clay trade where goods are used for architectural purposes. It is seldom, however, that a sufficient number of tests will be required to make it worth while to purchase a special hydraulic press for this purpose, and it is, therefore, usual to send the samples to a specialist having the necessary appliances.

Different results are obtained according to the position of the article in the press; thus, a brick tested 'on end' will have a compressive or crushing strength different from that which is shown if it is tested when laid flat. The difference appears to be due to the manner in which the brick is made. The compression test is an excellent indication of the uniformity of burning. The compressive strength of pipes is difficult to ascertain, as the conditions of service cannot be readily obtained in a laboratory test. Thus, it is not satisfactory to lay the pipe in a cradle when testing, as, in actual use, pipes generally break through insufficient bedding in the ground, with the result that the load on the pipe is not distributed as when a cradle is used, but is concentrated. For this reason, many engineers prefer to support the pipe to be tested on two knife edges 2 feet apart, and apply the pressure through a third knife edge to the top of the pipe.

Cones form a special mode of ascertaining the temperature of kilns, etc., devised by the late Dr Seger. They are particularly adapted for this purpose, and, in spite of much opposition, are rapidly gaining favour in this country. As the preparation of these cones is a matter requiring much skill and care, the clayworker should not attempt to make his own, but should obtain them from a reputable firm. At least one unreliable make of cones is obtainable, and should be avoided. (For further details, see p. 304, *et seq.*)

Contraction.—All clays diminish in volume on drying and, still more, on heating to redness. The causes of this having already been referred to

(p. 11), the method of measuring the change may be briefly described here. Although various modifications and methods are used by different clayworkers, the following will be found to be one of the most satisfactory, as it is sufficiently accurate without being tedious or complicated. A block of convenient size (say 9 × 4 × 4 inches) is made of the clay to be tested; the precise size is of little importance provided that it is sufficiently large and that the sides of the block are as square and the arrises as sharp as possible. This block is laid carefully on a smooth, level slab and a distinctive letter or number marked on the top. This is done so that the block may always be laid in the same relative position to the operator. A sliding caliper graduated in millimetres,[1] or in thirty-seconds of an inch, is applied to the block, and its length at the bottom carefully measured. A slip of wood, about a quarter of an inch thick, is then laid at each end of the block, the caliper again applied by resting it on the wooden slips, and the length again measured. This operation is repeated by the use of additional slips until the top of the block is reached, sixteen or seventeen measurements being taken in all. Very great care must be used not to alter the shape of the block during the measurements, as will occur if the caliper is moved carelessly. The block is allowed to dry white hard and the measurements are repeated, the difference being the contraction on drying. The block is then fired in the kiln, and, when quite cool, it is again measured as before, the difference between these and the first measurements showing the total contraction. The results may be expressed in various ways, but it is most convenient to express them in inches per foot —*i.e.* if a block of the wet clay exactly 1 foot in length is found to measure only 10·75 inches after firing, the total contraction would be $12 - 10{\cdot}75 = 1{\cdot}25$ inches per foot. As it can be proved that the contraction in volume is almost exactly thrice the linear contraction, there is no need to determine the loss of volume.

Where sliding calipers are not at hand, a sufficiently accurate result may often be obtained by carefully ruling two lines about 8 inches apart on the clay with a needle and measuring their distance carefully with dividers and a rule before and after drying and firing. It is essential that the clay to commence with should be of the right consistency, and, if comparative tests of the clay are to be made at intervals, the actual amount of water in the clay should be determined, as small differences in the amount of water present have a considerable effect on the contraction during drying: the contraction between the white hard state and after firing is not so much affected.

A Contraction Scale is very useful, and avoids troublesome calculations when making articles of definite sizes when burned. A separate scale is required for each clay or mixture having a different contraction. To construct such a scale, a large sheet of white paper is placed on a smooth surface and two lines at any convenient angle are drawn on it. One line is marked off in inches, its total length being exactly equal to that length of the fired piece of clay which was just 36 inches in the pasty or moulding state, this length being calculated from a series of trial pieces or the known contraction of the clay or body. The length of the other line is made exactly

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[1] If the sample is less than 9 inches long, the caliper should be divided proportionately. For samples only 2 inches long the caliper should have a vernier and read to $\frac{1}{10}$ mm. or $\frac{1}{200}$ inch. It is seldom necessary to use a micrometer to $\frac{1}{1000}$ inch, though this may be used if desired.

36 inches. The ends of the two lines are joined by drawing a third line, thus forming a triangle. Lines parallel to this third line are then drawn through each inch division across the triangle, and finally the divisions of the second side of the triangle are numbered to correspond to the first side.[1] The newly numbered divisions are those of the contraction scale. They may most conveniently be used by laying a strip of smooth wood or aluminium (other metals may stain the clay) with one truly straight edge alongside the contraction scale and marking off the divisions on the straight edge by means of a needle or fine scriber and numbering them appropriately. If this wooden or metal scale is then used for measuring a clay or body, articles made to such measurements will have the desired shrinkage. Thus, if a scale were made for a clay having a shrinkage of 1 inch per foot, each of the divisions on the second side of the diagram and on the wooden or metal scale would be $1\frac{1}{11}$ inches, and a block of clay paste 11 divisions (1 foot) in length would, after firing, be exactly 11 inches long. The contraction scale should be clearly marked on it, so that there may be no doubt as to the shrinkage for which it has been prepared.

Cornish Stone (china stone, pegmatite), which is important as a constituent of many bodies and glazes, cannot be distinguished from felspar by any simple chemical tests. To an experienced man the difference in texture and in melting point would be sufficient to decide whether one had been substituted for the other. On chemical analysis, Cornish stone is readily distinguished by its containing only 3 or 4 per cent. of potash as against the 12 to 16 per cent. contained in felspar. It must, however, be borne in mind that the terms felspar and Cornish stone are not used to denote single chemical compounds (the felspars form a group of minerals, whilst Cornish stone is a rock composed of several minerals), and therefore their composition varies considerably, especially in regard to the alkaline contents.

Apart from the appearance and 'feel,' Cornish stone is best tested by placing a good sample and the new one side by side in the kiln and removing them when the genuine sample has fused somewhat; the appearance of the two may then be compared. If they differ greatly, the new sample must be tested still further to ascertain whether it can be used with safety to replace the original (good) stone.

As unscrupulous dealers are prone to water their stone, it is wise to dry a weighed sample very carefully and to determine the moisture in it (see p. 276). Cornish stone is usually sold on the understanding that it does not contain more than 10 per cent. of moisture when in lumps, or 5 per cent. if water-ground and dried.

Counters which automatically register the number of waggons of clay, coal, etc., loaded, or articles made or of movements of a machine are an invaluable check both on the material used and on the work done by the carters and other workers. Several of the simplest counters have the disadvantage that the worker may easily rotate them by hand and so fictitiously increase the number recorded. This may to a large extent be prevented if each time the waggon, barrow, or other vehicle, when travelling in one direction (*i.e.* full), is made to depress a lever and so mark a rotating dial in such a way that the *time* at which the waggon passed is noted.

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[1] If there is any difficulty in ruling the lines truly parallel, the length of each division may be calculated and measured separately, but it is much easier and less liable to error if parallel lines are drawn as described. A large ruler for parallel lines can be purchased from dealers in artists' and draughtsmen's materials.

If the records succeed one another too quickly a further watch can then be taken.

Mill-counters and engine-counters, for determining the number of revolutions per day, are useful in keeping up the output and in ensuring the engine being run at a regular speed, and indicate whether the workers or the machine is at fault. They should be well protected from the dust. Plain counters with dials showing tens, hundreds, and thousands of revolutions are preferable to an automatic paper-registering apparatus. The counter should be so attached that it is out of gear when the machinery is running on the loose pulley.

Although no automatic counter exists which is specially sold for the purpose, it is very desirable that the amount of clay ground, tempered, pugged, pressed, and delivered should be registered daily, as in this way the regular working of the machinery is ensured and a product of higher average quality is obtained than when irregular work is the rule. An automatic recording weigh-bridge is useful for this and many other purposes, but is, unfortunately, costly and easily put out of action.

With the advent of wire-cut bricks has come the necessity for a counter to indicate how many bricks are turned out by each machine. In the usual form of apparatus, the column of clay passes over rolls which, in rotating, indicate on a modified form of 'speed indicator' the number of inches of column of clay produced, and this number divided by the average length of a brick gives (roughly) the number of bricks made. The number is often not quite correct owing to the tendency of the roller to 'stick' at times. This sticking is reduced to a minimum by covering the roller with felt and attending very carefully to its lubrication.

A particularly satisfactory counter for ascertaining the number of bricks taken from the machine to the drying-shed or to the kiln has been placed on the market by Messrs Thos. C. Fawcett, Ltd. Each barrow-load of bricks is weighed, and so sensitive is the machine that a single brick too few will result in the load not being counted at all. The machine is quite automatic.

Automatic counters for checking the number of bricks delivered to the kiln never show the number of bricks drawn from the kiln, as a certain number of bad and broken bricks have to be thrown out, and these bricks are counted on leaving the machine, but do not appear in the actual output. Automatic counters are much more reliable than the older method of counting by chalk marks on the wall or on a slate, and they avoid many unpleasant disputes with the workmen.

When once a correct system of checking is installed, it is easy to detect any slackening of speed in the machinery, or unusually slow working on the part of some of the men; and as the use of automatic appliances for such checking does away with much of the labour of an ordinary foreman, it effects a saving quite out of proportion to its cost.

Counters of time and work done by the makers may be more appropriately considered under the head of 'Costs' and 'Office Work.' Such appliances are obtainable from the very numerous promoters of card indexes, etc.

Dampness of air in drying-rooms (see p. 252); of materials (see p. 276).

Density is a term used to denote the relationship between the volume of a given mass of substance and its weight, or the relation between the weights of equal volumes of different substances. The term is also used somewhat loosely in the sense of being the opposite of porosity (p. 280).

The density of a clay may be expressed in three forms—referring to the clay (1) in its green or (2) in its fired state, or (3) to the density of a clay-slip.

The specific gravity of a substance is the weight of any volume of it divided by the weight of an equal volume of water; hence, the specific gravity of water is 1·000.

In the case of porous solids like fired clay, the specific gravity may refer to the whole piece—including pores,—or it may refer only to the solid material. If the former is understood, the specific gravity will vary with the fineness of the particles—*i.e.* with the grinding; but if the latter, it will be constant for the same material.

To find the *apparent density*, or specific gravity including pores, of a lump of fired clay, or other material, not affected by water, the piece is weighed on a delicate balance in the ordinary way, after which it is dipped in melted lard or similar material to cover up the pores; the coating of fat should, of course, be as thin as possible, so as not to affect the results. It is allowed to cool, and is then hung from the arm of the balance by means of a hair, or fine piece of silk of negligible weight. It is re-weighed, and is then completely immersed in water contained in a small vessel. When the balance swings evenly, it is weighed in this position; then

$$\text{sp. gr.} = \frac{\text{ordinary weight in air}}{\text{loss of weight in water}}.$$

If preferred, method (*a*), below, may be used, when

$$\text{sp. gr. of whole piece} = \frac{\text{weight dry}}{\text{weight soaked—weight suspended in water}}.$$

To find the *true specific gravity* of the substance itself (excluding pores), one of two methods may be used:—

(*a*) Find the ordinary weight of the piece, then soak it in water for some hours (preferably under reduced pressure) and find the weight of water absorbed (see 'Absorption,' p. 229) in grammes. This will give the volume of the pores in c.c.[1] Now weigh the piece suspended in water as above described and find the loss of weight. Then

$$\text{sp. gr. of solid} = \frac{\text{weight dry}}{\text{weight dry—weight suspended in water}}.$$

In the case of unfired clay, water cannot be used for soaking the material; paraffin or xylol should be substituted, and the numbers obtained for the 'liquid absorbed' and for the 'loss of weight in liquid' divided by the specific gravity of the liquid itself. Or the following method (*b*) for powders may be employed:—

(*b*) To find the specific gravity of a powder, a bottle is weighed empty and dry, then it is exactly filled with water to a mark on the neck, and weighed again; the increase in weight gives the weight of water held by the bottle. The bottle is again emptied and dried and nearly filled up with the powder and again weighed; the increase shows the weight of powder used. The bottle is now filled up to the mark with water and weighed once more;

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[1] The result will not be strictly accurate, as some pores may be of such a nature that water will not enter them. If these are to be included, the material must be ground to an impalpable powder before its specific gravity is determined.

the increase between this and the previous weight shows the amount of water-filled space not occupied by the solid. Hence,

$$\text{sp. gr.} = \frac{\text{weight of solid}}{\begin{array}{c}\text{weight of water to fill empty bottle—weight of}\\ \text{water occupying space not filled by solid}\end{array}}$$

To find the ***specific gravity of a liquid,*** whether a clear liquid or a slip matters not, weigh a dry empty bottle or flask, fill it to a certain mark on the neck (or, if a pycnometer is used, fill it completely) with water at a temperature of 60° F. and weigh again—increase in weight = water held by bottle. Empty out the water and dry and refill the bottle with the liquid, or slip, and again weigh so as to find weight of liquid. Then

$$\text{sp. gr.} = \frac{\text{weight of liquid}}{\text{weight of water}}.$$

It is important that the liquids should be as near 60° F. as possible, as the specific gravity diminishes with increased temperature.

To find the *density of a slip in ounces per pint,* multiply the specific gravity by 20; thus, specific gravity 1·30 = 26 oz. per pint, and, conversely, the density in ounces per pint divided by 20 = specific gravity, *i.e.* a slip weighing 27 oz. per pint has a specific gravity of 1·35 (see also p. 267).

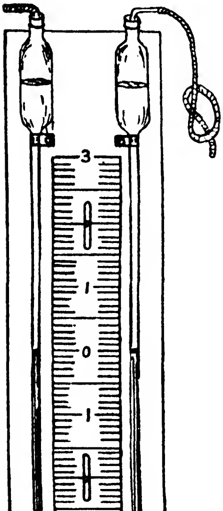

Fig. 12.

It is becoming increasingly common on the Continent to express the density of clay in another form by quoting the weight of 1 litre of the dry powder. This figure is obtained by filling a tared litre flask to the mark with the powdered clay or other material, and then weighing. This gives results differing from those obtained by other methods, but they are consistent and easily obtained. The best term for this figure is 'volume-weight'; in this way, it may be distinguished from the ordinary terms, 'density' and 'specific gravity.'

Draught-measurers are instruments designed to measure the pressure of the air supplied to boilers and kilns, whilst anemometers (p. 233) measure its speed. As, however, the speed is dependent on the pressure, the two instruments replace each other to a certain extent. As the temperature of the fuel in burning depends upon the air-supply, it is important to have some means of ensuring steadiness in this latter.

One of the simplest draught-measurers is that devised by Seger (fig. 12), which consists of a long glass tube bent in the form of a U and enlarged at its open ends, so that it there has a section ten times that of the tube itself. The upper half of the tube is filled with a suitable liquid and the lower half with an immiscible one of a different colour (water and a solution of carbolic acid stained almost black is commonly used). The instrument is provided with a sliding scale, so that the zero may be set at the junction of the two liquids when the instrument is at rest. One end of the apparatus is then connected with the flue, and the change in level of the liquid-junction is noted. This is ten times the actual depression of the liquid on the surface, so that the rise or fall in inches must be divided by ten. If, instead of keeping the instrument vertical, it is simplified into a plain tube with an inclination of 1 in 10, its sensitiveness will be correspondingly increased; or one arm may remain vertical, and the other may be so arranged as to have an inclination of 1 in 10 with the horizontal (fig. 13). Before using, the board on which this instrument is fixed should be carefully levelled, or its readings will be unreliable. The scale should also be adjusted so that under atmospheric pressure to top of the liquid in the sloping arm is exactly at 0 on the scale. It is then only necessary to read the sloping arm scale on the instrument. This is a very easy matter. The draught gauges just described do not give continuous records, and as the manager of the works requires to know that the draught has been properly controlled throughout the whole burning period, it is advisable to instal an automatic draught recorder. No British-made draught recorder has been specially designed for kilns, but one supplied by Messrs Alexander Wright & Co., Ltd., Westminster (fig. 14), will be found quite reliable and suitable, as its working parts are specially protected from injury by dust from the flues. In this instrument, a card is rotated at a regular speed, and a pen marks on this card the pressure of the air supplied to the boiler or kiln. The measurement of the draught, though a great means of economizing fuel with an ordinary intermittent kiln, becomes almost a necessity if a continuous kiln is to be burned

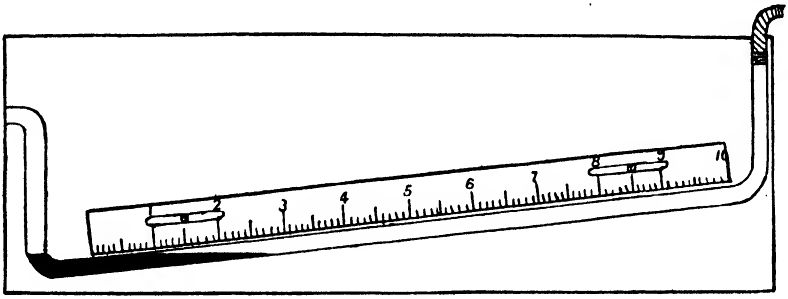

FIG. 13.

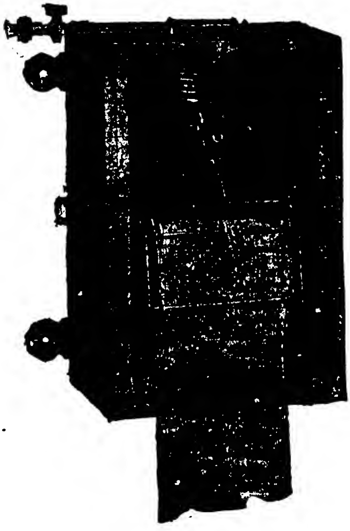

FIG. 14.

satisfactorily. In such a kiln, the gauge is placed nine holes before the fire, but in an intermittent oven it is placed between the burning space and the damper. Fig. 15 shows its position for a boiler. Some recording draught gauges have a disc instead of a roll of paper, but otherwise their construction is very similar to that shown in fig. 14. The actual draught pressure naturally varies with the kind of kiln and with the progress of the firing; it is seldom equivalent to a column of water more than $\frac{3}{8}$ or $\frac{4}{8}$ of an inch high, unless a fan is employed, when a reading of 2 inches may be obtained. It is, of course, important that the gauge should always occupy the same relative position to the fire, as the draught gradually diminishes with increasing distance from the source of heat. This is particularly necessary in continuous kilns in which the fire travels forward at the rate of one or more 'chambers' per day.

Drying.—The control of the drying of solid materials depends on the nature of the goods themselves. It is usually determined by noticing the loss of weight of a carefully weighed portion of the substance, which is re-weighed at intervals until it ceases to lose weight at the temperature at which the drying is allowed to take place. If this temperature is rather above that of boiling water (212° F. or 100° C.), all the true moisture will be removed by this treatment, but any 'combined water' will still remain, and is only to be completely removed at a red heat (see 'Drying,' p. 167). In drying clay goods on the large scale, however, so high a temperature cannot be used from the start, and the drying must be conducted under more gentle conditions. As the amount of drying the goods undergo depends upon the amount of moisture the air in contact with them can take up, it is important to keep the air in such a state as to work as efficiently as possible. Air at any particular temperature can only hold a definite weight of water per cubic foot, but the amount of water so retained increases very rapidly with comparatively small increases in the temperature; thus, air at 30° C. can retain nearly twice as much moisture as the same volume of air at 20°, and more than three times that at 10°. The drying-rooms should, therefore, be well supplied with thermometers hung in various parts, and the heating must be arranged in accordance with the indications of these instruments.

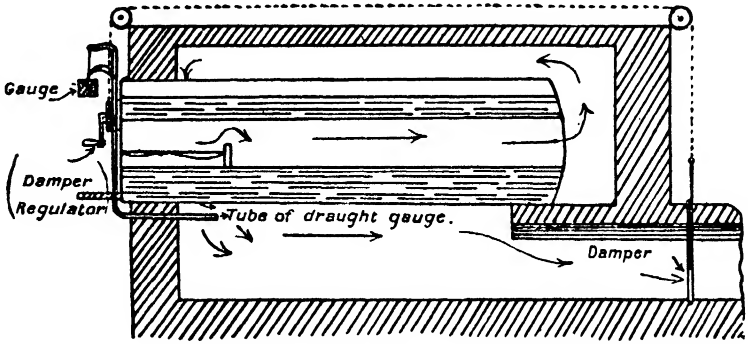

FIG. 15.

At the same time, it must be remembered that merely heating in an atmosphere saturated with moisture will not dry the goods, so that frequent estimations of the moisture in the air of the dryers should be made, and the air-supply so regulated that a definite quantity of water is abstracted from the goods in a definite time, the precise amount depending on the 'delicacy' of the clay.

A rough estimation of the evaporative power of the air may be made by means of a Piche evaporimeter, which consists of a graduated glass tube (fig. 16) with a small clamp on the lower (open) end supporting a small piece of filter-paper. The tube being filled with water and hung up in the dryer, the water is gradually evaporated from the filter-paper, a fresh supply from the tube keeping the paper always wet. The changing level of the water in the tube is read off at regular intervals and the rate of drying is thus ascertained. The results have no absolute value, but when obtained from instruments of identical dimensions using clean filter-paper and pure water, they agree well amongst themselves.

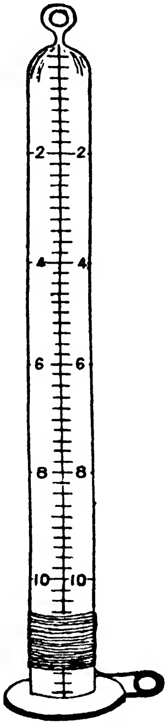

FIG. 16.

For accurate determinations of the amount of drying which the air can do under given conditions, it is necessary to employ some form of hygrometer. These are instruments which record the amount of moisture in the air in which they are placed. Although several forms are in use, there are two which are specially suited to the clayworker—the 'wet-bulb' and the 'hair' hygrometer. The former, though requiring rather more skill in use, gives more accurate results and is a more durable instrument.

The wet-bulb hygrometer (fig. 17) consists of two precisely similar thermometers mounted side by side, one of which has the bulb covered with a small piece of cotton so arranged that it is kept constantly damp. Water is supplied to the cotton by capillary attraction from a small vessel placed underneath the thermometer. As the water surrounding the wet bulb evaporates, it keeps the air in its immediate neighbourhood saturated with moisture, so that this wet-bulb thermometer reads lower than the dry one. This is because evaporation is always accompanied by a lowering of the temperature of the liquid evaporated, and in this case the depression is such as to cause the wet-bulb thermometer to register the dew-point of the air. From the difference in the reading of the two thermometers the dew-point, that is, the temperature at which (under these conditions) the air would be saturated with aqueous vapour, can be calculated. This is done by multiplying the difference by a factor given in the tables, and deducting this from the dry-bulb thermometer reading. If this showed a temperature of 15° C. and the wet-bulb one a temperature of 10° C. with the barometer at 760 mm., the dew-point would be 5·6° C. The vapour tension at this temperature is about 6·8 mm., and at 15° C. about 12·673. The ratio of these is as 100 to 54; so that the air is only 54 per cent. saturated, and can take up an additional amount of vapour equal to that it already contains.

The absolute weight of water which the air can still take up may be calculated from Proctor's table (p. 340) by deducting the maximum weight of water vapour containable by air at the dew-point from that at the temperature of the dry bulb; thus, 1 cubic metre of dry air at 15° C. can take up

12·8 grammes; if the air is not dry, but gives a wet-bulb reading of 10° C., the dew-point is 5·6° C., and at the dew-point the air can only hold 6·8 grammes. Hence, the air at 15° C. can still take up 12·8 – 6·8 = 6·0 grammes of moisture.

As the wet-bulb hygrometer is somewhat troublesome to keep accurate owing to the necessity of changing the cotton wrapping frequently, and considerable errors are introduced if the water supplied to it is dirty, a different form of instrument, due to Saussure and Kopp, is often preferred.

In this hair hygrometer a carefully prepared human hair is kept under tension by having one end fixed and the other attached to a small weight; to facilitate registration the hair passes over a tiny pulley, the axle of which carries a fine pointer. In a moist atmosphere the hair increases in length and so causes the pointer to turn towards the right, whilst in a drier atmosphere it turns towards the left, the extent of its motion in either direction being measured by means of a scale. In order that the instrument may be easily adjusted, the figure to which the pointer turns when a small vessel of water is shut up for some hours in the apparatus, so as to completely saturate the air within it, is marked 100 on the scale. If for any reason this number is not indicated, the length of the hair must be increased or diminished until the correct position of the pointer is reached. The vessel of water is then removed and the apparatus is ready for use. The scale used is an arbitrary one, having usually been made by comparing the readings of the instrument with those of a wet-bulb hygrometer. The absolute weight of moisture in the air may then be calculated as usual, or advantage may be taken of an admirable chart (fig. 18) published by the *Tonindustrie Zeitung.*

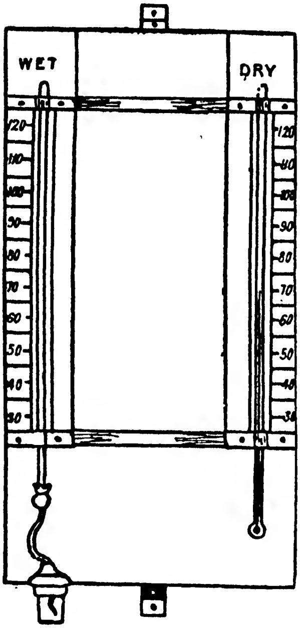

Fig. 17.

The numbers in the column A represent the numbers on the hair hygrometer scale, those in column B the relative humidity or dampness. Hence, if the hair hygrometer shows a reading of 85, the relative humidity is 70 per cent. and the air contains 70 per cent. of the total moisture it can carry at that temperature. To calculate the total weight of water in the air in grammes per cubic metre, a knowledge of the temperature is required: supposing it to be 35° C., the hygrometer remaining at 85 as before, then, as 85 on the hair hygrometer scale represents 70 per cent. of humidity, the horizontal line 70 must be followed until it cuts the sloping line of temperature 35, and a vertical line must be taken upwards from this point to the top of the scale; in the present case this will end at 28, showing that the air contains 28 grammes of water per cubic metre. If the vertical line be taken downwards instead of upwards, the dew-point, or temperature at which the air will deposit dew, will be shown; in the present instance at 28° C.

The rapidity with which the sloping temperature lines in the chart lose their perpendicularity shows, in a graphic way, the great advantage of a small increase in temperature in increasing the water-carrying power of the air. A rough test of the rapidity of the drying of bricks may be made by

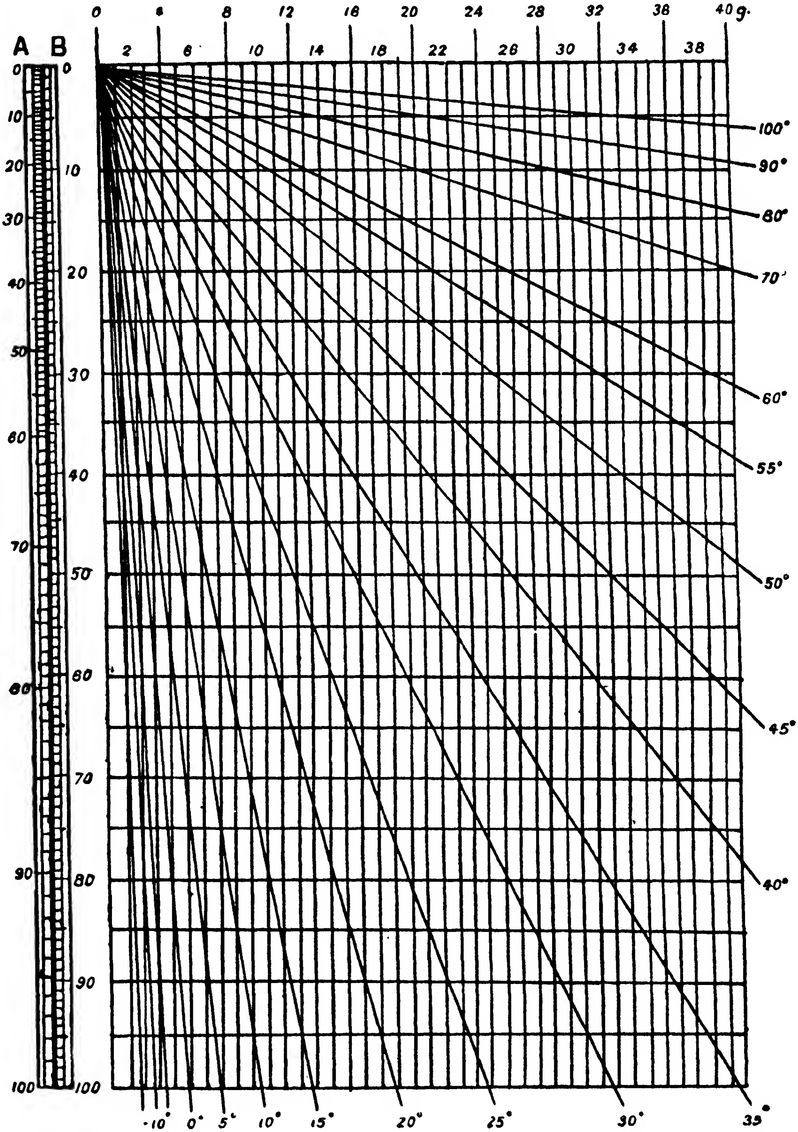

Fig. 18.

placing a brick on a glass or metal plate (so that no water will be absorbed by the plate) and weighing both brick and plate at frequent intervals.

Durability is an important factor of certain materials, particularly bricks and artificial stones.

Durability is usually tested in regard to three influences—rubbing, crushing, and weather. Resistance to rubbing may be tested (though only with partial satisfaction) by a rough practical test, as described on p. 288. Resistance to crushing may be tested by means of a special crushing or compression machine (p. 245). The hardness may be tested as described on p. 273.

Resistance to weather may be tested by soaking the bricks in water for some time, wiping them dry, and then keeping them at – 15° C. (= 5° F.) in a refrigerator for several hours and again warming them up to the ordinary temperature of the air. This process of soaking, freezing, and warming is repeated a considerable number of times (say twenty-five times), and the resistance of the bricks so treated to crushing is then determined; the difference between it and the crushing strength of an unfrozen brick will give some idea of the effect of exposure of the brick to the weather. This test would seem, however, to be unnecessarily severe for general use. (See p. 288.)

It has also been suggested that a reliable way of testing the frost-resisting power of more or less porous goods is to soak the article in a cold, saturated solution of sulphate of soda. When quite saturated with the solution the article is hung up by a piece of fine string to dry. As the water evaporates the soda begins to crystallize, and, as the process of crystallisation goes on, goods which are not frost-proof will be split. This test is admittedly only a rough one, but is useful in sorting out samples from a large number of different kinds of goods submitted for examination with a view to purchase.

For testing the durability of glazed bricks, etc., Weber exposes the sample under a glass 'shade' (such as is used by confectioners, fig. 23) to the vapours of strong hydrochloric acid for several hours. If, after this exposure, the sample on warming gently shows no signs of scumming, Weber considers it to be capable of resisting ordinary atmospheric influences.

Efflorescence is the term given to certain varieties of scum forming on bricks during use. It is commonly due to soluble salts soaked up by the goods through their standing on wet ashes, or to the presence of free calcium sulphate in the clay (see p. 191). Soluble salts in bricks and similar goods may be estimated as described on p. 290.

Engine testing. See 'Power,' p. 281.

Expansion (see also 'Contraction,' p. 245).—When fired, all clays have a less volume than in the unfired state, so that on the whole it is true to say that clays contract in firing. At the same time, however, it must be remembered that this contraction is really the difference between the expansion and contraction of the clay. Thus, during the drying the clay contracts in proportion to the amount of drying it undergoes, but when placed in the kiln the heat causes the particles of clay to expand in proportion to the temperature, whilst at the same time the loss of water from the mass causes it to contract. As soon as this contraction ceases, the clay follows the normal characteristic of heated bodies and expands with increasing temperature.

This matter of expansion is chiefly of importance to the clayworker in reference to the application of engobes and glazes to his goods. If the expansibility of the clay (biscuit) goods differs much from that of the covering material, the latter will roll off, blister, or craze. (See these various headings in Chapter XI.)

It is a matter of extreme difficulty to measure the expansion taking place at such high temperatures as occur in kilns, and, fortunately, it is not necessary to know the *actual* expansion.

The defects arising with glazes and other 'covering materials' are dealt with in Chapter XI.

Felspar is a term used to denote a group of mineral silicates of which orthoclase or 'true felspar' is the best-known member. When decomposed under suitable conditions it loses a variable proportion of its basic constituents and produces china clay, Cornish stone being an intermediate product. A theoretically pure potash felspar contains—

Silica, ...	64·72
Alumina, ...	18·35
Potash, ...	16·93

but almost all analyses of orthoclase show varying small amounts of soda, lime, magnesia, and iron oxide.

When heated to a moderate temperature it softens, but at a temperature corresponding to Seger cone 9 it melts to a white porcelain-like mass, which often breaks up into small white drops. At a considerably higher temperature it melts to a more or less clear glass. It is chiefly employed in the clay industry as a convenient means of introducing potash as a flux, as felspar is practically insoluble, although the finely ground powder has a slight alkaline reaction.

The value of the felspar depends chiefly on the alkali it contains, and this can only be ascertained by analysis. A determination of the fusing point (p. 263) and a test to show its freedom from more than slight traces of iron oxide will, however, often be found to be sufficient tests of its purity. The iron oxide may be tested for as described under 'Glaze' (p. 265).

Firing Control.—The control of the firing of the kilns should be made in connection with—

(*a*) The Draught.
(*b*) The Temperature.
(*c*) The Composition of the Flue-Gases.
(*d*) The Fuel.
(*e*) Warners.

These methods and instruments will be found described under their separate heads, and general information on the subject will be found on p. 160. It is, however, essential to remember that firing kilns does not so much mean reaching a certain temperature as obtaining a certain effect in the goods; hence, skilled supervision can never be entirely replaced by any automatic appliances, though these latter are invaluable aids to the former.

Flint is a moderately pure form of silica, found in nodules in the upper strata of the chalk beds of this country. Its chief impurity is iron oxide, which may be tested like a 'frit' (see p. 25), but when bought in the ground state it should be analysed in order to ensure its not having been contaminated with lime from the grinding stones. When heated to the highest heat of the kiln, it should burn perfectly white and be quite unfused. When specially pure silica is required, ground quartz is sometimes substituted for flint. Ground flint is, like other ground glaze materials, liable to contain an excess of water; it should never lose more than one-twentieth of its weight on drying at 100° to 110° C., and should be bought only on condition that it will not do so.

Flue-Gases.—As the proper combustion of the fuel in the boiler fires and kilns depends on the proper regulation of the air-supply, it is necessary to make repeated tests of the products of combustion as they pass through the flues. The great heat of these gases makes their collection somewhat difficult, but, nevertheless, it should be attempted as often as possible. The gases are drawn through an iron or, preferably, a porcelain tube one end of which projects into the centre of the flue and the other is attached to a sampling tube (fig. 29) and suction apparatus. The temperature of the gases in the flue should be observed at the same time, so as to enable the necessary corrections to be made. Before analysing a flue-gas it must be allowed to cool to the temperature of the atmosphere, or very erroneous results will be obtained, as the gas, when passed into the reagents, will be cooled, and will show a reduction in volume which has nothing to do with its composition.

As nine-tenths of the combustible matter in ordinary coal consists of carbon, the chief product of combustion is the compound of this with the oxygen of the air, viz. carbon dioxide, or (as it is often conventionally termed) carbonic acid gas. For its complete combustion, carbon requires $2\frac{2}{3}$ times its weight of oxygen and about $11\frac{1}{2}$ times its weight of air. If too little air is present, a lower oxide of carbon (called carbon monoxide) will be formed in proportion to the lack of air; whilst if too much air is supplied, the unnecessary air must be heated, and so will absorb heat which would otherwise have been usefully employed in warming the kiln. It has never been found possible in practice to burn coal effectively with exactly the correct proportion of air, and, so far, the best results have been obtained when 13 volumes of air were used in place of each 10 volumes theoretically needed; this corresponds to 15 per cent. of carbon dioxide in the flue-gases. Should the flue-gases contain less than 15 per cent. of this gas, an unnecessary waste of fuel is going on, probably caused by an improper regulation of the draught of the kiln, as must almost always be the case when no draught-gauge (p. 250) is employed.

Two totally distinct methods are used in the testing of flue-gases for their carbon dioxide content—the one physical and the other chemical. The physical method of testing depends on the fact that carbon dioxide is specifically denser than air, and that, consequently, the relative density of a gas composed of air and carbon dioxide will vary with the proportion of the latter gas present. Of the various forms of apparatus for determining this difference in density, that of Krell & Schultze, of Berlin, deserves special mention. It consists of two vertical tubes, each nearly 6 feet long, the lower ends of which are connected with a differential pressure-gauge consisting of a fine calibrated glass tube containing a thread of coloured alcohol. The position of this thread relative to the scale indicates the percentage of carbon dioxide present, as the flue-gas passes through one of the tubes and ordinary air is passed at the same rate through the other. If the position of the thread of alcohol be registered photographically, a continuous record of the composition of the flue-gases is obtained. Although the results obtained in this way agree remarkably well with the more accurate chemical analyses of flue-gases, they are open to the objection that the production of carbon monoxide, which, on account of its strong reducing action, is sometimes very objectionable, is not shown by this apparatus.

A similar criticism applies equally to the chemical analysis of flue-gases for carbon dioxide only, although its continuous estimation by the ingenious 'Ados' or other automatic apparatus is of great value when supplemented occasionally by more complete analyses. In this instrument, the flue-gases are pumped at regular intervals into a measuring vessel acted upon by caustic potash, and the diminution in volume, due to the removal of the carbon dioxide recorded, the whole of these operations being carried out automatically. Although constructed for the determination of this one constituent of the flue-gases, it is quite possible for the apparatus to also estimate the proportion of carbon monoxide present; when this is the case, the instrument affords an almost perfect control of the firing.

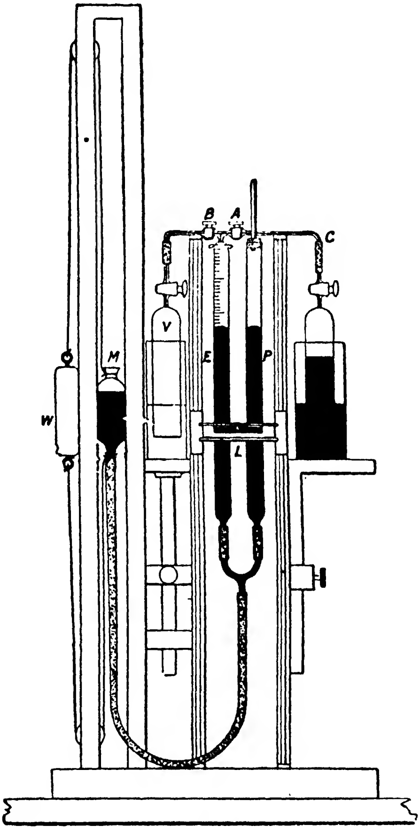

Fig. 19.

Automatic carbon-dioxide recorders are delicate instruments, and should not be touched by anyone unfamiliar with them. Each time the chart is changed, the levels of the potash and scaling liquids should be set to correct zero. The potash solution (s.g. 1·27) should be changed every week or ten days.

Where it is desired to make an analysis of the flue-gases in the ordinary way, the apparatus devised by Orsat or by Stead, or one of the many forms of the Lunge 'nitrometer,' may be employed. In all the best forms, the volume of the sample is first accurately measured; the gas is then subjected to the action of some chemical which will remove one of the constituents without affecting the others, and the change in volume is noted. A second constituent is then removed and the volume of the gas is again ascertained, these operations being repeated until only the nitrogen remains.

A fair, average sample[1] of the gas to be tested having been obtained in the 'laboratory vessel' in the manner described on p. 292, and the gas apparatus being filled with mercury and ready for use, the first operation consists in measuring off a definite quantity of gas. For this purpose a short piece of thick-walled rubber tubing is used to connect the fine capillary tube of the laboratory vessel with the corresponding capillary at A (fig. 19). (Before making the connection the gas apparatus must be filled with mercury to the end of the tube A, and the rubber tube just referred to should also be filled.)

The tap, A, and that of the laboratory vessel are then opened, the reservoir, M, lowered cautiously until about 80 volumes of gas are drawn into the apparatus. The taps of A and C are then closed and the laboratory

---

[1] If, as is usually the case, the gas is hot when collected, it must be allowed to become quite cold before the analysis is commenced.

vessel detached. The reservoir, M, is then carefully raised up or down until the mercury is at the same level in the measuring tube, E, and in the plain (or 'pressure') tube, P, the slide, L, being raised or lowered for this purpose. The number of volumes of gas in E is then carefully noted (first reading). A second laboratory vessel, V, containing a 30 per cent. solution of caustic potash, is now attached to the capillary tube at B; its tap and that of B are opened, and the reservoir, M, is raised so that all the gas and a few drops of mercury are passed from E into V. The tap, B, is then closed. After five minutes the tap B is again opened, the vessel M is lowered, and the gas drawn back into E, the greatest care being taken not to allow any potash to enter E. Tap B having been closed, and the mercury in E and P being at the same level, the volume of gas is again read off (second reading), the difference between the two readings being the volume of carbon dioxide in the gas. In many cases, this is all that is required; but if a fuller analysis of the gas is desired, the vessel, V, is replaced by a similar one containing a strongly alkaline solution of pyrogallol, the gas is passed from E into this, allowed to remain in contact for some minutes, and again drawn back into E and measured (third reading). The difference between this and the second reading is the amount of oxygen in the gas. The amount of carbon monoxide may be found by similarly treating the gas with a strong solution of copper chloride (made by allowing hydrochloric acid to stand for some time in contact with an excess of copper turnings).

It is not usually considered necessary to estimate the proportions of hydrogen and hydrocarbons present in flue-gases, as they can only be present in such small amounts; the volume of gas remaining in E after the removal of the carbon dioxide, oxygen, and carbon monoxide may, therefore, generally be regarded as nitrogen.

The Orsat apparatus is also excellent for the analysis of flue-gases. This apparatus has the advantage that the gas is passed in succession into each of the reagents without any disconnection and reconnection of the apparatus. This is a great convenience to the skilled worker, but it makes the apparatus much more delicate and fragile, and repairs are more costly. In other respects it closely resembles Stead's apparatus and is used in a similar manner.

As it is the proportion of the various gases in the mixture and not their absolute volume that is required, it is not necessary to make any correction for temperature and pressure unless the duration of the analysis is unusually long; where such a correction is required, a 'compensating tube' (p. 242) may be employed.

The *composition* of the gases naturally varies in different boilers and kilns. In a Hoffmann kiln 3 per cent. of carbon dioxide is not unusual, if the gases are sampled near the chimney, but in a pottery kiln in first-class condition 6 or 7 per cent. may be regarded as normal. If the percentage of carbon dioxide in the gases is increased to correspond to that in boilers, the contents of the kiln will almost certainly be spoiled.

As a coal of average composition requires 10·34 times its own weight of air for its proper combustion, the percentage composition of the flue-gases should, under perfect conditions, be about 19 per cent. of carbon dioxide, 81 per cent. of nitrogen, and should contain traces only of other gases, carbon monoxide being entirely absent. Consequently, if 19 be divided by the percentage of carbon dioxide in the flue-gases, the result will be the number of times excess of air over the theoretical amount which is passing through the flues. Thus, if only 3 per cent. of carbon dioxide is found, then $19 \div 3 = 6$, which shows that six times the proper quantity of air is being supplied. As already stated (*cf.* p. 228), it is never possible in practice to work with the theoretical volume of air and yet obtain perfect combustion, and 15 per cent. of carbon dioxide may be considered to be the highest obtainable in ordinary practice. A high percentage of carbon dioxide generally indicates that only a small excess of air has been used; it does not necessarily mean correspondingly good combustion, as it may be accompanied by carbon monoxide. A low percentage of carbon dioxide may be caused by an excess of air or by insufficient air (in which case there will be a high proportion of carbon monoxide), improper mixtures of air and gas, or a large proportion of hydrogen in the fuel. No attempt should be made to get a very high proportion of carbon dioxide merely by cutting down the draught (unless the analysis of the gases shows that this does not increase the proportion of monoxide), as when the draught and resistance of the fuel to the passage of air are in proper relation to each other, a high proportion of carbon dioxide can be obtained with either a high or low draught.

If *carbon monoxide* be found in flue-gases, it indicates, quite independently of the amount of carbon dioxide, that too little air is being supplied. As both these gases are derived from the carbon of the fuel, an increase in one may often be accompanied by a decrease in the other; but as the heat produced by burning fuel to the monoxide is far less than when complete combustion to dioxide takes place, the formation of the former should be regarded as a direct waste of fuel. Any proportion of carbon monoxide exceeding $\frac{1}{2}$ per cent. in a flue-gas indicates (1) badly designed furnace; (2) improper management of the fire and air; (3) unsuitable fuel; (4) improper mixing of the burning gases and air; (5) a low temperature in the furnace or combustion chamber; (6) an insufficient supply of air.

The estimation of carbon monoxide should seldom be omitted in flue-gas analysis, as the presence of a relatively small proportion of this gas may indicate a serious loss of fuel.

The presence of *oxygen* in the flue-gases is another indication of an excess of air, although it is difficult to reduce the proportion of this to below 5 per cent. If both oxygen and carbon monoxide are present in the flue-gases it is probable that the temperature of the fire is too low to bring about proper combustion; or imperfect combustion may be brought about by an insufficiency of air to the fuel, together with a leak, through which the kiln draws air which never comes in contact with the fuel.

The importance of avoiding these excessive amounts of air as well as leakages may be better realized by considering a by no means uncommon case, where the flue-gases on analysis showed only 3 per cent. of carbon dioxide. This, as already explained, means that $\frac{19}{3} = 6{\cdot}33$ times the correct quantity of air was used.

As 1 lb. of coal requires 10·34 lbs. of air, in this case 55·14 lbs. of air were unnecessarily heated to the temperature of flue, 450° F. above that of the surrounding atmosphere; and as $450 \times {\cdot}237$ B.T.U. (p. 124) are needed to raise 1 lb. of air by this amount, it follows that $450 \times {\cdot}237 \times 55{\cdot}14 = 5880$ B.T.U. will be needed to heat the excess air supplied in this case, per pound of fuel. As good coal may be assumed to liberate 13,000 B.T.U. per pound, this means that 45 per cent. of the fuel used would be wasted in unnecessary heating of the air. A further short calculation will soon show in how short a time the expense of flue-gas testing will repay itself.

The amount of *dust* in flue-gases may be determined by drawing a measured volume of the gas through a filter-tube, previously weighed, containing glass-wool, asbestos, or cotton-wool and then re-weighing, the increase in weight being the amount of dust in the volume of air used.

Frits may be tested for fineness, etc., in the same manner as glazes, and analysed in a manner similar to a fired glaze, although boron compounds, if present, complicate matters. Further particulars regarding the composition, etc., of frits will be found on page 25 *et seq.*

Frost affects clay goods both in the green and in the biscuit state, although glazed goods are but little injured if the glazing has been properly carried out. If the glaze has a different coefficient of expansion to the body of the goods, exposure to frost will cause crazing.

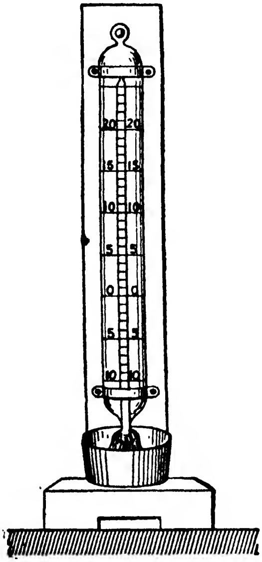

FIG. 20.

Some idea of the probable effect of exposure to frost may be gained by exposing the goods or materials to a 'freezing test' such as is frequently applied to building materials. In one form of this test, the article or material to be tested is dried at 110° C., weighed, and boiled in water for thirty minutes. It is then allowed to cool and is placed in ice-cold water for one hour, after which it is placed in a refrigerator and kept at about − 7° C. or 20° F. for twenty-four hours. It is then thawed and boiled again. This treatment is repeated twenty times, the loss in weight being noted each time and expressed as a percentage of the total dry weight of the article. It was at one time supposed that there is a relationship between the porosity of burned clay goods and their resistance to freezing, but this is not the case. A more rapid 'freezing test' consists in immersing the article for forty-eight hours in a 15 per cent. solution of sodium sulphate in water at 21° C., withdrawing it, and then placing it in a dryer at 110° C. for about seven hours. This treatment is repeated as often as may be desired. H. F. Staley has stated that the effect of such treatment is equal to two ordinary freezing tests, the pressure of the crystals of sodium sulphate being similar in action to that of ice.

The chief reason why frost damages goods is that the moisture in the pores increases in volume as it turns into ice, the expansion splitting the goods. It is, therefore, of the greatest importance that the temperature of the drying-rooms or sheds should never fall below 32° F. (= 0° C.). Where artificial heat is employed for drying the goods this is easily arranged, but in outdoor drying any means of predicting frost is worth attention. On the Continent, it is invariably found that the reading of the 'wet-bulb' of a thermometer (fig. 20) at 2 or 3 p.m. on any day is 4° C. (= 7° F.) higher than the lowest temperature likely to occur during the night. In England, the proximity of the sea makes the readings rather less constant than they are abroad; but this instrument is, nevertheless, a valuable guide. It is not necessary to employ an expensive thermometer; an ordinary 'chemical' or 'dairy' one may be fitted in a suitable stand, its bulb wrapped round with cotton gauze or loose wick, which is kept moist by the lower end of the material dipping into a small vessel of clean water. The bulb of the thermometer should be at least an inch above the level of the water in the vessel; it is kept damp by the capillary action of the cotton. The instrument must be kept in the open air, in the shade, and protected from the wind and from radiations from buildings; the water and cotton used must be clean and free from grease.[1] It will then be found, as a rule, that if the thermometer be a Fahrenheit instrument, whenever it indicates a temperature of less than 39°, or, if Centigrade, a temperature of less than 4° C., there will be frost during the night. The Cunyngham frost predictor is similar to one just described but is more costly. According to testimonials received by the manufacturers it is remarkably accurate in its predictions.

The capacity of bricks and of other materials to resist the action of frost may be tested as described under 'Durability' (p. 256).

Fuel.—Control must be maintained over the quantity used per gallon of water evaporated, per kiln fired, and per ton, or per thousand of goods dried, etc. A careful analysis of the distribution of the coal and the amounts used for these purposes will often enable considerable economies to be effected. See also pages 60, 160, and 228.

Fuel testing (see 'Coal,' p. 244, and 'Producer-gas,' p. 286).

Fusibility.[2]—The fusibility of clays, glazes, etc., may be tested most conveniently by forming them into small tetrahedrons (fig. 21) of the same size and shape as Seger cones. When the material has not sufficient plasticity to be formed into shape, a little dextrine may be added to the water used for making it into a paste. These 'trials' are dried and are then placed side by side with suitable Seger cones and heated in an electric, gas-blast, or Deville furnace until they begin to bend. The 'fusing point' or softening point is to be taken as the temperature required to cause the trial to bend over until its point just touches the base line of the material on which it stands. The Seger cone, which bends under the same conditions as the trials, indicates the temperature. If the cones used have all bent before the test-piece, a fresh experiment must be made, using a higher series of cones; if the trials bend before the cones, a lower series of cones must be employed in the next attempt. In order to prevent the cones and trials from falling they are embedded to the depth of an eighth of an inch or less in a compressed mixture of fireclay (or china clay) and bauxite. Owing to the small size of experimental furnaces, great care and some skill is needed to obtain a correct result; the heating must not be too rapid—about 10° C. per minute is satisfactory—the trials and cones must be properly placed so as not to be unevenly heated and not to interfere with each other as they bend over. These conditions will be the more readily fulfilled if, instead of placing cones and trials at the bottom of the crucible, as in the ordinary way, a suggestion of Dr. Seger's successors is acted upon, and the cones, etc., are attached to the base block, the crucible being merely used as a cover (fig. 22).

The 'indicating point' of Seger cones is when their apex is level with their base, and in testing the refractoriness of clays and other materials it is customary to heat the sample (shaped like a Seger cone) until it behaves in a similar manner. In the Gas Engineers' Standard Specification (see Appendix),

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[1] The cotton should be soaked at least twenty-four hours before using so as to remove any starchy matter.

[2] The term 'fusibility' is a misnomer, as what is determined is not the temperature at which a material fuses, but that at which sufficient fusion takes place to soften the material and cause it to bend.

on the contrary, the 'indicating point' is the appearance of signs of melting in the sample (see footnote on p. 263).

When testing clays which undergo great shrinkage on heating, the test-pieces are almost certain to fall before they are hot enough to bend; in such cases, it is best to use trials made of equal parts of the burned and unburned clay. This does not in anywise alter the melting point of the clay, but by diminishing the shrinkage enables the test to be made more speedily and accurately.

In determining the melting point of a non-plastic material, if in slip form, it must first be dried, mixed into a paste with water containing a little dextrine, and moulded in the metal mould shown in fig. 21. (The mould must be slightly oiled each time it is used.)

The 'fusibility' of coal ash may be similarly tested. The melting point of a glaze is generally considered to be that at which it fuses to a glossy, glass-like mass. Unfortunately, glazes have no definite melting point, so that any attempt to ascertain this characteristic is necessarily largely abortive. Doulter, Mellor, and others have suggested the use of an electrically heated furnace containing sharp angular fragments of the glaze to be melted. The material is observed through a specially arranged microscope, the temperature at which partial fusion becomes visible being measured by an electric pyrometer. The figures thus obtained indicate the lowest temperature at which fusion can be observed, but they are much lower than the temperature required to melt the glaze and to produce a satisfactory 'finish.' This latter is the temperature ordinarily required by the manufacturer, and it can, as a rule, only be ascertained by heating a trial-piece of ware covered with the glaze and reading the temperature with a pyrometer, or, less accurately, with Seger cones. As glazes are usually required to be employed at pre-determined temperatures, it is generally sufficient to place several sample glazed articles in the ordinary kiln along with some Seger cones. If the glazes are unsatisfactory at the average temperature of the kiln, it is more convenient to alter the glaze than to try to alter the kiln temperatures, except in experimental work in a small kiln. The results obtained in test-kilns are, however, of small commercial value, as the conditions are usually quite different from those in a larger one (p. 269).

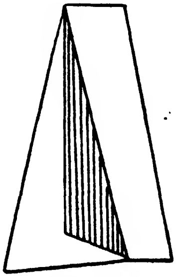

FIG. 21.

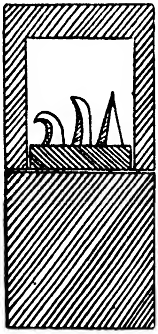

FIG. 22.

Gases are tested according to the purposes for which they are required. Flue-gases are apt to contain too much air, thus causing a waste of coal in the kilns. They may be tested as described on p. 258. The composition of flue-gases is discussed on p. 260.

Producer-gas is sometimes used for heating kilns in place of solid fuel, over which it has several advantages. (See pp. 158 and 286.)

Coal-gas is seldom or never made on a clayworks; its testing is, therefore, outside the limits of this book, especially as it is sold without any guarantee as to its quality, illuminating or heating power, or freedom from objectionable impurities.

Glazes require to be tested as regards (1) composition and purity; (2) fineness; (3) density (if in slip form); (4) fire test to ensure brilliancy, etc. These four points must be considered in turn:—

The composition of the glaze, and the purity of the materials used in its preparation, must be determined, when necessary, by analysis. The chemical analysis of glazes is, however, too complicated a matter to be treated here, as the number of different ingredients which may be present is almost limitless. The most that the ordinary clayworker can do is to buy his materials under guarantee as to purity and condition, and to exercise the greatest care in the preparation of the glazes, etc., he uses. It is generally advisable to buy the raw materials and to prepare the glaze rather than to trust to ready-made glazes. When large quantities of fritted glaze are used the case is somewhat altered, as it does not pay to prepare very small quantities of frit.

It is of the greatest importance that no one should be allowed to speak to the glaze-mixer when he is weighing, or measuring out, his materials, as neglect of this precaution is one of the most frequent sources of error in the preparation of glaze.

Another source of error is faulty calculation, especially when larger or smaller quantities than those usually worked with are being prepared. It is always advisable to have the calculations checked by an independent worker so as to ensure the arithmetical part of the operation being correct. Glazers who have some knowledge of chemistry will often require to calculate the composition of a glaze, or engobe, from its chemical formula, and *vice versâ*; and the chance of arithmetical error is then greatly increased, particularly with calculations involving the composition of substances, like felspar, which do not in practice correspond exactly to any definite chemical formula. In such cases, it is generally best to calculate direct from the percentage composition of the material, and not to first calculate the formula of each material. Where the materials are sufficiently pure the formulæ may, of course, be used, and the calculation correspondingly shortened. Examples of these calculations will be found in Jackson's *Ceramic Calculations* (see Bibliography, in Appendix).

The use of 'dummy weights' instead of ordinary ones is convenient and saves errors. These weights are made of iron or other suitable material, and each is exactly equal to the weight of the corresponding material used in one 'batch' of glaze or body. Thus, if a particular recipe requires the mixing of 3 lb. of Cornish stone, 2 lb. of felspar, 1½ lb. of whiting and 1 lb. of flint, four 'dummy weights' would be used, weighing respectively 3, 2, 1½, and 1 lb. If the weights are clearly marked they save many mistakes.

Some rough tests of the purity of the materials will be found under the heading of the materials themselves.

Iron is, perhaps, the most frequent accidental impurity in the glaze not directly derived from the raw materials. Its detection in fritted glaze is somewhat difficult, as the frit must be fused with thrice its weight of pure sodium carbonate in a small platinum crucible, and the fused mass when cool tested like a raw glaze, as follows:—

One ounce or more of the glaze slip, or a proportionately smaller weight of the dry glaze material, is placed in a suitable glass flask, and hydrochloric acid, together with a few drops of nitric acid, added until the liquid is distinctly acid (the amount required will depend on the composition of the glaze). The acid liquid is boiled for a few minutes to secure complete solution of the iron, and is then filtered through a small paper filter contained in a glass funnel, the paper being folded in such a manner that it forms a cone which exactly fits the funnel. If dry glaze material is used, an equal weight of pure water should be added previously to the addition of the acid. The clear filtrate should be received in another glass flask, and the residue on the filter should be washed by pouring water on to it in small quantities at a time until the volume of water thus added is about equal to the original volume of the liquid filtered. The volume of the liquid is now made up to a convenient measure (say 100 c.c.) or to a convenient weight by the addition of more water, and a definite proportion of it is then transferred to a clear glass cylinder and 20 drops of a 10 per cent. solution of ammonium thiocyanate in water is added and the liquid well stirred with a clean glass rod. If iron is present, a rich red colour will be produced, and the amount of it may be estimated by comparing this colour with that produced by treating various measured quantities of a standard solution of iron in a precisely similar manner (except that, as the iron solution is clear, there is no need for filtration). A suitable standard iron solution may be made by dissolving 2½ grammes of iron wire (piano wire for preference) in a little hydrochloric acid to which a few drops of nitric acid have been added, warming until all the metal is dissolved and diluting the liquid with distilled water to exactly 1 litre. One c.c. of this solution will then contain 0·0025 gramme of metallic iron, so that if 20 grammes of glaze material were found to produce the same colour with ammonium thiocyanate as 2 c.c. of the standard solution, it is clear that 20 grammes of the sample contain $2 \times 0{\cdot}0025 = 0{\cdot}005$ gramme of iron or 0·25 per cent. If the colour is too dark to compare properly, a smaller quantity of the sample or standard solutions must be employed for the test. On the other hand, if the colour is too light, a larger quantity must be used, or Mellor's method (p. 230) may be employed. Slips should be tested in this way before and after 'magneting.'

Where any of the materials have been fused the iron will not be extracted by acid, and the glaze must, therefore, be fused with carbonate of soda as if it were a frit.

It is always wise before actually using any glaze or similar material to send a small sample through the kilns as a trial; in this way, with a minimum of trouble, the spoiling of a whole batch of goods, owing to an error in mixing or in materials, may be avoided.

Fineness is an important factor in the successful application of glaze: if too finely ground it will not adhere properly to the clay, whilst if too coarsely ground complete combination of the different materials used will not take place, and an irregularly fused product will result. The actual degree of fineness depends, of course, on the materials employed; the more easily fusible ones may, as a rule, be coarser than the more refractory, but in the case of colouring materials it is scarcely possible to obtain them in too fine a state. For sanitary ware, sieves with 60 or 80 meshes per linear inch are usually sufficiently fine, though 100 mesh sieves are sometimes employed: for art ware, finer sieves (lawns) with any number up to 150 meshes per inch may be used according to the materials and the class of ware to be produced. In addition to the frequent sifting practised by the glazers it is always well to take a sample, at least once a day, from each tub in use, and to sift this, carefully looking out for dirt, coarse particles, etc. Where the glaze is used in a pasty or solid condition (as when gelatin has been added to it) it may be heated sufficiently to thin or sufficient water added to produce a slip. Testing of fineness takes a somewhat longer time, but it is nevertheless well worth while to make the test. It may conveniently precede the testing for iron and other impurities.

Density ('weight per pint') has already been referred to (p. 248). An ordinary specific gravity bottle is, however, not a practical piece of apparatus in the hands of a foreman or glazer; it is, therefore, replaced in the works by a specially constructed pint measure made of zinc, which is first weighed empty and then full of the slip, the increase in weight giving the density in 'ounces per pint.' From this, the specific gravity may be found approximately by dividing by 20. Where more accurate results are required the pint measure may be replaced by a graduated litre flask, the specific gravity being found in this case by dividing the weight of slip held by the flask by 1000, or a specific gravity bottle may be used if a sufficiently delicate balance be employed.

To find the weight of dry material in a given weight or volume of slip it is necessary to know the specific gravity of the former as well as that of the latter. Hence, if W = dry contents of a pint of slip, P = weight to the pint in ounces, and G = specific gravity of the dry substance, then

$$W = (P - 20)\frac{G}{G - 1};$$

or if a litre flask is substituted for the pint measure, then

$$M = (L - 1000)\frac{S}{S - 1},$$

where M = dry contents of a litre of slip, L = weight of a litre of slip, and S = specific gravity of the dry substance.

Thus, if a material has a specific gravity (dry) of 2·5, and a pint of the slip weighs 28 oz. or 1 litre weighs 1400 grammes, then the dry contents will be

$$(28 - 20)\frac{2{\cdot}5}{2{\cdot}5 - 1} = \frac{8 \times 2{\cdot}5}{1{\cdot}5} = 13{\cdot}333 \text{ oz. per pint, or}$$

$$(1400 - 1000)\frac{2{\cdot}5}{2{\cdot}5 - 1} = \frac{400 \times 2{\cdot}5}{1{\cdot}5} = 666 \text{ grammes per litre}$$

respectively.

As volume = weight ÷ specific gravity, the volume of the dry solid matter is 13·333 ÷ 2·5 = 5·333 fl. oz. per pint, or 666 ÷ 2·5 = 266 c.c., so that the slip is composed of—

(By weight)	Solid	13·33	oz.	666 grammes
	Water	14·66	oz.	733 grammes
		28	oz.	1400 grammes
or (By volume)	Solid	5·33	fl. oz.	266 c.c.
	Water	14·66	fl. oz.	733 c.c.
		20	fl. oz.	1000 c.c.

From the formulæ just given it is clear that in slips of the same material, but of different strengths, the dry contents vary according to the difference between P and 20 or between L and 1000, so that where the different materials are made into slips and then mixed together it is not necessary to get the slips of exactly the right density, for a table can be drawn up from which the dry contents of the slips of varying densities can be ascertained. Thus if, in a given recipe, it is usual to employ 12 volumes (whether 'wet inches,' gallons, or litres matter not) of a china clay slip at 26 oz. per pint, a table might be drawn up for 24 to 28 oz., rising ¼ oz. at a time, showing the volumes of slips at these densities equivalent to the standard (in this case 12 vols. at 26 oz.). For example, if the slip were at 25 oz.—as (25–20): (26–20) : : 12 vols.: vols. required—viz., 14½; so that the whole table for china clay at these densities would be—

oz.	24	24¼	24½	24¾	25	25¼	25½	25¾	26	26¼	26½	26¾	27	27¼	27½	27¾	28
vols.	18	17	16	15¼	14½	13¾	13	12½	12	11½	11	10½	10¼	9¾	9½	9¼	9

If a similar table be drawn up for each kind of slip in common use, the control of the mixings will be greatly facilitated and a considerable amount of the glaze-mixer's time will be saved. As the specific gravity of the different solid materials is practically constant, a "Slip, Flint, and Stone Calculator," calculated by W. J. Furnival, of Stone, may be used for all but the most accurate work.

In those cases where the specific gravity of the dry substance is not known, the weight of dry material in a slip can only be ascertained by evaporating a weighed or measured portion of the slip to complete dryness in a weighed dish; the operation requires a considerable amount of care if accurate results are desired.

Attempts have been made to employ hydrometers for estimating the density of slips, but though they may be used with some success in the case of glazes, with clay-slips their readings are often far from accurate. Such hydrometers generally consist of two glass bulbs mounted on a glass stem, a little mercury or shot being introduced into one of them to secure the proper adjustment of the instrument. The stem is marked in such a way that the number on a level with the top of the liquid (slip) corresponds to the specific gravity. It is necessary to have the slip in a sufficiently deep vessel so that the instrument does not rest on the bottom, and care must be exercised in reading the instrument to get the eye of the observer as nearly as possible on a level with the top of the liquid.

The *fire test* is, after all, the most comprehensive test of the correctness of the composition of a glaze. It consists simply in firing a suitable piece of ware dipped or painted with the material as nearly as possible under the same conditions as the actual goods will be fired. In this way, many mistakes in mixing, as well as impurities in the materials used, will be noticed before the bulk is fired, and the goods may thus be saved. It may be urged that this may require double the amount of storage room for glaze materials; but a little consideration will show that it is better to spend money on this, rather than run the risk of having a big batch of goods spoiled in the kilns. The test may be carried out in a small experimental kiln, or the articles used as test-pieces may be placed in the ordinary kilns; for most purposes this latter is the more satisfactory course. In experimental work, where various temperatures are required in making the tests, a small kiln is a necessity; but the difference in speed of heating between it and the larger kilns used in commerce renders its results somewhat uncertain, and it is, therefore, desirable to confirm them by another trial in a larger kiln. With care, it is generally possible to get glossier results with a small kiln, particularly with leadless glazes, owing to the great rapidity with which it can be heated; on the other hand, it is more difficult to avoid the action of undesirable fire-gases.

The melting point of a glaze may be most conveniently tested as described on p. 264. It must, however, be remembered that not only the melting point but also the covering and adhesive powers of a glaze are of very great importance; these can only be properly tested by working on articles of the size and kind it is desired to decorate or glaze; thus, felspar cannot be used alone at temperatures near its fusing point on account of its gathering together into drops instead of remaining evenly spread over the article it is supposed to cover. At higher temperatures this peculiarity in glazes containing felspar is less marked.

For special purposes, some or all of the following tests may be desirable:—(1) freezing test (p. 262); (2) imperviousness (by applying red ink to the glazed surface and ascertaining whether the stain penetrates through the glaze); (3) corrosive vapour test (by placing the brick in a chamber containing fumes of hydrochloric, hydrofluoric, or other acid or vapour whose action it is desired to test); (4) scouring test (by rubbing the glaze in an abrasion machine or by scouring the surface by sand and water).

Grinding.—The efficiency of the grinding machinery must be tested in regard to output and quality of product. The output depends so much on the character and condition of the plant, the way it is managed, and the nature and conditions of the materials to be ground, that no general figures can be given. The clayworker should find by experiment the best speed at which to run the plant, the best way of feeding, and the most suitable quantity to feed in at once, and should endeavour by constant supervision to see that this standard is maintained. In order to increase the men's output, a bonus may be offered for each ton of material over a certain number ground each day.

The quality of the product requires even more attention; it must be frequently tested for fineness and freedom from impurity or admixture, and, when a number of different materials are mixed and ground in one operation, tests should be made to ensure that the proportions of the different ingredients are correctly arranged. This is difficult when they are of different degrees of hardness, and a preliminary crushing of the harder material is in such cases advisable. The fineness of the material may best be tested by mixing about 2 lb. of it with four or five times its weight of hot water, rubbing it slightly with a wooden pestle so as to secure the breaking up of any cakes of material, and yet avoiding as much further grinding as possible. After being well mixed and stirred in this way the thick liquid is decanted carefully through a sieve or lawn, the fineness of which depends on the material being tested. For clay, a sieve of 100 holes per linear inch is suitable at this stage. The material is aided in its passage through the sieve by gently rubbing with a soft brush about an inch wide. The residue on the sieve is put back into the vessel from which it was originally decanted, again rubbed up with water and again sifted, this operation being repeated until the water running through the sieve is no longer rendered turbid by the material. The residue is then carefully dried and weighed; it may afterwards be examined with a lens so as to give some indications of its nature. This is especially desirable with clay. If the proportion of residue on the sieve is large it may be desirable to repeat the operation, using coarser sieves and weighing the different residues; much valuable information may often be gained in this way which will explain defects in the ware which would otherwise be puzzling to remove. In a similar way it may be desirable to use finer sieves, though it is then usual to substitute a 'washing apparatus,' such as that devised by Schoene. A given weight of the clay or other material is placed in this apparatus and a stream of water of definite speed is allowed to pass through it and to wash out the finer particles. By working at various speeds of flow, particles of different sizes and characteristics are obtained separate from each other. Many precautions must be observed in using this apparatus in order to obtain accurate results; particulars of these will be found in Ashby's *How to Analyse Clay.*[1] The principle underlying the elutriation process is that a stream of water moving at a definite and constant rate acts towards solid particles suspended in it like a liquid of greater density, with the result that the solid particles gradually rise to the top of the liquid and are carried away into another vessel, where, the water being allowed to remain motionless, they are again deposited; by changing these collecting vessels when the speed of the water is changed, a very complete separation of the different constituents of the material can be made. Seger, who studied this method in great detail, has proposed what are still regarded as the standard separations for clay, viz. :—

'Clay substance'[2]: all grains washed out of a Schoene's elutriator by a stream of water of 0·18 mm. velocity per second; less than 0·010 mm. in diameter.

'Silt': all grains washed out by a stream of 0·70 mm. velocity per second; from 0·010 to 0·025 mm. in diameter.

'Dust sand': all grains between 0·025 and 0·04 mm. in diameter, washed out with a stream of 1·5 mm. per second.

'Fine sand': all grains between 0·04 and 0·33 mm. in diameter.

'Coarse sand': all grains above 0·33 mm. diameter (*i.e.*, all that remain on a No. 40 sieve).[3]

The collection of fractions by elutriation is so tedious, and in the case of brick clays is often so unnecessary, that it has long been customary to use a series of sieves (p. 311). The author for some years past has used a series of sieves with the following apertures: 0·5 in. for stones, 0·05 in. for gravel, 0·01 in. for coarse sand, 0·005 in. for medium sand, and 0·0025 in. for fine sand. Any material passing through the last named is 'silt and clay substance,' and any further fractionation must be made by elutriation. Mellor has suggested a different series, using 'standard sieves' (p. 85) and elutriation of the final product at the same rate as proposed by Seger for his 'clay substance,'[4] and Boswell (see p. 272) a third series in which he defines 'gravel' as particles greater than 2 mm. diameter, 'sand' as particles between 1·0 and 0·1 mm. diameter, 'silt' as particles between 0·1 and 0·01 mm. diameter, and 'clay' as particles less than 0·01 mm. diameter.

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[1] See Bibliography, in Appendix.

[2] Although this fraction contains all the 'clay substance,' it may also contain extremely fine material other than clay (see p. 231).

[3] Strictly, the material remaining on a No. 40 I.M.M. standard sieve has a diameter of 0·317, and not 0·333 mm. as suggested by Seger. The ordinary No. 75 sieve has long been used for separating 'coarse sand,' but the No. 40 I.M.M. standard is preferable.

[4] The difference between these series is chiefly in the sizes of the particles termed 'stones' and 'gravel.'

It should be noticed that although the material separated in this manner usually contains the whole of the 'clay substance,' it may also contain other substances. For this reason, the term 'dust,' suggested by Mellor, is preferable to Seger's term 'clay substance.'

Mellor's proposed fractions are as follow :—

Residue.	Extreme Diameters of Particles.	Material.
On No. 1 sieve, . . .	Above 12·7 mm.	Stones.
On No. 10 sieve, . . .	1·27 to 12·7 mm.	Gravel.
On No. 120 sieve, . . .	0·107 to 1·27 mm.	Coarse sand.
On No. 200 sieve, . . .	0·063 to 0·107 mm.	Fine sand.[1]
Through No. 200 sieve, .	0·010 to 0·063 mm.	Silt.
Washed out by a stream of 0·18 mm. per sec.,	Below 0·010 mm.	Dust.[2]

It is a matter of some difficulty to judge of the fineness of samples from the results of their treatment on sieves or on washing (elutriation), as just described. A tolerably good way is to calculate out the weight per cent. of material which would remain on sieves of different meshes; but when the samples are very nearly alike, exact comparison is almost impossible. In such cases, the ingenious 'surface factor' devised by W. Jackson may be usefully employed. This factor is a single number based on the average surface of the particles, and depends on the fact that the finer the particles the greater the surface of the whole unit mass. As the average diameter of such small particles may be taken as being inversely proportional to their surfaces, the surface factor may be found for particles less than 0·33 mm. diameter by multiplying the weight of the fraction whose extreme diameters are—

mm.		mm.		
0	to	0·010	by	3367
0·010	to	0·025	by	962
0·025	to	0·040	by	518
0·040	to	0·330	by	91

—adding all the products together and dividing by 100. Thus, if a clay contain the following sized particles,

Diameter in mm.	0	to	0·010	60·2 per cent.
	0·010	to	0·025	16·8 ,,
	0·025	to	0·040	11·0 ,,
	0·040	to	0·330	12·0 ,,
				100·0

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[1] Mellor uses the term 'grit,' which implies an *angular* material, so that 'fine sand' is preferable, especially as 'grit' is a definite geological term.

[2] This usually contains the whole of the 'clay substance,' except in some shales. H. G. Schurecht has proposed to separate this material into three fractions with speeds of flow of 0·059 mm. and 0·0197 mm. per sec., corresponding to particles of 0·0052 and 0·0026 mm. diameter.

Jackson's 'surface factor' is found by multiplying

$$\begin{array}{rcrcr} 60{\cdot}2 & \text{by} & 3367 & = & 202693 \\ 16{\cdot}8 & \text{by} & 962 & = & 16162 \\ 11{\cdot}0 & \text{by} & 518 & = & 5698 \\ 12{\cdot}0 & \text{by} & 91 & = & 1092 \\ \hline & & & & 225645 \end{array}$$

which, divided by 100, gives 2256. A finer sample will give a larger surface factor and a coarser sample a smaller factor.

The principle may be extended, though with less accuracy, to the coarser fractions, the factors for which are as follows:—

Passing a No.	30	sieve	= 0·4 mm.	mesh—	factor	45
,,	25	,,	= 0·5 mm.	,,	,,	36
,,	12	,,	= 1·0 mm.	,,	,,	23
,,	5	,,	= 2·5 mm.	,,	,,	9

Mellor has shown that the arithmetical mean of the limiting diameters is not the true average diameter of the fractions, and that a truer value is obtained by using the formula

$$\begin{array}{l}\text{Average} \\ \text{diameter}\end{array} = \sqrt[3]{\frac{(D+d)(D^2+d^2)}{4}}$$

where D = the maximum diameter and d the minimum diameter in any given fraction.

He has also suggested that the surface factor be calculated from the formula

$$\frac{6}{s}\left(\frac{W_1}{d_1}+\frac{W_2}{d_2}+\frac{W_3}{d_3}+\ \ldots\right)$$

where s denotes the mean specific gravity of the powder, W_1, W_2, W_3 . . . the respective weights of the fractions 1, 2, 3 . . . per unit weight of powder (commencing at the finest), and d_1, d_2, d_3 . . . the corresponding average diameters of the grains in the respective fractions. For materials with a specific gravity approaching 2·65, and with the limits suggested by Mellor (p. 316), the surface factor reduces to

$$359\ W_1 + 53{\cdot}9\ W_2 + 26{\cdot}0\ W_3.$$

A convenient means, found by P. G. H. Boswell[1] to be particularly satisfactory for sands is equally useful for comparing clays and allied materials. It consists in adding together the percentages of material in each sifted or elutriated fraction, and plotting the results on 'logarithmic paper' the cumulative percentages being arranged vertically and the sizes of the particles horizontally. Thus, in fig. 23 the vertical line AB represents a gravel, all the particles of which are 2·1 mm. in diameter. CD represents sand, all the particles of which are 0·25 mm. diameter, EF a silt all the particles of which are 0·045 mm. diameter, and GH a 'clay' in which all the particles are 0·005 mm. diameter. The curved lines represent actual materials, TU being a Cornish sand suitable for glass manufacture, WX a sample of London clay used for brick manufacture at Ipswich, and YZ a glacial clay from Hasketon, Suffolk. A comparison of the curves pro-

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[1] *A Memoir on British Resources of Sands suitable for Glass-making*, 1916 (Longmans).

duced by various clays readily shows their general characteristics in a manner which is often more convenient than the 'surface factor.'

Hardness.—The hardness of clays and clay products may be tested by means of a Brinell ball or a Shore scleroscope, the former giving more concordant results. For the Brinell test a piece of very thin foil about 2 in. square should be placed on the clay or other article to be tested, and a standard Brinell ball made of hardened steel and measuring exactly 10 mm. in diameter, placed on the foil. A steady pressure (preferably hydraulic) of 500 kg. or 1·102 lb. is then supplied to the ball for 30 seconds, after which it is released, the ball removed and the depth or diameter of the indentation measured. The hardness is then found from a Table supplied with the Brinell ball, or calculated from the formulæ:

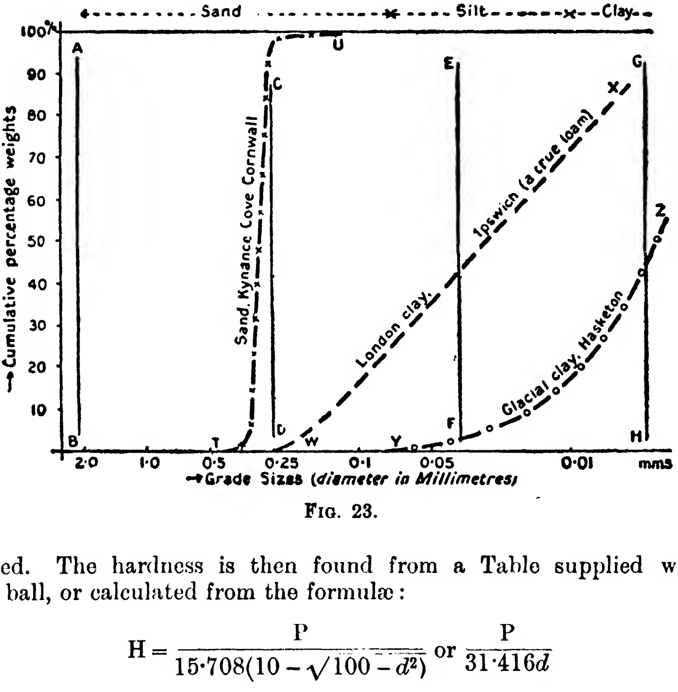

FIG. 23.

$$H = \frac{P}{15{\cdot}708(10 - \sqrt{100 - d^2})} \text{ or } \frac{P}{31{\cdot}416d}$$

where H = the hardness number, P = the pressure applied in kg., D = the diameter, and d the depth of the indention.

Heat-measuring.—See 'Temperature' and 'Calorimeters.'

Hygrometers.—See 'Drying' (p. 252).

Indicators.—Indicators are of two kinds—mechanical and chemical; the former class includes temperature indicators, pressure measures, water and gas meters, levels and floats, and various appliances for registering speed, counting, or weighing.

Chemical indicators, on the other hand, are less well known; they are used chiefly to indicate a change of state in the composition of a substance, and are mostly of organic origin and closely related to the dyes.

Acid and alkali indicator is usually a solution of litmus which turns red in presence of free acid or blue in presence of free alkali. It is used in the form of a solution or decoction in water, or in the form of paper which has been soaked in the solution and allowed to dry. As it is affected by carbon dioxide, it is often replaced by a solution of methyl-orange in the assay of whiting and similar substances (p. 239).

Boiler-water indicator is used to ascertain whether enough softening agent has been added to the water (p. 34); it usually consists of a very weak solution of phenolphthalein in dilute alcohol, a drop of soda solution being also added so as to give the indicator a faint colour and ensure its neutrality. If a few drops of this indicator be added to a softened water where lime or soda has been employed as softening agent, the water will be coloured red if sufficient lime or soda has been used, otherwise it will remain colourless; if too much has been added, the colour will be an intense red. If the water is not colourless, it is often easier to use strips of filter-paper soaked in the indicator and allowed to dry; to test the water, one of these strips is allowed to remain in the water for a few moments and it is then taken out and examined. The test is so simple that it ought to be made daily, so as to avoid undue production of scale on the one hand, and waste of softening material on the other.

The term 'indicator' is used to cover so wide a range that reference must be made, for further particulars, to the object for which the indicator is required.

Iron should invariably be tested for in new batches of clay and glaze materials (p. 265). When used in machinery, it should have as much of its surface as practicable painted to prevent particles of rust and iron scale falling into the materials and so contaminating them.

Kilns are difficult to test satisfactorily, but special attention should be paid to their 'tightness,' their draught, and general state of repair (see p. 143 *et seq.*).

Kilns and flues may be tested in regard to the tightness of their joints, etc., (1) by means of a candle placed on one side of the wall, the observer being on the other. This method is only of limited application; (2) by means of a draught-gauge (p. 250). If the draught of the kiln or flue is measured in a number of different places it will generally be easy to determine, by means of the different readings of the gauge, where the leakage occurs. If a continuous kiln is being tested in this way, it will, of course, be necessary to close the dampers of each chamber whilst it is being tested, so as to make the gauge readings as large as possible, and also to prevent the inclusion of more than one leak for each reading. Wet clay containing a large proportion of burned clay (grog) is usually the most satisfactory material for repairing kiln cracks. This mixture does not contract so much as clay alone, and the crack or leak is, therefore, more durably mended.

Lead used in the form of the oxide (red lead), the basic carbonate (white lead), and in combination with tin oxide (tin ashes), is a source of continual trouble in those clayworks where it is used, owing to its poisonous nature and to the consequent requirements of the legislature. White lead is especially liable to adulteration with baryta and chalk. Galena (lead sulphide) appears to be free from these objections, but the sulphur it contains renders it unsuitable for some glazes. As the metal (lead) is the only constituent of importance to the clayworker, this may be conveniently determined by fire assay as follows:—

An accurately weighed portion of the sample (not exceeding 10 grammes) is mixed with about four times its weight of fusion mixture, consisting of (1) equal weights of sodium carbonate and potassium carbonate to which a little borax has been added, or, preferably, (2) argol with thrice its weight of sodium carbonate, and placed in a small porcelain crucible. The mixture is then covered with a further small quantity of fusion mixture, and the crucible and its contents heated for some time in a small muffle kiln until the mass is completely fused and the lead is formed into a distinct metallic bead. Excessive heating should be avoided. The melted mass is then poured on to a level cast-iron plate in such a way that the bead of metal is left at one end of the slag, which it should leave easily and cleanly when cold.

As tin produces a more infusible slag than when lead alone is present, a somewhat larger proportion of flux may be necessary when tin ashes are being tested, and the tin must afterwards be separated by analysis.

Where more accurate results are required a proper chemical analysis of the material should be made.

Lead in Glaze.—According to the Amended Special Rules for the Decoration of Earthenware and China, of 28th November 1903, it is ordered that "no glaze shall be used which yields to a dilute solution of hydrochloric acid more than 5 per cent. of its dry weight of a soluble lead compound calculated as lead monoxide when determined in the manner described below:

"A weighed quantity of dried material is to be continuously shaken for one hour, at the common temperature, with one thousand times its weight of an aqueous solution of hydrochloric acid containing 0·25 per cent. of HCl. This solution is thereafter to be allowed to stand for one hour and to be passed through a (paper) filter. The lead salt contained in an aliquot part of the filtrate is then to be precipitated as lead sulphide and weighed as lead sulphate."

The precipitation of the lead may be conveniently carried out as follows: 10 grammes of the glaze or frit are treated with acid, as described above, and to the filtrate (contained in a small glass beaker) an excess of a solution of ammonium sulphide is added, or a current of sulphuretted hydrogen gas is passed through it until all the lead is precipitated as a black sulphide. After standing for some time to ensure the precipitation being complete and to allow the precipitate to settle, the liquid is filtered through a paper filter, the black residue washed with water to which a little ammonium sulphide or sulphuretted hydrogen has been added, and then transferred to the filter and again washed; the filter with its contents is placed in a warm place to dry (care being taken to keep it free from all dust, etc.), and it is then placed in a weighed porcelain crucible, heated gently over a bunsen burner until all the paper has burned away and the sulphide is turning lighter by oxidation. It is then allowed to cool, is moistened with a few drops of nitric acid, and is again ignited over the burner, the treatment with nitric acid being repeated until the residue is white. The lead sulphate thus formed is then allowed to cool and is weighed. Its weight multiplied by 0·7364 gives the amount of lead (calculated as monoxide) dissolved out under the conditions of the test. It must not exceed one-twentieth of the weight of the sample used for the test.

Lubricants.—The testing of oils and lubricants is too complicated a matter for the non-professional analyst. They should, therefore, be bought with a guarantee as to their flash point, and, if solid, as to their melting point. In a matter of this kind the clayworker is, to a great extent, in the hands of his oil merchant, and should be careful to trade with reliable firms.

Melting points of clays, etc., may be determined, as described on p. 264, by making a pyramid or 'cone' of the material and comparing its bending point with that of a standard, such as the Seger cones.[1] A pyrometer may sometimes be used for glazes, etc., in those cases where the material to be melted has no tendency to destroy the material of which the pyrometer is made, whilst for substances with a lower melting point than 360° C. or 680° F. a mercury thermometer is most convenient. The bulb of the thermometer or the end of the pyrometer should be immersed in the material to be tested and the temperature raised slowly and regularly, the thermometer scale being carefully protected from draughts. A useful check on the accuracy of the result consists in allowing the molten mass to cool slowly whilst the bulb or junction still remains in position, when it will be found that the temperature sinks gradually to a certain point, then remains constant for a certain time during which the mass becomes solid; a further decrease in temperature then continues until the mass is quite cold. The temperature at which the thermometer reading remained constant for some time is the 'solidifying point' of the substance; it should not differ materially from the melting point of a pure substance. In the case of a mixture, on the contrary, there may be two or more points at which a constant temperature is noticeable; in such cases, these temperatures indicate the solidifying points of the different substances composing the mixture. Such mixtures (amongst which are clays and glazes) can have no definite fusing point.

Mills.—The control of the mills chiefly consists in the keeping up of the output, both in regard to quantity and quality, due attention being paid at the same time to the amount of power absorbed. A careful record of the amount of material ground or pugged should be kept, with particulars of the cost of grinding. The quality of the product should be carefully tested for (*a*) freedom from iron and other impurities, and (*b*) fineness of the different particles of which the material is composed. (See 'Grinding,' pp. 52 and 74.)

Moisture.—No matter how dry a clay may feel, it often contains a considerable amount of water in the form of moisture, and the same is true of many glaze materials. Hence, it is important in buying these materials to ensure that one is not paying for water at the rate of clay, felspar, etc. In addition to this, it is often desirable to ascertain the percentage of moisture left in goods which have been partially dried.

Although much may be accomplished without any special appliances for drying, yet, if accurate results are desired with the minimum of trouble, some form of drying oven with automatic temperature regulator will be required.

The temperature at which the drying should take place is of importance, as many materials contain combined water in addition to moisture, and this will be driven off if they are heated too strongly. As a general rule, then, moisture is understood to mean that water which is expelled from a sample exposed to a temperature not exceeding 100° C. or 212° F. until it is of constant weight, *i.e.* until no further loss of weight occurs on further heating. In practice, it is usual to substitute a slightly higher temperature (110° C.), as some materials do not part with all their moisture at the lower temperature.

The drying oven may conveniently take the form of a strong, double sheet-iron box about 18 inches each way, fitted with a door, inside which is another

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[1] The fact should not be overlooked that the bending of a cone does not give the *melting point* of a material. Sometimes, the lowest temperature at which fusion can be observed (p. 264) is taken as the 'melting point.' This is equally erroneous, as many clays begin to fuse at 1000°C., but at the highest temperatures attainable fusion is still incomplete, so that no true melting point can be obtained.

similar box, the space between the two allowing of a better distribution of the heat from the gas burner or lamp placed underneath. This space between the two boxes should be about 3 inches at the bottom and 1 inch round the sides and top. The door is most convenient when at the front. Through the top of the oven two $\frac{3}{4}$-inch pipes are fixed, so as to allow of the insertion of a thermometer and of the tube of a temperature regulator. Where gas is not available, the space between the boxes may be arranged to contain water which can be kept constantly boiling by any convenient source of heat. In this case, the temperature can never exceed 99° C. (210° F.) in the inside of the oven, so that the drying will take somewhat longer and tends to be incomplete. In order to keep the temperature constant an automatic temperature regulator is desirable.

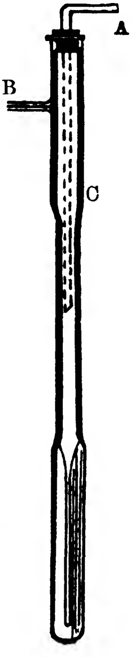

Fig. 24.

There are many patterns of thermo-regulators for moderate temperatures on the market. Although they vary greatly in efficiency, the same principle is used in all, viz. the expansion of a fluid moving a column of mercury in such a way as to shut off the gas-supply. (If steam of sufficiently low pressure is used, or if the apparatus contains constantly boiling water, no regulator is required.) A sensitive pattern of regulator is shown in fig. 24.

The tube, A, is connected to the gas-supply by means of rubber tubing; B is similarly connected to the gas-burner (a bunsen burner of the ordinary upright form, carefully made so as to allow of its being turned down considerably without 'lighting back'). A small hole in A (near C) permits of a sufficient passage of gas to keep the burner alight when the regulator has 'shut off' the supply, but the amount of gas passing through this by-pass must not be sufficient to keep the oven hot. The lower portion of the apparatus is occupied by mercury, which moves up and down the tube with the varying temperature, and, by allowing a freer or more restricted flow of gas to the burner, permits of increased or diminished heat supply. The regulator is so adjusted that, when the thermometer inside the oven shows the desired temperature (110° C.), the regulator just shuts off the gas-supply, but partially opens it as soon as the temperature falls to 109° C.

To determine the moisture in a sample,[1] a definite portion is accurately weighed in a tared watch-glass or weighing-bottle (the weight must be exact to at least a milligramme); the glass, or bottle, with its contents is then placed in the oven and the drying commenced.

The size and weight of the pieces to be dried will vary with their nature; a greater weight of a porous article may be used, but, as a rule, 5 to 10 grammes is quite sufficient; if too large a weight is employed, the drying will be so prolonged as to be liable to introduce other errors. For many purposes, half these quantities will be more satisfactory.

After an hour (if the oven was at the proper temperature to begin

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[1] When the material to be tested is very irregular in composition (as boulder clay) it is exceedingly difficult to obtain a small representative sample. In such a case, a rougher determination of the moisture should be made on several pounds of the material, by drying it on a strong dish or plate in an oven heated to 110° C., and after it has become partially dry crushing the material carefully (so as not to lose any) until it resembles sand. The errors due to using so large a quantity are largely compensated by the more representative nature of the sample than when only 5 grammes are used.

with) the glass or bottle is taken out, and at once placed in a desiccator to cool.

In weighing small quantities of clay, it should be remembered that dried clay is very hygroscopic and rapidly absorbs moisture from the air; it must not, therefore, be allowed to cool in an exposed place, but a desiccator must be employed.

The desiccator (fig. 25) is a vessel intended for keeping objects free from moisture whilst they are cooling, and consists of a glass basin, or vessel, with a well-fitting lid, the bottom of the vessel being covered with concentrated sulphuric acid. A small glass table or shelf inside forms a resting-place for the object to be cooled, and the acid keeps the air in the vessel dry by absorbing all its moisture. The acid must, therefore, be renewed from time to time.

When perfectly cold, the glass, or bottle, with its contents, is again weighed, the loss of weight being due to moisture which has been removed if the experiment has been properly performed. In order to ascertain whether all the moisture has been removed, the glass is again placed in the oven for another hour, cooled in the desiccator and again weighed, these operations being repeated until two successive heatings, each lasting at least half an hour, show no difference in weight. Then the total loss of weight suffered by the sample represents the moisture originally present. Thus, if the following figures were obtained:—

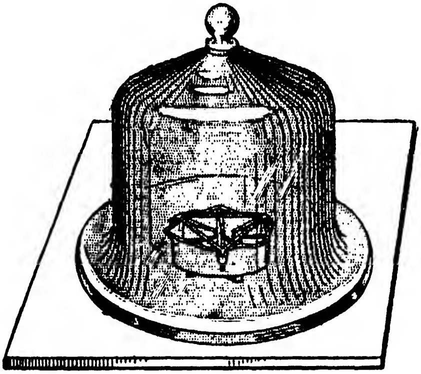

FIG. 25.

Weight of empty weighing-glass	2·334 grammes
,, glass + sample	4·462
,, ,, ,, after drying 1 hour .	4·322
,, ,, ,, after drying 2 hours .	4·316
,, ,, ,, after drying 3 hours .	4·315
,, ,, ,, after 3½ hours . .	4·315 (const.)

Then 4·462 − 4·315 = 0·147, which divided by the weight of the original samples (= 2·128) gives 6·91 per cent. of moisture.

When, for purposes of getting out goods with the greatest speed, they are weighed during their drying on the floors, a large pair of scales must be used and the drying continued until a certain weight based on experience, or calculated on the previously estimated moisture in the clay, is reached.

With such large blocks, it is seldom possible to drive off all the moisture, but in practice all that is required is to eliminate so much of it that what is left will do no harm to the goods if they are placed in the kiln. It frequently happens that, with large pieces of ware, a little trouble taken in weighing them during the drying will not only ensure their dryness being known and not guessed at, but will often enable them to be placed in the kilns some days before it would otherwise have been considered safe. To prevent damage in handling, the goods should be kept on a board of some kind which should be weighed with them (tared). It is necessary that the weighing-machine should be sensitive to a variation of at least 1 per cent. of the weight of the sample; thus, if a large slab weighing 1 cwt. were being dried, the scales should turn to at least 1 lb. Much greater sensitiveness is not absolutely necessary, as 1 per cent. of moisture in an article will cause no damage to it when placed in the kiln in the usual way.

Oils.—See 'Lubricants,' p. 40.

Permeability is a term used to indicate the extent to which gases or fluids will pass through a material. It is specially used with reference to filters and roofing tiles and, in a converse sense, to stoneware. The permeability of a filter or other vessel is measured by rinsing out a vessel with water, almost filling it with an accurately measured volume of water, allowing it to stand for 24 hours, then pouring out and re-measuring the water, so as to ascertain how much has been absorbed or has passed through the vessel. A check test may be made by rinsing the vessel with varnish and repeating the test, to show how much water adheres to the inner surface of the vessel when all the pores have been closed. The permeability of roofing tiles and similar articles is measured by cementing or clamping the article on the mouth of a bottle containing a measured volume of water in such a manner that, when the bottle is inverted, no leakage of water can occur except through the pores of the article. The article and bottle are mounted on two slender supports (see fig. 29 on p. 290) for 24 hours, after which the volume of the water remaining in the bottle is measured and the difference represents the permeability of the sample. This test may be improved in various details, but at best the permeability of a piece of burned clay is an uncertain factor, different samples made from the same material under apparently identical conditions differing very greatly in their permeability.

There appears to be no definite relation between permeability and absorption.

Plaster of Paris must not be confused with Paris White (see 'Whiting'). The 'superfine' quality is chiefly used for moulds in clayworks. It varies greatly in quality even when from the same factory, and is at all times a difficult material to test, as its value for mould-making depends on its physical rather than on its chemical properties. The author has found that the properties which should be possessed by good plaster for clay-working purposes are largely in agreement with the conclusions arrived by the German Association of Plaster Makers as the result of experiments by their chemist, Dr Moye:—

1. At least 95 per cent. of the plaster should pass through a sieve size No. 75, and about half of this through a No. 175.

2. For 100 parts of water, from 100 to 150 parts of plaster will be necessary to form a well-setting mass, and this mixture should stiffen so rapidly that after two or three minutes it can no longer be poured easily from

one vessel to another. (Some mould-makers prefer a plaster which sets more slowly than this, as it allows them to work less rapidly; but unfortunately, the slow-setting plasters seldom set so hard as the more rapid ones.)

3. The amount of water absorbed by a small cube of the set plaster which has been allowed to stand for several days will usually equal a quarter of its volume of water in ten minutes; but this test does not seem to be very reliable, as the presence of small quantities of sodium carbonate in the water used in mixing the plaster will make the cube absorb far more water after standing.

See also p. 99.

Plasticity (p. 10) is a property of clay which it is extremely difficult to measure satisfactorily, and most of the methods suggested determine one or more of the forces which go to form plasticity without constituting the whole of it. (See 'Binding Power,' p. 234.)

F. F. Grout concludes, as the result of numerous experiments, that plasticity is proportional to the product of two factors—viz. the load required to sink a Vicat needle a definite depth into the mass of clay, and secondly, the deformation of the clay under stress, which he measures by the increase in area of a clay cylinder produced by the load which just causes cracks to appear. If these two factors are separately observed for a given clay tempered with different quantities of water, it is found that the products obtained by multiplying each set of corresponding factors together lie on a smooth curve which has a well-defined maximum for some particular proportion of tempering water. He finds, moreover, that whilst fine grinding generally improves the plasticity of a clay, this is not invariably the case. The addition of sand or crushed quartz impairs the plasticity, though the effect only begins to be marked when the amount added is appreciable.

Zschokke, on the contrary, considers that plasticity is not a peculiarity of clay but is possessed by all substances composed of sufficiently minute particles with sufficient affinity for each other and with a high power of combining with water, and that it may best be measured as the product of the tensile strain and the percentage elongation under maximum tension.

The ordinary method adopted by clayworkers for judging plasticity consists in feeling the consistency of the material—a characteristic which is very difficult to measure accurately.

Porosity of fired clay goods may be tested by various methods, the commonest of which consists in replacing the air contained in the pores by an equal volume of water. This is accomplished by immersing the article in water, wiping off the excess of liquid after some time and weighing the article (p. 13). Its increase in weight is understood to be due to the water 'absorbed' by the pores, and the volume of the latter may be calculated from the weight of water thus retained on the assumption that 1 oz. of water measures 1¾ cubic inches, or 1 c.c. of water weighs 1 gramme. A very rapid test of porosity is to hold the tongue in contact with the brick. If a distinct suction is felt the brick is very porous. If there is no distinct suction but the water is absorbed rapidly it is moderately or slightly porous.

Although it is the usual custom to express the porosity in a unit of *weight*, it is more correct to express it in terms of volume, and the figures representing the porosity of an article should indicate the volume of the pores it contains in relation to the total volume of the article itself. If the article under examination is regular in shape, its volume may be directly calculated (in the case of a brick, by multiplying its length by its breadth and the result by its depth); but if the shape does not permit of this being accurately carried out, the volume of the article may be determined by finding its loss of weight when suspended in water by means of a fine thread from one arm of a balance, as in 'specific gravity determinations.' Then

$$\text{Porosity} = \frac{\text{weight when soaked with water} - \text{weight when dry} \times 100}{\text{loss of weight when suspended in water by a thread}}.$$

If the porosity of unfired clays is to be estimated, some other liquid must be substituted for the water—paraffin is very suitable. The above formula holds in this case also if the word 'liquid' be substituted for water.

The volume of the original article may also be measured by means of a 'volumeter'— a glass cylinder with a movable lid, the shape of an inverted funnel. The apparatus is filled, to a mark on the neck of this inverted funnel, with water, and some of the water is then run into a tared glass by means of a tap near the base of the cylinder.[1] The lid of the apparatus is then removed, great care being taken that none of the water is spilt during this operation, and the article to be tested is placed in the cylinder. If sufficient water has been run into the tared glass none will overflow the cylinder when the test-piece is inserted. The lid is now replaced and the apparatus again filled to the mark with water, this time from the tared glass. The tared glass and its contents are now weighed, the increase in weight being the weight of a volume of water equal to that of the test-piece. The operation may be simplified somewhat by using a finely-graduated measuring glass instead of a plain tared one, and so measuring the water displaced instead of weighing it. The Seger volumeter is well adapted for this purpose, whilst in the Ludwig apparatus it is intended that the displaced water should be weighed. Considerable accuracy in weighing, or measuring, is necessary, as different determinations made with the same piece of clay should not differ by more than $\frac{1}{100}$th of the weight of the test-piece used.

Power.—The testing of the power given out by an engine is accomplished by means of an 'indicator' or by means of a special form of 'brake.' This latter may also be used to determine the power absorbed by the different mills, etc. Power is commonly measured in terms of 'horse-power,' one horse-power being the work done in raising 33,000 lbs. through a distance of 1 foot in one minute. This unit is a purely arbitrary one, as the power exerted by a horse varies with its condition and, to some extent, with the nature of the work. It is important to realise that the time occupied is an essential feature, and that a unit of power indicates the *rate* at which the work is performed. Strictly, a horse power relates to work done in one minute, but a unit known as the horse-power-hour, which is 60 times the former unit, is largely employed. Engine indicators merely record the variations in the pressure in the engine cylinder during various portions of the stroke. These are automatically plotted in the form of a graph on a rotating or reciprocating drum by means of a pencil attached to a piston of known area which moves in a vertical direction according to the pressure exerted on it by the steam or gas in the cylinder of the engine. The piston is fitted with a carefully calibrated spring which reduces the movements of

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[1] In some volumeters, this is replaced by a burette or graduated tube connected to the tap of the apparatus, the water being drawn into this tube by suction at its upper end. If the air is removed from the pores of the sample by exhausting the apparatus, a more accurate result is obtained.

the pencil to convenient limits so that direct readings of the movements of the pencil on top of the pencil rod can be made.

For gas engines it is preferable to employ a photographic indicator, as this gives more accurate results than one with a pencil, but for steam engines the latter is quite satisfactory. The indicator should be connected first to one end of the engine cylinder by means of a short pipe of small bore. After a test has been made, the indicator should be detached and connected in a similar manner to the other end of the cylinder and the test repeated with a fresh sheet of paper on the drum. The practice of connecting both ends of the cylinder to a centrally placed three-way tap is not satisfactory, as it involves the use of excessively long connecting pipes.

Engine indicators are of two chief types: *continuous*, in which a single curved line is drawn, and *reciprocating*, in which a closed curve is produced. One of the best continuous indicators is the M‘Innes-Dobbie pattern for steam engines and the Hopkinson photographic indicator for internal combustion engines.

The drum of a reciprocating indicator is connected through suitable reducing gear to the engine-crosshead, but considerable care is required in the arrangement of this mechanism or serious errors may result. On the whole, a long vertical lever with a long connecting link is the most suitable. Care is also required in the choice of a spring for the instrument, as too strong a spring produces too small a diagram, and with too weak a spring the lines are so wavy as to prevent accurate measurement. A 40-lb. spring is generally used for boiler pressures under 90 lbs. and a 60-lb. one for greater pressures.

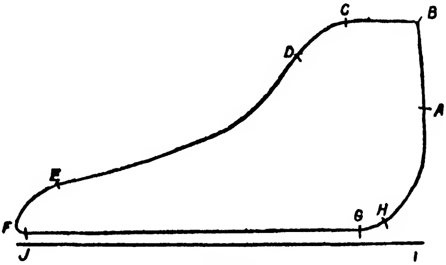

Fig. 26.

A piece of paper, or thin card, having been attached to the rotating drum of the indicator, and this set in motion by means of the reducing gear connecting it to the engine, the pencil on the instrument will draw a closed curve the shape of which will depend on the accuracy of the engine and its capability of using the steam supplied to it (fig. 26).

This ‘diagram,’ if drawn by a correctly adjusted engine, will be made up as follows:—The admission of steam commences at A and is continued to B, where the maximum pressure is reached (it will be seen that the point B is the highest above the base line JI); thence to C, the horizontal line BC showing that the steam pressure is fully maintained without leakage until the cut-off commences at C. At D the steam supply entirely ceases and the steam in the cylinder begins to expand, the amount of expansion being indicated by the line DE. The exhaust is similarly indicated by the line EH, and HA is the line representing the compression. The base line or atmospheric line is drawn by rotating the drum of the indicator before commencing the test, and therefore is the 'diagram' drawn when no work is being done by the steam. A careful study of an indicator diagram will show: (1) variations in pressure consequent upon the admission, cut-off expansion, etc., of the gas or steam in the engine cylinder; (2) whether the variations occur at the correct moment; (3) whether any throttling occurs; (4) whether the valves are leaky or slow in action, as a sensitive indicator is an excellent guide in setting valves; (5) whether the gas or steam used is sufficiently powerful; (6) whether the engine is working with maximum efficiency, and (7) the indicated horse-power of the engine.

Variations from a standard indicator diagram are often of a complicated nature and are difficult to interpret without the aid of much experience; much information may, however, be obtained from Pickworth's *The Indicator Diagram: Its Analysis and Calculation*, and other books.

The *indicated power* of an engine may be calculated from the mean effective pressure recorded by the diagram, obtained by finding the average height of the line BF above the line FA and multiplying it by the scale of pressure for the particular strength of spring used. Then, if

P = mean effective pressure of steam in lbs. per square inch,
L = length of stroke in feet,
A = area of piston in square inches,
N = number of strokes per minute = revolutions per minute × 2;

$$\text{the indicated horse-power (I.H.P.)} = \frac{PLAN}{33{,}000}.$$

Brake Horse-Power is the difference between the indicated H.P. and that absorbed by the friction of the engine itself, *i.e.* the actual power measured at the crank-shaft or fly-wheel. For most of the engines used in clayworks, the brake H.P. may be found by taking a diagram with the indicator, but for smaller and more delicate engines it must be measured by means of a special brake or dynamometer. A convenient arrangement is a Prony brake, which consists of a rope on which are strung two or more blocks of wood shaped to fit the rim of the fly-wheel of the engine. One end of the rope is attached to a spring balance of the Salter type, the other end of the balance being attached to a strong staple in the floor, the rope is placed around the rim of the fly-wheel and to the free end of the rope is attached a weight sufficient to effect a marked reduction in the speed of the fly-wheel when the blocks on the rope are pressed against the rim by the suspended weight.

The brake horse-power may then be calculated from the following formulæ:

$$\text{B.H.P.} = \frac{RB(W-T)}{33{,}000}$$

when B = circumference of brake in ft.; W = suspended weight in lbs.; T = tension on spring balance in lbs., and R = number of revolutions of fly-wheel per min.

The measurement of the power used by a machine is peculiarly difficult of measurement, but one of the most satisfactory methods yet devised is to employ a Gibson's Flashlight Torsiometer. Fig. 27 shows the general arrangement to consist of two thin metal discs secured to the shaft at opposite ends, and revolving with it. The discs are exactly similar, and each has a small radial slot close to the periphery. A fixed lamp placed behind one of the discs has a mask provided with a similar slot. A movable torque-finder is fitted behind the opposite disc, and is provided with an eyepiece which can be moved circumferentially, and a slot similar to those already mentioned. When the shaft is revolving without transmitting power, the four slots are in the same radial plane, and on looking through the eyepiece of the torque-finder a flash will be seen at every revolution of the shaft. When the shaft is transmitting power, it twists and so displaces

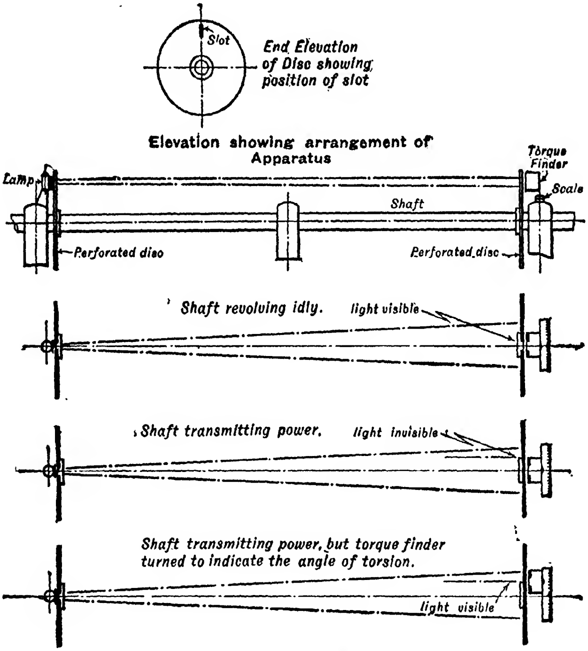

FIG. 27.—Gibson's Flashlight Torsiometer.

the slots in the discs relatively. In order to observe the flash again, the eyepiece must be moved circumferentially to an amount equal to this torsional displacement. The eyepiece is provided with a vernier and scale, so that the angle of torsion may be read off in degrees. The width of the slots is eliminated by using the edges and noting the exact instant the last ray is cut off as the eyepiece is moved over. This method enables the torque to be measured to $\frac{1}{100}$ of a degree. Mr Gibson states that no difficulty in practice is experienced in obtaining this degree of accuracy. In starting a test the shaft may be allowed to run idle with no appreciable torque or it may be left at a standstill. The eyepiece of the finder should then be moved until the flash is just cut off and the zero reading obtained. This reading must be subtracted from any future power reading. If the machine is now put to work, the actual angle of torsion under power may be found as previously described. Suppose the angle of power torsion to be 1·5° and the zero angle to be 0·4°, the effective angle of torque is 1·1°. The horse-power is found by reference to a power diagram supplied with the instrument.

A device which is simpler to construct, though less accurate, shown in fig. 28, consists of a pulley *a* fitted with a projecting piece *a* which is so shaped that it engages with a similar projecting piece *b*, but the latter is tubular, and free to turn around the shaft. A ring or tube *d* is fitted to the shaft, and is kept in position by a screw. When the pulley and attached portion *a* turns, it engages with *b*, pushing the latter towards *d* to an extent dependent upon the spring *c* and the power exerted in turning the pulley *a*. The movement of the piece *b* causes the needle *e* to pass an appropriate distance over the dial *f*, which is graduated to indicate the power used. This arrangement is very simple and does not easily get out of order.

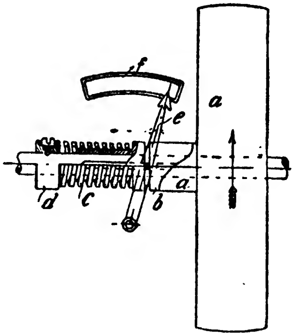

Fig. 28.—Power Measurer.

Boiler-Power.—The power of a boiler depends on the engine used, and the amount of steam per hour this latter requires; thus, if

G = grate area of the boiler in square feet,
C = lbs. of coal consumed per square foot of grate area,
W = lbs. of water evaporated per lb. of fuel burned,
S = lbs. of steam per indicated horse-power (I.H.P.) per hour consumed by the engine;

$$\text{I.H.P. of the boiler} = G \times C \times W \div S.$$

Hence, the smaller the value of S the greater the I.H.P. of the boiler; this expression is, therefore, to be used with caution.

An engine horse-power, a boiler horse-power, and a gas-producer horse-power (p. 286) are very different quantities, although they may fit well enough together under certain conditions. For instance, a boiler horse-power of steam, supplied to a common slide-valve throttle-governed engine, will develop only from one-half to two-thirds of a horse-power of work. Hence, the common practice of generous allowance of boiler-rating above engine-rating, particularly in small plants. This same boiler horse-power of steam, however, supplied to a modern compound condensing engine, will develop from two to three actual horse-power. In large power plants, the ratings of engines and boilers are proportioned accordingly.

One *electrical horse-power* consists of 746 watts, or about three-quarters of a unit (1000 watts). This assumes perfect conversion between mechanical and electrical energy.

Pressure may be tested by suitable gauges, the nature of which will depend on whether a gas, like air, at slight pressure, or at a higher pressure, as steam, is to be tested. For very slight pressures a 'draught-measurer' (p. 250) is most suitable, or some form of barometer may be employed; but for greater pressures a Bourdon gauge, such as is used in connection with steam engines, must be used. Where a firm is willing to face the outlay, a recording steam pressure gauge is advantageous, as it shows exactly what steam has been used at any hour of the day or night and thus tends to greater uniformity at the boiler as well as in the use of the steam.

When town's gas is used in large quantities, the usual wastage due to variations in the gas pressure may be avoided by the use of a governor on the main so arranged that the gas can never be supplied above a certain pressure (say that equal to two inches of water). Various forms of governor are on the market; the author has had most experience of one made by Stott Brothers, and has found it to be in every way satisfactory and economical.

Producer-Gas may be conveniently tested in a similar manner to flue-gases (p. 258); but the presence of hydrogen and of hydro-carbons complicates the analysis somewhat. The reader is recommended to get some analytical friend to show him how the estimation should be conducted, half an hour's observation of this nature being far more satisfactory than the reading of a whole volume on the subject. Good producer-gas, as a rule, contains about 40 per cent. of combustible gases, the remainder being nitrogen with a few per cent. of carbon dioxide and a trace of oxygen. Its use, instead of coal, as a fuel for kilns is at present in a state of infancy, but is increasing rapidly. It is essential for successful kiln-firing that the proportion of combustible gases should be maintained at as high a standard as possible, and that of these the proportion of hydrogen should be greater than is usually the case with producer-gas. In this respect, Mond gas has an advantage over the common Dowson gas

For kilns in which a long flame is required, however, it is essential to use a tarry gas, as one which has been scrubbed or filtered burns with a short flame. The use of a cleaned gas has been the chief cause of failure in several works where producers have been found useless for burning kilns. The well-known Glenboig firebricks have been burned with producer gas for over forty years; in other branches of clayworking, producer-gas is equally satisfactory to those who know how to use it.

Magruder has suggested the adoption of a standard *producer power* of 10,000 B.T.U. per hour, for use with gas-producers supplying power-gas. This would be a most convenient figure if adopted; but it would not become exact until the conditions of producer operation and of gas-calorimetry were also specified.

Pugging Clay.—The mixing of clay and water may be tested most conveniently by 'washing,' through a series of sieves of gradually increasing fineness, as described on p. 269. This will ensure that no lumps of extraneous matter have entered the machine. When fine white clays, such as china bodies, are being made, the material should be tested with a magnet.

In the mixing of brick-clay, fireclay, and other relatively crude materials, the stiffness of the paste and its homogeneity are the most important characteristics needing attention. If the mixer is not working properly, an examination of the mass with a strong lens will show that some of the grains of clay are still dry, and the 'feel' of the clay together with its want of plasticity will indicate that it has not been thoroughly mixed. It is, however, a matter of some difficulty to say whether a sample containing much ground, fired material (sagger) has been well mixed or not, and if any doubt is felt in such cases it is better to put it through the machine a second time.

Pyrometers are instruments for measuring temperatures which are so high that a thermometer of the ordinary type cannot be employed. Pyrometers are of many and varied forms and types; the most important in regard to the clay industry are referred to under the heading of 'Temperature' (p. 293).

Quartz.—A very pure variety of silica (SiO_2) is used in glazes and bodies where unusual freedom from iron is required, especially on the Continent. In England, flint usually takes its place. It is highly refractory, and quite insoluble in all ordinary solvents with the exception of hydrofluoric acid, which reacts with it, as with all silicates, to form the volatile SiF_4. To test quartz for impurities it should, therefore, be warmed with this acid, and the residue left after several treatments examined as to its nature. Although generally very pure, the possible impurities in quartz are very numerous, and, being mostly of the nature of 'staining oxides,' their examination requires considerable analytical skill.

Refractoriness.—One of the most important properties of certain clays, notably the fireclays, may be tested by determining the bending point of the clay (p. 263); but this is not always sufficient, particularly when the clay is intended for use in the interior of furnaces (furnace linings), where, in addition to the direct action of the heat, the variations in pressure, owing to the expansion and contraction of the material by the heat, produce strains which cause far more damage to the clay than the direct action of the heat itself. It is always difficult to ascertain, without actual trial, whether blocks or bricks made of a particular clay will efficiently resist the combined action of heat and pressure; probably the best way is to build a few of the bricks into a furnace lining, to watch them and to carefully note their behaviour in comparison with bricks of other clay in a similar part of the furnace. The resisting power of fireclay to the action of molten steel and other metals is also best ascertained in a similar manner; experiments on a very small scale are largely, if not entirely, unreliable.

Although the refractoriness of a clay is, to a certain extent, dependent on its composition, it does not at present seem possible to obtain any 'factor' which can adequately represent its power in this respect and be deduced from the analysis of the clay. Bischof and Seger both suggested factors of this kind, and although both are accurate within certain narrow limits, they are not, on the whole, satisfactory. Ludwig has plotted out a series of curves showing the relation of composition to refractoriness, on the assumption that the fluxing materials are in the form of a 'solid solution' with the clay as solvent. This is the most helpful work on this subject up to the present, but many more samples must be examined before this theory can be regarded as conclusive.

In making a direct determination of the bending point of a clay on a small scale (p. 263) by heating a small cone of the clay in an electric or oxy-hydrogen furnace, great care must be taken to repeat the test several times, as otherwise the results may be far from accurate; on such a small scale, the ordinary errors of experiment are necessarily very large, and in so important a matter as the resisting power of a clay to heat, too much care cannot be taken to obtain an accurate result. Useful information may be obtained by heating a sample of refractory material under a load of 50 lbs. per square inch, and observing the temperature at which the sample loses its shape. This test of refractoriness under load—originally suggested by Bleininger and Brown—appears likely to be one of the most important single tests for refractory materials. Fireclays under the conditions of the test are distorted slowly, but silica bricks collapse suddenly at the critical temperature (about 1350° C.).

For further information see the author's *Refractory Materials; their Manufacture and Use* (C. Griffin & Co., Ltd.).

Resisting Power to frost and weather may be roughly tested by soaking the finished goods in a hot, strong solution of Epsom salt, and then allowing them to cool by exposure to air. The salt will crystallize out during the drying and cooling, and will tend to rupture the goods in a manner similar to frost and ice. If the crushing strength of goods treated in this way be compared with that of the untreated goods, a rough idea will be obtained as to the effect of weather. (See 'Durability,' p. 256.)

Resistance to *rubbing* may be tested by rotating a number of the pieces to be tested in a 'rattler' machine.[1] The barrel, which is 20 inches long and 28 inches diameter, should be of polygonal cross section and made of grey cast iron, not chilled or case-hardened metal. Seven runners are fitted to each end, as in no case should the stuff pass through the barrel. The charge consists of ten bricks (or blocks) having a volume of about 1000 cubic inches, which are dried and weighed before testing, and 300 lbs. of balls of grey cast iron of two sizes, viz. 10 large balls weighing about 7 lbs. each and 245 to 246 smaller balls weighing ¾–1 lb. each. The barrel is revolved 1800 times in one hour. The bricks or blocks are then removed from the machine, all pieces less than 2 inches diameter are discarded and the remainder is weighed. The loss in weight is regarded as a measure of the quality of the material tested. The rattler test is recognised as a standard for roadmaking materials in the United States, though various authorities differ considerably in their specifications of the test.

A modification of the rattler test which is greatly preferred by the author consists in lining a cylinder about 2 feet in diameter and 9½ inches long with the bricks or blocks to be tested, the dimensions of the cylinder being varied so that the bricks need not be cut. The bricks or blocks are held in place by wooden wedges which are flush with the surface. The cylinder is then charged with 100 lbs. of cast-iron balls, mounted with its axis horizontal, and is rotated 1800 times in one hour, as in the standard test. The bricks or blocks are then taken out, examined, and all pieces larger than 2 inches diameter are weighed as in the standard test.

The object of all forms of the rattler test are two-fold: (1) to determine whether the bricks are tough enough to use in a pavement, and (2) to determine whether the material is uniform in quality. The *first* is determined by the average loss of a charge, and the second by the uniformity of loss of the several bricks. Uniformity of wear is an important quality,

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[1] To make this test of any scientific value, it is necessary to have some standard method of conducting the experiments. Several methods of standardizing this test have been proposed. Bricks that had seen service in a pavement and pieces of well-known natural stones used for paving purposes, together with small pieces of scrap cast iron, were rolled in a rattler. Shortly after being proposed, this method was quite widely adopted; but it did not give satisfactory results, chiefly because the original experiments were made with a rattler having wooden staves, while subsequent tests were made with rattlers having cast-iron staves. The method was objectionable on account of the trouble and expense of preparing the pieces of natural stone. Later each of four radical modifications of the test gained prominence in succession for a time. Finally, it was found that seemingly unimportant details materially affected the results, as, for example, the material, the stiffness of the staves, the frequency of renewal of the staves and abrading material, the speed of rotation, the method of driving the rattler, etc. Copies of complete specifications for the inspection and testing of paving bricks may be had by addressing Secretary, American Society for Testing Materials, Philadelphia, Pa., or Secretary, National Paving Brick Manufacturers' Association, Cleveland, Ohio, U.S.A.

for a single soft brick may wear so as to make a hole in the pavement, and then each passing wheel will rapidly destroy adjacent bricks even though they themselves are of excellent quality.

To determine the uniformity of wear, the rattler test should be so conducted so as to find the loss of each brick. This requires the marking of the bricks so that they can be identified after being tested.

The standard specifications do not prescribe any limit for the permissible loss; but distinctly state that such limit shall be determined by the contracting parties. The standard specifications give the "following scale of losses to show what may be expected of tests executed under the foregoing specifications":

For bricks suitable for heavy traffic . . .	22 to 24 per cent.
For bricks suitable for medium traffic . . .	24 to 26 ,, ,,
For bricks suitable for light traffic . . .	26 to 28 ,, ,,

"Which of these grades should be specified in any given district and for any given purpose, is a matter wholly within the provinces of the buyer; and should be governed by the kind and amount of traffic to be carried and the quality of paving bricks available."

An entirely different result is obtained by employing a 'rubbing machine,' consisting of a horizontal iron plate, which is rotated at a definite speed for a definite number of times. The clay, brick, or other test-piece is fastened to a weighted horizontal arm in such a manner that its under surface is just in contact with the iron plate and presses on it with a force corresponding to the weight on the arm (say 10 lbs.). The piece is weighed both before and after testing in the machine, and the loss of weight is taken as the effect of the rubbing or 'wearing.' In order to facilitate the operation for very hard materials, a weighed quantity of fine emery is applied to the rotating wheel. It is usual to express the result in terms of the percentage loss of volume; this is accomplished by dividing the loss of weight by the specific gravity (p. 248) of the material, or by measuring the volume of the test-piece before and after the test.

Resistance to *blows* is usually tested by dropping a heavy ball of iron from different heights above a flat piece of the material (such as a tile or brick) and recording the greatest height through which the weight can fall on the test-piece without breaking it. The size of the weight will depend on the size of the test-piece, and in making any report on the matter particulars of both these data should be mentioned.

Resistance to *corrosion*, especially at very high temperatures, is difficult to test satisfactorily. Some of the best results obtained so far have been on bricks or blocks with a depression or cup formed during the moulding or pressing of the brick, into which a corrosive slag was placed; the bricks were then heated to a suitable temperature in a furnace and when cool the extent to which the slag had penetrated was judged by sawing the brick vertically and examining the fractured face. Attempts to weigh the slag which had not penetrated the bricks have not been successful. Cavities formed in the burned bricks are useless for testing corrosion, as in making these cavities the natural close surface of the brick is destroyed and the more porous interior is exposed. When refractory rings are cemented on to bricks so as to form cells to hold the slag, the results are not concordant as the slag attacks the rings and the cement as well as the brick to be tested.

Transverse tests are increasingly preferred to compression or crushing tests as they are easy to make and require no costly machine. The brick, or other test-piece (a bar being preferred to any other shape) is placed on two steel knife edges as far as possible apart and a gradually increasing weight is applied through a third knife edge resting on the top of the test-piece half-way between the two others. To prevent the sample being cut by the upper knife, the latter may rest on a sheet of glass. The load is increased until fracture occurs, the results being reported by means of the formula: $\frac{E=kbd^2}{l}$ where E = the breaking strain in lbs. per square inch; k = a constant depending on the material; b = the breadth; d = the depth, and l = the length between the two supports, all of these dimensions being in inches.

Resistance to *weather* is referred to under 'Durability' (p. 256).

Salts in bricks and other terra-cotta goods are frequently the cause of a particular variety of scum known as 'efflorescence.' The sources of this defect remained for a long time undiscovered, but Dr. Mäckler, of Berlin, as the result of a lengthy research, has shown that the presence of crystallizable salts in goods with but little porosity is the chief cause.

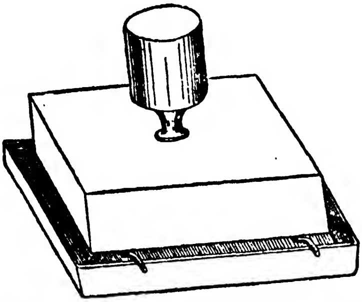
Fig. 29.—Mäckler's Test for Soluble Salts.

As the percentage of crystallizable salts is usually very small, chemical analysis is not of much use, and in order to ascertain whether a particular material is likely to effloresce it is far better to endeavour to produce the conditions under which efflorescence is most likely to occur, and from the results of such a test to pass or condemn the goods. The most satisfactory method of doing this consists in supporting the brick, or other article to be tested, on two horizontal glass rods over a shallow (photographic) dish, and on the top of the brick to place, upside down, a bottle full of distilled, or rain, water. If this is carefully done, the brick will slowly absorb all the water from the bottle and yet will not allow any of it to 'run away.' In this way, the salts contained in the brick will be dissolved by the water, carried to the surfaces of the brick, and deposited there as a white scum when the brick dries. Although a pint bottle is the most convenient for ordinary use, a smaller one may be necessary with certain clays, as the water should not be supplied so freely as to drop off the brick. For the proper carrying out of the test it is necessary that the mouth of the bottle should be ground sufficiently flat to fit the brick. The easiest way to get the bottle inverted on the brick is to hold it the right way up in the right hand, place the brick on top with the left hand, and by a sharp turn invert both and place them on the glass rods. If the water leaks between the bottle and the brick, a washer of soft rubber or plasticine may be interposed.

As this test is a very delicate one, and will produce scums with such small quantities of salts as would never be detrimental in actual practice, it is safe to neglect very slight traces of scum and only to condemn those bricks which show a marked deposit. It is essential that the water used should be distilled or rain water, as if it contains any dissolved matter it will yield false results.

Sampling is an operation requiring the greatest care and no small amount of skill if reliable results are to be obtained. The principle involved in correct sampling is that if a sufficient quantity of the well-mixed material be itself well mixed, and a portion of this be removed, again mixed, and another portion abstracted, the process being repeated until a sufficiently small sample has been obtained, this resulting sample will, as far as possible, truly represent the composition of the whole bulk. It is usual to take one quarter of the mass in each abstraction, but in some cases $\frac{1}{8}$th or even $\frac{1}{12}$th will be found to yield accurate results. If the original bulk is in bags these should be emptied one at a time, their contents well mixed, and a reasonably large portion of the mixture set on one side, to be in its turn well mixed and quartered as often as may be considered desirable. If the material is in lumps it must, when the quartering has reduced it sufficiently, be ground roughly, again quartered, and the operations of grinding and quartering repeated until the requisite size of sample is obtained. Most materials used in the clay industry will be sufficiently ground when they will pass through a No. 10 sieve, but the chemist who undertakes their analysis will have to grind them still further before he can use them. He should in no case be supplied with less than half a stone of most raw materials, though where the material is expensive, as in the case of glaze stains, a much smaller quantity will have to suffice. With clay freshly dug, about a stone is the least that should be submitted for examination, and for some purposes, several cwts. are needed.

In taking samples of *clay* direct from the pit, especial care is required, and it is always wise to send a separate sample of each geological layer for examination, these samples being placed in separate wooden boxes carefully labelled so as to avoid error. It is not advisable to send borings for analysis as the various layers are apt to be mixed and so yield a false result, though properly produced 'cores' may be quite satisfactory. It is preferable to draw a line on the surface of the ground equal in length to the depth of the clay seam, or to the depth to which it is proposed to dig, and to dig a trench the length of which is that of the line, and the depth at one end is that of the proposed workings and at the other but one yard, increasing by a yard with every yard in length. In this way, a series of steps will be formed which form convenient shelves for the different samples.

When a single sample is required from a clay face it is best to cut a strip about 6 inches wide by 6 inches deep from top to bottom of the face; this material is then mixed thoroughly. When it is desired to examine a clay which is being worked it is best to take a 2-lb. sample from each of fifty wagons entering the mill house, mix these well together and 'quarter' repeatedly, until a convenient sample is obtained.

It is sometimes necessary to bore as many trials as possible in different parts of the estate with a core-forming drill and to examine these independently; but the results so obtained can never be relied on as really correct, as by the very action of boring an undue grinding of the material takes place.

Sand and *non-plastic materials* may be sampled by the same methods as clay but with more accurate results as a uniform material is more readily obtained. In sampling a mixed material, both coarse and fine portions should be taken in the same proportions as they exist in bulk. If the material is in the form of a heap or tip, it may easily happen that some of the larger particles have rolled to the edge. Hence, special care is needed to secure a really representative sample. In such a case, the only reliable method is to take a large number of 2- to 4-lb. samples from many parts of the heap, mix them thoroughly and reduce by 'quartering' as described on p. 291. The smaller the particles of material the more accurate will be the quartering and the better the sample. Consequently, if no examination is to be made of the sizes of the grains, it is usually desirable to grind the material to powder before completing the quartering.

When it is required to determine the *ferrous oxide* in a material the sample should not be ground very fine, as unnecessary grinding causes oxidation of the material by exposing it unduly to the air.

Phosphor-bronze sieves are generally used to sift the powder, but they may introduce metallic impurities. For very accurate work silk lawns should be employed, though these are apt to tear and may slightly increase the proportion of organic material present.

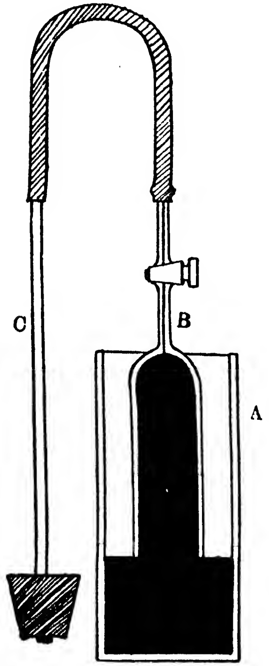

FIG. 30.

In sampling *slips* and other liquids great care is necessary to have them well stirred up before the sample is taken, and even then it is advisable to take three or four times as large a sample as is really necessary and to stir this up thoroughly before withdrawing the final sample.

In sampling *gases* — particularly flue-gases — care is required to avoid eddies in the gas. The sample is usually taken through an iron or glazed porcelain tube (4 feet in length) built into the flue, with one end projecting sufficiently to allow the attaching of a rubber tube or cork. This is connected to a glass sampling vessel, of which there are various forms, the one recommended by Arnold being both simple and strong. It consists, as will be seen from fig. 30, of a glass cylinder, A, 5 inches long and 2 inches diameter, about one-third filled with mercury.[1] In it is placed the 'laboratory vessel,' B, which has been filled by suction at the point C with mercury from A, the mercury being retained by closing the glass tap. It is important that the mercury shall rise well above this tap into the capillary tube. The cork, or rubber stopper or tube, C, connects this apparatus to the gas to be sampled. In order to sweep out all the air from the tube between B and C, it is advisable to disconnect the rubber tube from the glass just above the tap and to allow a good current of the flue-gases to sweep through the pipe; an aspirating pump may be used if necessary. The laboratory vessel is then connected to the flue, the tap opened, and by the fall of the mercury, the gas drawn into it. The tap is then closed, and the sample, after being allowed to cool, is ready for use. Although the operation of collecting a sample of gas is by no means difficult, it requires great attention to small details, such as air-tight taps, etc.; but if sufficient care is exercised, samples can be drawn with ease as often as may be desired. It is important that the portion of the tube inside the flue should project sufficiently far to be in the full flow of the gases; it is often bent at right angles

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[1] A large sampling vessel may be used if desired and, in some cases, a saturated solution of salt may be used instead of mercury. Water should not be used as carbon dioxide is soluble in it.

to facilitate the entry of a fair sample. This tube should be blown through occasionally to ensure a clear passage through it, as it is apt to become choked by dust, etc., from the fuel. It is desirable to insert a plug of loose asbestos in the tube to exclude dust unless this is to be determined. Numerous other forms of sampling vessels are in use, each of which has some special advantage for certain purposes. The collection of samples of gas in a gas analysis apparatus (without the intervention of a sampling vessel) should not be permitted. All the reagents are unduly warmed by this procedure, and the delay in allowing them to cool is greater than if a sampling vessel is used.

Scum or deposit on the surface of goods may be due to a great variety of causes (see p. 201). Its composition is, therefore, complicated in the majority of cases, and it is better to examine it in conjunction with the conditions under which it was probably formed rather than to attempt to ascertain its composition by the ordinary processes of analysis.

Shrinkage.—See 'Contraction' (p. 245).

Slip Testing consists chiefly of ascertaining that the slip has been sufficiently well ground and sifted ('lawned'), and that it is of the correct density or 'volume-weight.' The fineness of the lawn or sieve used will depend on the nature of the material and the purposes for which it is intended (p. 24). It is also wise to test a portion of the slip with a magnet at frequent intervals where white bodies are used, so that any particles of metallic iron may be detected when present. The density of a slip may be determined by one of the methods described on p. 248 *et seq.*

Specific Gravity or density.—See p. 248.

Speed of engines, mills, and other machinery should be kept as constant as possible if the best results are to be obtained. Various speed indicators have been placed on the market from time to time, and they are useful as occasional checks; the value of a mill, however, is more directly ascertained from its output than from its speed, and a careful checking of the number of tons of material prepared per day will usually give a result which will replace any record of the speed, as an engine which often 'races' will generally give results inferior to one of a steady though somewhat less average speed. The manager of the works should, however, know the best speed at which to run the various machines, and should he notice that any of them are running slowly he should at once investigate the cause.

Steam may be measured by means of various appliances, of which the best are applications of the Pitot tube. Most works have a gauge to record the *pressure* of the steam, but few measure its *volume.* Yet the amount of steam used is often an important indication of waste. Automatic steam measurers and pressure recorders are advertised in the leading engineering journals.

Temperature is comparatively easily measured if it is below 300° C. (570° F.), but above this it is complicated by the fact that ordinary thermometers cannot be used. In connection with *drying rooms* it is often convenient to use a maximum and minimum thermometer, such as is employed in meteorology. In this apparatus, a small index is moved along by the liquid in the thermometer in one direction but not in the other, so that, according to the form of the instrument, the highest or lowest temperature since the last 'setting' of the instrument is automatically recorded. In some thermometers, the mercury column is constricted very considerably so that the mercury can only flow in one direction, with the result that the maximum temperature only is shown. The clinical thermometer of the medical man is a well-known example of this type.

Thermometers used in drying rooms and in similar places should be placed some inches, at least, from the walls, so as to truly register the temperature of the air of the room and not that which has been in contact with the walls alone. A useful form of thermometer for this purpose is shown in fig. 31. It is known as a 'window thermometer,' but an ordinary 'chemical thermometer' hung from a convenient beam will serve the purpose equally well. In purchasing a thermometer it is well to remember that the wider the column of liquid the less accurate is the instrument; but as a very fine column is often difficult to read, a compromise must be effected. For ordinary purposes, an error of 1° is not of much importance in a dryer.

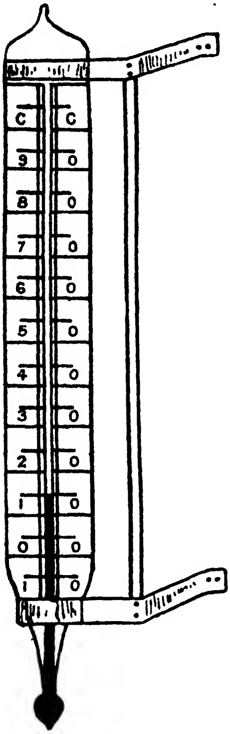

Fig. 31.

Thermometers which ring an electric bell or otherwise act as warners when the temperature passes outside a pre-determined limit are valuable in dryers, as they can be arranged to indicate whenever the dryer needs attention.

For indicating the temperature of the *boiler* feed-water, a thermometer reading to 250° F. will be generally found satisfactory. It should be inserted into the direct current of water and at a fair distance from all check valves, as these cause vibration and may easily break the thermometer.

Steam temperatures are best taken by the aid of a brass pocket let into the steam-pipe and containing quicksilver to the depth of 1½ inches, the rest of the pocket being filled with cylinder oil to prevent undue cooling of the thermometer stem.

The best place to take the temperature of the *flue-gases* is immediately beyond the boiler setting, and if a bolt be removed or a ¼-inch hole drilled in the side of the flue, the thermometer may be easily inserted. Of course, with brick flues it may not be possible to get a thermometer to work, in which case recourse must be had to a pyrometer. As regards the selection of the position of the thermometer—a most important point—care must be taken that the bulb is actually in the full current of the gases, or reliable readings cannot be obtained. It may happen that a bend in the flue, or the proximity of a damper, may so deflect the gases as to shield the thermometer effectively. This must be guarded against. For both flue and steam temperatures, the same thermometer may be used—reading to about 600° F., depending chiefly on the steam pressure at which the boiler is working—though two thermometers will be found more convenient. The instrument should never be held horizontally when taking a reading or during cooling; the bulb should always be lowest, or the readings will be valueless. It will be found best to keep the thermometers in the heat only just long enough to obtain a proper reading—itself a matter of minutes—as otherwise local heating of the mercury may cause the thread to split or even disintegrate into small bubbles, rendering subsequent reunion difficult. Indeed it may be necessary to heat the instrument to the full temperature and allow it to cool slowly with the stem vertical. Further, deformation of the bulb may result from prolonged heating at 400° to 500° F., and the thermometer may take days to return (if it ever does so) to its proper state after prolonged heating.

For determining the heat in the *chimney*, a similar thermometer, but with a stem two or three yards long, may be employed in those cases where the flue-gases passing up the chimney never exceed the limits of the thermometer in temperature; this should be very carefully watched, as the passage of gases at a higher temperature than 300° C. up the chimney-stack indicates great waste of heat.

For determining the temperature of a *kiln* in the earlier stage of heating, and especially during the 'smoking,' a thermometer enclosed within a metallic case should be used. It should be capable of indicating up to 350° C. or 660° F., and the case should have a strong metal ring at the top by which to suspend the instrument in the kiln—a long, slender chain being attached for this purpose. As the thermometer is uncomfortably hot when withdrawn from the kiln, a pair of thick gloves, or even asbestos pads, should be worn.

For determining temperatures between 300° C. and 850° C. a special thermometer may be used, in which the space above the mercury is filled with nitrogen, carbon dioxide, or other inert gas which prevents the mercury boiling at its normal temperature. These instruments are very expensive and delicate and are not really suitable for regular use in clayworks.

For measuring all temperatures above 300° C. it is necessary to use instruments which are known by the general term of 'pyrometers' (a word with a similar meaning to 'thermometer' but conveying the idea of a more intense heat). The terms 'pyroscopes' and 'thermoscopes' are used for particular forms of pyrometers, though some pyroscopes (such as cones and thermoscopes) measure 'heat effect' rather than temperature.

The skilled fireman does not usually depend upon the instruments to be described, but pays attention also to the appearance and *colour* of the kiln itself, the rate at which the temperature appears to increase, etc.

Pyrometers have been made depending on almost every change of property undergone by bodies on exposure to heat. Many of these instruments have merely an historical or antiquarian interest; others are of great value to the clayworker, and will be mentioned briefly here.

The earliest form of pottery pyrometer is that devised by Wedgwood. It consists of small cylindrical pieces of clay which have been previously heated to a low temperature, and their length accurately measured in a special scale. These small pieces of clay are then placed in the kiln and are drawn out one at a time, allowed to cool, and their length again measured, the contraction giving a rough idea of the temperature. By the use of the special scale just mentioned all calculations are avoided, and the method is, therefore, very simple and easy of application; but, unfortunately the contraction of clay appears to depend on the manner of heating as well as on the nature of the clay, so that, though a useful test in the hands of a skilled worker well experienced in the clay he is burning, this form of pyrometer cannot be regarded as really satisfactory. The same principle (that of the contraction of the clay proportionately with the heat) is much used in brick kilns in the employment of a 'pining rod'—a long metal bar with a handle and a slide which can be moved up and down the bar, but which when left alone retains its position. This rod is inserted in the top of the kiln until its lower end rests on the top row of bricks in the kiln;

the slide is then moved down as far as possible and the rod withdrawn. The position of the slide will indicate the amount of contraction which the clay has underdone during the firing. If the goods 'slip' or fall when in the kiln, this method is rendered inaccurate.

Although, for some purposes, the shrinkage or contraction of the ware is the best guide in the firing, it cannot be used in all cases, and a pyrometer which is quite independent of the ware is then substituted. Thus, one ingenious (Brown's) pyrometer suitable for use at moderately low temperatures is based on the difference in expansion of steel and graphite at high temperatures; it will stand moderately rough usage, dust, and dirt, and may be used up to a temperature of 850° C. but not higher, so that in clayworks it is chiefly used for flue-gases.

Various attempts have been made to dilute the hot air of the kiln with cold air, and to measure the temperature of the mixture with an ordinary thermometer, but without much success, though an instrument in which a current of water (instead of air) was allowed to flow through a coil of pipe inside the kiln has been used in the porcelain works at Sèvres and Limoges.

Siemens' *calorimetric pyrometer*, in which a small piece of metal is placed in the kiln and withdrawn from thence into a measured quantity of water, and the rise in temperature noted, is too cumbersome for ordinary purposes, but is occasionally used in special work. A description of the instrument with instructions is given in most good text-books on practical physics.

A draught gauge is often used in order to control the temperature of kilns. In any case, the temperature itself is not measured, but, as it depends on the rate of combustion and this again on the air-supply, an indirect reading is obtained. This method (p. 250) is exceedingly useful as an auxiliary to some form of pyrometer or pyroscope.

Optical pyrometers of various forms may be used for determining the temperature of a kiln. The ones chiefly employed are: (1) those in which the radiation from the hot contents of the kiln is compared with a coloured glass, the latter being calibrated by means of an electrical pyrometer (Livibond; Wedge); (2) those in which the radiation is compared with the filament of an electric incandescent lamp, the illumination of the latter being varied as required; the amount of current is then measured, and from this, the temperature of the kiln is estimated by means of a table (Holborn-Kurlbaum; Siemens); (3) those in which the luminosity of the kiln or its contents is compared with that of a standard flame by means of a photometer (Le Chatelier; Wanner). Most of these instruments are based on the Stefan-Boltzmann law that the light radiated from a black body is proportional to the fourth power of the absolute temperature. No truly black body exists, but the interior of the kiln, if the external light is kept away, acts sufficiently like a true black body to permit such instruments to be used with a degree of accuracy sufficient for most practical purposes.

Pyrometers using coloured-glasses are of two kinds: (*a*) those in which the colour of the hot object is compared with one or more pieces of coloured glass, arranged to form a colour scale which corresponds to a wide range of temperature. Such a comparison is only rough, but is often sufficient for checking purposes; (*b*) the Wedge pyrometer[1] (fig. 32) which consists of a telescope containing a wedge of dark red glass, which is moved across the field of

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[1] Manufactured by the Optical Pyrometer Syndicate, Audrey House, Ely Place, London, E.C. 1.

vision until the image of the part of the kiln under observation just disappears. The temperature is then read on a scale.

The annexed figure shows the pyrometer in plan. In this figure *a* is the eye-piece of the telescope, *b* the objective, *c* the rackwork for focussing the telescope on the heated object. The carrier, *d*, mounted inside the brass tube is actuated by a rack-and-pinion, *e*, and carries two glass wedges, *f*; one is the essential wedge of dark glass, the other, fitting into it, is of plain glass, and is introduced to correct the effects of refraction.

Although less accurate than some of the more elaborate instruments, the Wedge pyrometer is often convenient, and it may be used by an ordinary burner without much risk of damage to it.

Filament pyrometers have recently been improved very greatly. They consist essentially of a telescope containing a small electric lamp so placed that its filament occupies the centre of the field of view. When the filament is cooler than the hot object it appears dark against the latter, but by increasing the current flowing through it the filament becomes lighter and, if overheated, will appear lighter than the hot object. When the radiation from the hot object and the filament are alike the latter will be invisible. The current passing is then read by means of a suitable ammeter and by reference to a table the temperature of the hot body is ascertained. If the instrument is well made and carefully calibrated, it appears to be very accurate, but requires occasional re-calibration and careful use. Overheating the filament is specially to be avoided. Various modifications of this pyrometer are available.

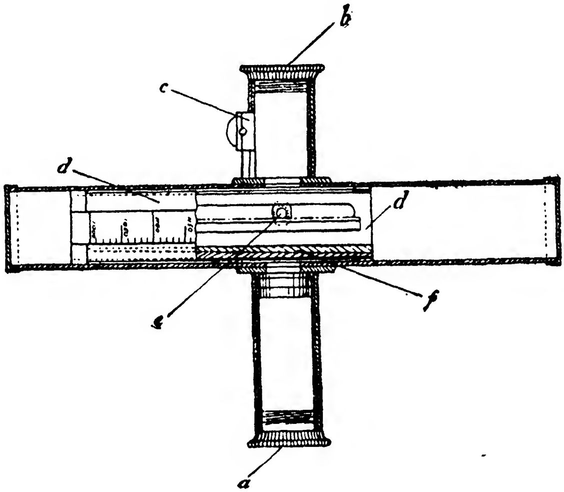

Fig. 32.

Flame pyrometers, in which the radiation of the hot body is compared with a standard flame, are seldom used in clayworking, as they are not sufficiently convenient. Le Chatelier's pyrometer is excellent for research work. In the Wanner pyrometer, an amyl acetate lamp is used as a standard, with which the electric lamp in the instrument is compared frequently. Its use, therefore, involves considerable judgment and skill.

In the management of all optical pyrometers, careful usage is essential, and considerable skill is needed when tints have to be matched. Careful attention must be paid to the standard lights; if flames, regulation to the standard height is essential; if electric lamps, care must be taken not to use them for a longer period at a time than is really necessary, or their useful life will be seriously reduced. Accumulators should be recharged regularly—say once in two weeks—to keep in good order. Separate parts, such as absorption glasses, should be kept in a place of safety, as their destruction may involve a new calibration.

Closely allied to optical pyrometers, and based on the same law, are radiation pyrometers described on p. 301. Both these types of pyrometers have the great advantage of not being deteriorated by the heat of the kiln and can be used at the highest temperatures; they are the only type which can be employed successfully above 1500° C.

Two main forms of *electrical pyrometer* are in use, viz. 'resistance pyrometers' and 'thermo-couples.' The former is in many ways the best and most accurate, except for temperatures above 1550° C. The principle on which the resistance pyrometers are based is that when a metal is heated its resistance to the passage of a current of electricity increases progressively with its temperature, so that the temperature of a furnace can be measured by determining the electrical resistance of a platinum coil placed in the furnace and comparing this with the resistance at various other temperatures determined by means of an air- or nitrogen-thermometer. One of the most convenient forms of resistance pyrometer is that patented by Callendar and Griffiths, made by the Cambridge Scientific Instrument Co., Ltd., and shown in fig. 33.

Briefly, it consists of a galvanometer, or electricity measurer, connected to an accumulator and to a Wheatstone bridge or current balancer, along which slides a self-acting arrangement, whereby the recording pen is moved backwards and forwards along the face of the paper cylinder according as the temperature rises or falls. To this recording apparatus is connected, by means of suitable wires, a resistance coil of platinum or a platinum alloy. A 'compensating coil' is also provided to neutralise the resistance of the wires leading from the coil to the galvanometer. The resistance coil is enclosed in a suitable sheath to protect it from injury and corrosion by furnace gases, as the diameter of the platinum wires greatly affects its resistance, and is placed inside the kiln, and the connecting wires carried, in a manner similar to telegraph wires, to the recorder, this latter being advantageously placed in the office. As the paper roll revolves at the same time that the pen moves across its surface, a temperature-time diagram is obtained similar to that shown in fig. 34—in which vertical distances represent the temperature, and horizontal distances (from left to right) represent the time.

By means of a suitable switch any number of kilns can be connected, and their indications recorded, though if more than one kiln is at the same temperature the diagram becomes somewhat complicated.

A rather different type of resistance pyrometer devised by E. F. Northrup depends on the resistivity of tin at high temperatures. Tin in a state of high purity may be obtained at a relatively low cost and so is suitable for pyrometry. It melts at 232° C., but does not begin to boil before 2270° C., and is not liable to contamination after prolonged heating at 1680° C. in contact with graphite. Wires of pure tungsten (which do not melt in tin at 1680° C.) may be used as electrodes for measuring the resistivity of the molten metal. When tin is heated in a covered graphite vessel, the carbon monoxide present prevents its oxidation and enables it to retain a surface of mirror-like brightness. Its increase in resistivity and decrease in density with an increase of temperature are of a strictly linear character and the tin is, therefore, an excellent material for determining temperatures. The relation between the temperature and resistivity may be best found by the method employed by Northrup and Sherwood.[1] The method is very delicate, and is hardly suited for use in clayworks, though a permanently installed apparatus may be very useful in some cases.

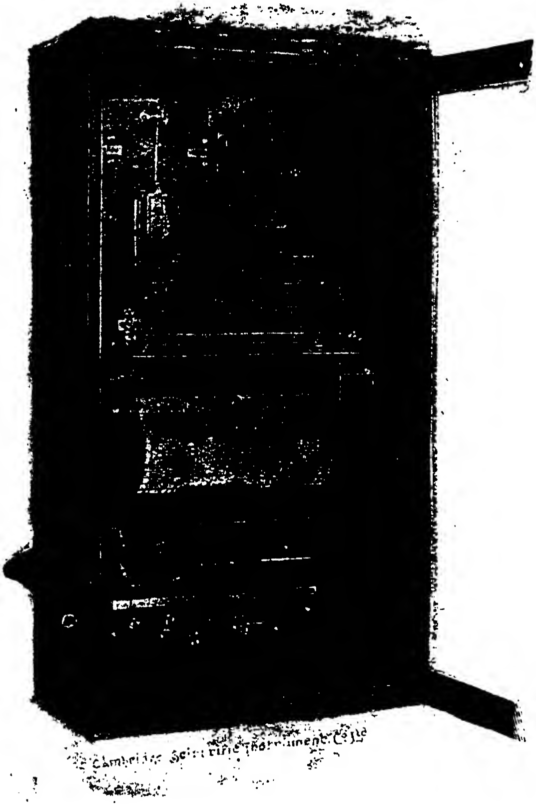

Fig. 33

Resistance pyrometers are excellent where an exact temperature is required under fairly constant conditions, but they do not respond so easily as the thermo-couple to sudden changes of temperature. Owing to the effect of heat on platinum, resistance pyrometers are not suitable for prolonged exposure to temperatures above 1000° C.

A thermo-couple pyrometer depends on the fact that when two suitable

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[1] *Journ. Franklin Inst.*, 1916, 182, 477.

metals are joined together an electric current is produced which is proportional to their temperature, and may be measured by a galvanometer graduated so as to give direct temperature readings. The current produced in the thermo-couple may be measured by a milli-voltmeter or by a potentiometer, the latter being far more accurate, but too elaborate for ordinary works use. Thermo couples may be used in connection with either indicating or recording pyrometers, a Thread recorder made by the Cambridge Scientific Instrument Co., Ltd., being particularly suitable for clayworks, though a recorder with a long roll of paper is more convenient than one with a sheet about 12 inches in length.

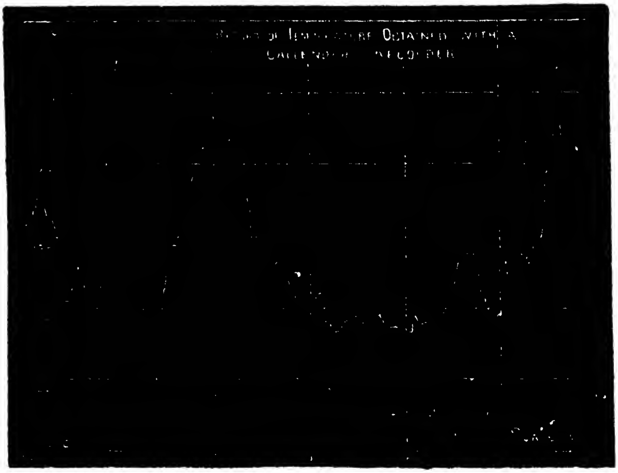

FIG. 34.

Various pairs of materials are used for the junction, according to the temperatures attained in the kiln, the following being largely employed:

	Maximum Temperatures at which the Metals may be used.	
	° C.	° F.
Platinum and rhodio-platinum . .	1400	2550
Two rhodio-platinum alloys . .	1600	2900
Platinum and iridio-platinum . .	1100	2000
Nickel and constantan. . . .	1000	1850
Nickel and copper	900	1650
Nickel and carbon	1000	1850
Nickel and iron	1000	1850
Iron and constantan	1000	1850
Copper and constantan . . .	800	1475
Silver and constantan	800	1475
Two nichrome alloys	1350	2460

As the wires made of nickel, copper and some alloys are much cheaper and stronger than those of platinum, etc., it is desirable to use them when the temperature is sufficiently low, the more expensive and delicate junctions being reserved for the higher temperatures.

Thermo-couples give little trouble when used skilfully, but they are very fragile. When in regular use they should be tested weekly by placing them in a fireclay tube partially immersed in (*a*) molten salt,[1] (*b*) molten pure copper,[2] which is then allowed to cool slowly, and observing the reading at which the temperature remains constant for a minute or more. This is the melting point of the material.

The chief advantages of pyrometers with thermo-couples are: (1) simplicity of construction and use; (2) they are cheaper than resistance pyrometers; (3) more adaptable to various purposes; (4) easier to repair; (5) not liable to get out of order, except as regards frequent calibration as their indications vary slightly. Thermo-couples have the following disadvantages: (1) they are liable to error through fluctuations in the temperature of the cold junctions of the fine wires and the stouter ones leading to the galvanometer, so that these junctions must be kept at a constant temperature; (2) they require very careful treatment; (3) the calibration on testing, though simple, cannot be entrusted to an ordinary workman; (4) they cannot be used continuously at temperatures above 1200° C.

Radiation pyrometers depend, like optical ones (p. 296), on the relationship between the heat radiated from a black body and its temperature. The two most important patterns in this country are the Féry adjustable focus pyrometer and the Foster fixed focus pyrometer. These instruments are very similar to each other, the latter being slightly simpler, and rather cheaper, but incapable of being used where the pyrometer requires to be focussed on the hot body. A spiral pyrometer has also been devised by Féry, but it is not so satisfactory in clayworking.

In the Féry pyrometer, the heat radiated through a 'sight-hole' in the kiln is received on to the junction of a copper constantan couple, and the radiation effect is measured by means of a sensitive galvanometer.

As the amount of heat radiated from the inside of a kiln, under the conditions under which such a pyrometer is used, is proportional to the fourth power of the temperature of the kiln, the readings of the galvanometer may, by suitable calibration, be made directly in ° C.

By using the radiated heat, instead of inserting a part of the pyrometer in the kiln, the wear and tear of the instrument is reduced almost to zero; an ingenious focussing arrangement enables the distance of the hot part of the kiln from the instrument to be varied within wide limits, and may be used for measuring any temperature above 800° C.

The construction of the instrument is shown in fig. 35, which is a sectional view of the pyrometer. This consists of a metal cylinder about 7 inches long and 4 inches wide, having a small eyepiece (O) at one end. Inside this cylinder, just behind the eyepiece, is a concave mirror which focusses the heat radiated from the kiln on to the thermo-couple junction, the two wires of which are marked R and D in the figure. In order that the accuracy of the focussing may be as great as possible, two small mirrors are placed immediately in front of the junction in such a manner that when the part of the kiln giving out the radiant heat it is desired to measure is in focus, a clear view of it (reflected from the large mirror on to the smaller ones) is obtained on looking through the eyepiece (O).

With this arrangement the distance of the heated object from the instrument is a matter of indifference so long as the image on the junction

[1] Common salt melts at 800° C. or 1472° F.

[2] Copper (covered with graphite) melts at 1084° C. or 1893° F.

is more than sufficient to cover it. When this is the case, the instrument gives identical readings at 3 feet and 30 feet from the object.

That the indications of the instrument, when used as directed, are independent of distance can be proved from theory as well as verified in actual work.

The radiated heat develops an electric current whose voltage is proportional to the temperature of the junction receiving the radiation. This current is led by wires from the terminals (*b b'*) to a sensitive galvanometer, which, for convenience, may be graduated to show temperature-degrees.

As one of the chief objects of measuring the temperature of a kiln is to have a continuous record of the manner in which it has been heated, it is advisable to substitute a recording galvanometer for the direct-reading instrument just mentioned.

The Cambridge Instrument Co., Ltd., of London and Cambridge (who are the chief makers of electric temperature recorders in this country), have therefore patented a special form of recorder for the Féry pyrometer. In this recorder (fig. 36) the pointer of the galvanometer moves backwards and forwards over a horizontal drum covered with a specially ruled paper, and at intervals of a minute it is pressed down by a light metal frame on to a thread soaked in a special ink, so that the thread, on touching the paper, makes a dot. As the drum revolves by clockwork once in twenty-four hours, the dots form a dotted line on the paper, the curves in this line representing the variations in the temperature of the kiln. Six temperatures can be recorded simultaneously.

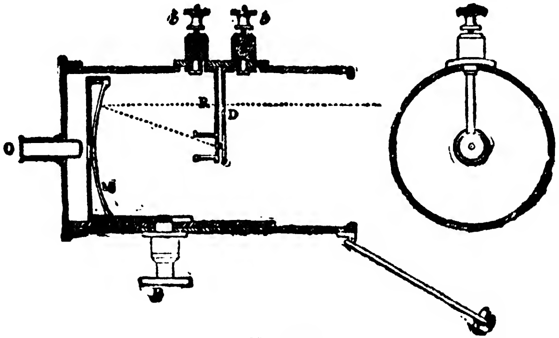

FIG. 35.

There is no reason why the 'warning attachment,' described previously, should not be added to this recorder as well as to the Callendar instrument, as it would then be possible for the head fireman, or the works manager, to be called by an electric bell if, for any reason, the temperature of the kiln were allowed to get outside of certain limits. Aid is thus summoned before any serious amount of mischief is done. In this respect, electric recorders of temperature are well worth the somewhat high first cost, as it is not possible to warn outsiders so quickly that anything is wrong by any other means within the author's knowledge.

Radiation pyrometers require careful treatment. The focussing must be accurate or the reading will be low. If an indicating galvanometer is used, the needle should be adjusted to zero before each reading and the instrument properly levelled. The surface of the mirror must on no account be damaged. If there is any dirt on it which cannot be removed by gentle brushing with a camel's-hair brush, the instrument should be returned to the makers.

The chief advantages of radiation pyrometers are: (1) they can be used at any temperature above 'black red heat'; (2) they do not deteriorate as rapidly as other electrical pyrometers as they are not exposed to the kiln-gases; (3) they are portable; (4) they require only occasional calibration, and (5) they are quite suitable for use in connection with most kinds of kilns. Radiation pyrometers cannot, however, be adapted for use on one central recorder (p. 299), so that it is necessary to have a separate recorder for each.

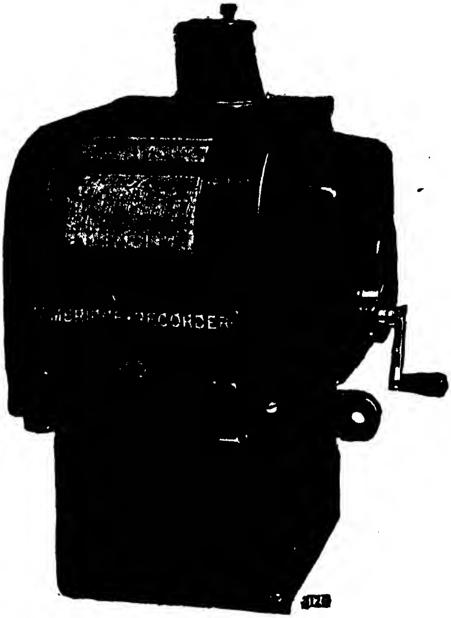
FIG. 36.—Thread Recorder.

Further information on the pyrometers just mentioned will be found in C. R. Darling's *Pyrometry* (E. & F. N. Spon, Ltd.).

In addition to the instruments which measure the temperature, clayworkers may usefully (and, sometimes, preferably) employ pyroscopes which record the effect of heat. Such pyroscopes include various mixtures of fusible salts or alloys, as well as 'trials' made of the same materials as the goods in the kiln.

Fusible metals and salts are not usually suitable for clayworks purposes, but Watkins heat recorders are largely used, and the following substances which have definite melting points are sometimes useful:

	Melting point.	
	° C.	° F.
A mixture of 7 parts sodium chloride and 8 parts of potassium chloride . . .	650	1202
Common salt	800	1472
Anhydrous sodium carbonate . . .	850	1562
Anhydrous sodium sulphate . . .	900	1652
Sodium plumbate	1000	1832
Anhydrous potassium sulphate . . .	1070	1958
Anhydrous magnesium sulphate . .	1150	2102

Watkins heat recorders consist of a series of small pellets of progressive melting points which are placed in depressions in a refractory block. The block is placed in the kiln at the same time as the goods, and is removed occasionally and the pellets examined. The melting point of the most refractory member showing signs of fusion, by the rounding of the edges, is taken as the temperature of the kiln. The composition of the materials is similar to those of the cones and thermoscopes, or pellets made of fusible salts mentioned on p. 303 may be substituted.

Mixtures of silicates may also be used, two modifications of the latter, viz. Seger cones and Holdcroft thermoscopes, are particularly useful and are extensively employed. They both depend on the change of shape which a prism of siliceous mixture undergoes when heated to a critical temperature, dependent on its composition.

Seger cones are composed of mixtures of felspar, china clay, with quartz and certain fluxes including iron oxide, marble, and boric oxide, so arranged that there is a definite increase in the indicating temperature of each successive cone in the series, the *average* difference being 20° C. or 36° F. (See Table in the Appendix.) The series has been altered on several occasions, but the present ones are now largely used as a standard, although it is recognised that they do not necessarily correspond to the temperatures with which they are usually associated.

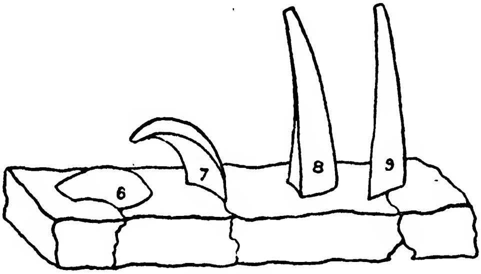

Fig. 37.

The materials for the cones are carefully proportioned and finely ground and mixed in a ball mill, so as to pass completely through a 100-mesh sieve. A few cones are made from the mixture and tested. The composition is then adjusted until the cones can be relied on to behave as required. It is not advisable for clayworkers to make their own cones as considerable skill is needed in the manufacture and accurate cones can be obtained at about one penny each. It is most unwise to buy cheap cones of unknown origin as they are usually unreliable.

Seger cones are small pyramids (tetrahedrons) about 2½ inches high, this form being chosen as enabling the pieces to be placed vertically in the kiln, and at the same time being very sensitive to heat, so that when the correct temperature is reached the 'cone' bends over until its point touches the tile or brick on which it is standing (see fig. 37). A set of smaller cones —about 1 inch high—is used for the highest temperatures.

If the cone is melted to a greater extent than this, a higher cone must be used; if not so much, it shows that the temperature corresponding to this particular cone has not been reached. Hence, if the correct cone for finishing a kiln is known, the insertion of three cones will ensure a correct registration of the temperature, viz. one below the required temperature, one for the correct temperature, and one above it. Then the first cone will act as a warner that the finishing point is nearly reached, and the third cone will show, by its remaining unbent, that the temperature has not been excessive; under-firing and over-firing at the points where the cones are placed is, therefore, much less likely to occur than when other trials are used. In order that the cones may not fall over during the firing, it is convenient to insert them to the depth of ⅛-inch or so in a piece of soft clay; this may then be placed directly in the kiln, or in small boxes of fireclay specially made for the purpose, in such positions that the cones can be easily seen during the progress of the firing through a sight-hole in the kiln wall. It is advisable to have a number of sets of cones in different parts of the kiln so as to secure an equal temperature throughout. For the determination of the highest temperature in a kiln (*i.e.* for the finishing heat), the Seger cones appear to be the most satisfactory form of pyrometer yet introduced.

Unfortunately, they do not indicate whether the kiln has lost any heat at any part of the firing, as, for instance, by the fireman going to sleep during the night; they are only 'maximum temperature recorders.'

Before Firing. After Firing.

FIG. 38.—Holdcroft Thermoscope.

Holdcroft 'Thermoscopes' (fig. 38) are similar in composition to Seger cones, but their shape is that of a bar of square section. A series of three or four thermoscopes are placed one above the other in a fireclay holder somewhat resembling a diminutive ladder, and, as the temperature affecting them is reached, they soften and bend downward in the centre; those which are not affected by the heat retain their straight, horizontal position. Although this form of test-piece finds many to recommend it, the author prefers the Seger cones as being more easily seen when in position in the kilns. (See also p. 334.)

The *Calorites* (fig. 39) made by Wengers Ltd., of Etruria, Stoke-on-Trent, resemble the thermoscopes just mentioned; they are small bars of square section, one end of which is painted to indicate their melting point. They are suitable for temperatures from 500° C. to 1470° C.

Trials are of various kinds, from the good old-fashioned rings of red-burning clay which are drawn out of the kiln at intervals and examined as to their colour and which are still of considerable value in careful and experienced hands, to pieces of clay glazed with special colours or glazes, and which are examined in a similar manner to the rings. In some cases, a fusible 'body' is painted on to conveniently shaped test-pieces, and drawn out and examined from time to time, whilst for other classes of work it is sufficient to withdraw a piece of clay, such as the goods are made of, and to test that for hardness, porosity, etc. These methods, whilst sufficient for certain purposes, are not to be considered as pyrometers in the strict sense of the word, as they do not *really measure the temperature of the kiln in terms of any particular scale;* but they are still largely employed, and are most conveniently dealt with in this section.

In short, it is not safe to rely merely on the shrinkage of the clay to determine the finishing point of the kiln, as clay has a great tendency to contract irregularly, or a slip in the goods may cause them to shrink unduly. Electric pyrometers, though excellent for the automatic recording of the temperature throughout the whole of the firing, are not very durable when exposed.

Many other forms of pyrometer have been used at various times in connection with clayworking but they have not met with sufficient success to be regarded as of practical value for this purpose, though often useful in other industries. The 'air-thermometer' and the 'water-current-pyrometer' are good instances of this class of instrument.

Time-temperature Chart.—No matter whether a recording pyrometer is used or not it will be found desirable to prepare a time-temperature chart or schedule which will act as a standard for the firemen, and if the changes in the temperature of each kiln are marked on a series of such charts, a direct comparison can easily be made. A comparison of these diagrams with the ware from the kilns, usually enables very considerable improvements to be made in the quality of the ware, the consumption of fuel, and the time spent in firing and cooling. Irregularities in firing are clearly shown and other minor advantages are obtained. A supply of standard charts for each kiln can be printed lithographically (in red) for a small sum, and they have proved invaluable in many cases in the author's experience.

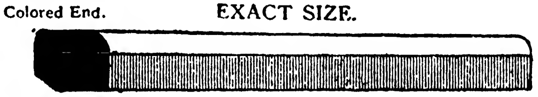

Fig. 39.—Calorite.

In a temperature diagram such as that shown in fig. 40, the vertical distances represent the temperature and horizontal ones the time; hence a point on the diagram which is on both a temperature and a time line will indicate the temperature of the kiln at that particular time. Such a diagram will be automatically drawn by pyrometers of the Callendar (electric) type, but in other cases they must be made out by observation as follows:—

The time of lighting the kiln is noted, and at sufficiently frequent intervals the temperature of the kiln is ascertained by means of a thermometer, a pyrometer, or by observation, using the Table of 'Colours' on p. 334. The time of each observation is carefully noted. A piece of paper ruled in small squares is next converted into a scale by numbering all the vertical lines to represent degrees of temperature and the vertical lines to represent hours after lighting the kiln. In order to keep the chart within reasonable limits of size, it is generally advisable to allow each vertical line to represent 10° or even 50°, and each horizontal line to represent one hour; but as practice renders the use of the chart more easy, it is possible to reduce the scale still further and to allow a distance of $\frac{1}{25}$th of an inch to represent 10° C. and one hour respectively.

The chart is then drawn by marking with a fine dot the meeting place of each line corresponding to a certain observed temperature with the line corresponding to the time of the observation: thus in fig. 40 the point B indicates a temperature of 1000° observed twenty-five hours after lighting the kiln, because it is at the junction of the horizontal line representing 1000° and of the vertical line representing twenty-five hours, the time at which the kiln was at the specified temperature. The other observations are similarly indicated by dots. These dots are then joined together by a fine ink line, and so produce a curiously shaped line somewhat resembling the one illustrated. In some cases the line thus produced will roughly resemble a curved line, and it is on this account known as a 'time-temperature curve.' As the temperature of the kiln increases, the curve will tend to rise towards the top of the chart until the highest temperature of the kiln is reached (E), after which it will gradually descend until it reaches the level from which it started; the kiln is then perfectly cold. The dotted line shown in the figure indicates the shape of the 'curve' if the heating and cooling had been perfectly regular, and although the curve made from observations of kilns is never so regular as this dotted line, it is often useful to draw it (by ruling a straight line from the starting temperature to the finishing temperature (E) of the kiln and from this latter to the cooling point, (H)), in order to see how far the actual result has followed this theoretical line. It will, of course, be understood that this chart will only show serious variations in the temperature of the kiln; smaller variations require the use of an automatic recorder, in which the record is continuous and not made at more or less regular intervals; but in spite of this disadvantage the chart illustrated is of great value in accounting for otherwise inexplicable variations in the quality of the ware. For the sake of clearness, only eight observations are shown, but in practice the observations would be made much more frequently than this, especially when the kiln is near its finishing point; at this stage

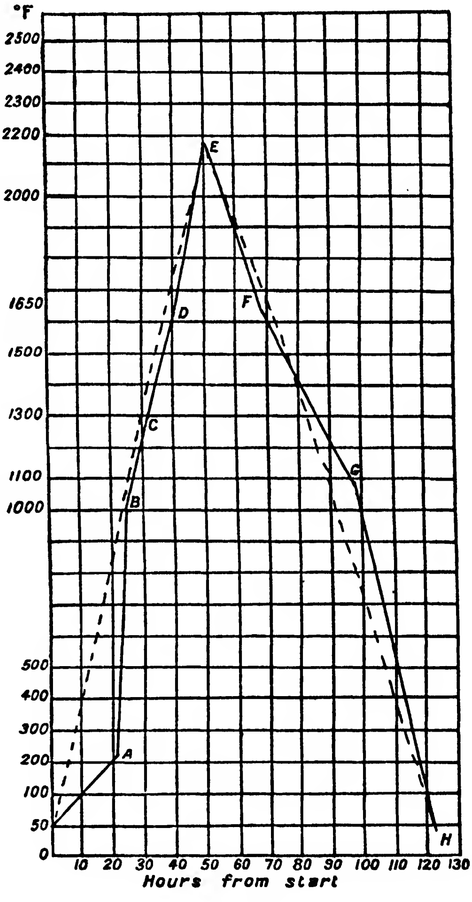

Fig. 40.[1]

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[1] If an automatic recorder were used to form this chart, the sharp angles would be obliterated, and the apex E would be strongly rounded.

the presence of three or four Seger cones is invaluable (in the absence of an electrical pyrometer) for recording the exact temperatures. It is then best to mark on the chart the time at which the different cones bend slightly, moderately, and completely.

A useful accessory to this chart consists in drawing a second vertical scale (preferably on the right-hand side of the paper) which shall represent the weight of fuel consumed by the kiln. If the kiln is properly fired this fuel-time line will then have a similar form to the heating line of the kiln, but will often be somewhat steeper near the top, as more fuel is required per hour when the kiln is at a bright heat than when it is but moderately heated. A study of this fuel line has on more than one occasion enabled the author to detect the wasting or stealing of fuel by the fireman. It also provides information as to the most economical temperature at which to finish the heating of the kiln.

In all kiln-firing it must not be forgotten that the pyrometer will indicate the temperature much more rapidly than the goods themselves, and that if the kiln is considered to be 'finished' as soon as the pyrometer (of whatever make) indicates a certain temperature, perfect goods will not be obtained. The temperature must be maintained for a certain time—particularly with some goods. When Seger cones are used, the length of this maturing time is so short as to be practically negligible, because the cones themselves take a certain time before they bend over completely. This slight disadvantage of the cones for certain purposes is an actual gain to the clayworker, as it saves him from worrying about the time to continue his heating: he may consider the kiln as finished as soon as the desired cone has bent over until its point just touches the clay on which the cone stands.

For notes on suitable temperatures for drying, see p. 118, and for firing various classes of goods, see p. 160.

Temperature-Regulation cannot be effected automatically in ordinary kilns, but in drying-rooms in which steam is used as the heating agent a self-acting regulator devised by Sodeau (*Jour. Soc. Chem. Ind.*, 1904, 1134) is useful (fig. 41). This consists of a 1½-inch valve actuated by a zinc tube some 66 inches long, directly connected to it by means of a wooden insulator. Such a tube expands ·002 inch for each 1° C. rise of temperature; hence all the connections must be free from play as far as possible. On this account Sodeau substitutes a slate slab for the wooden base usually provided with such instruments, and attaches the instrument by steel bolts of about the same expansion as the slate. Conduction of heat from the valve is greatly reduced by fitting a steel cap to the end of the valve spindle (VS), the point of the cap resting in a hole in the steel plate P^1. A similar plate, P^2, on the end of the zinc tube, T, is connected to P^1 by means of three steel distance-pieces, D, slipped into slots in the plates, stiff paper being used to prevent metallic contact. All play is taken up by a strong spring, S, coiled around the external portion of the valve spindle, VS. The zinc tube is supported by a series of guides, G, and is prevented from rotating by means of a pin sliding in a slot (not shown in fig. 41). The further end of the tube is adjusted by means of a differential screw (twelve and sixteen threads), one turn of which makes an alteration of $\frac{1}{48}$-inch, or a difference in temperature of 16° C. The steam may be supplied at a low pressure (say 10 lbs. per square inch), and should preferably be passed through a separator to remove water and other impurities which might clog the valve. With careful use this arrangement works exceedingly well, and will run many months without any attention. A thermometer should, however, be placed in the dryer, and read at occasional intervals, in order to ensure that the adjustments have not been interfered with.

If such an apparatus is not installed in the dryers, it is at least desirable that a sensitive 'fire alarm' should be installed, so that a too sudden rise in temperature may be at once communicated to the person in charge, as otherwise, in the case of delicate clays, the goods may be easily spoiled. Such alarms may be obtained in various forms, and need no further description here than to say that when the temperature reaches a pre-determined point, an electric circuit is completed and a bell rung, either until switched off and the alarm re-set or until the temperature falls again to its normal height.

Where steam-heated water is used for drying purposes a thermo-regulator similar to those used in hotels and schools may be advantageously used, and will be found to effect a considerable saving in fuel.

Tension Tests of the tensile strength of clay are made in a special machine which is too costly for the ordinary clayworker, who must, therefore, send his bricks to an expert to be tested. The general principle on which such machines work is similar to that described as being used for determining the binding power of clay (p. 234), only that the enormously greater power required necessitates the use of a different method of applying the force. As these tensile machines are used for testing steel, an acquaintance in a neighbouring large steel-works may be able to make the test, but it is better, as a rule, to get it carried out by an expert in *clay*, who, by his constant practice in this material, is more likely to obtain a correct result.

H. Ries (*Trans. Amer. Ceramic Soc.*, 1904, 79) has shown that an excessive proportion of fine clay particles weakens raw clay in the same manner as a large amount of sand, and that the strongest clays are those with grains of various sizes, so that they will interlock with each other; the fine particles of the clay substance must, however, preponderate. By the careful consideration of the sizes of the grains of two clays, Ries was able to prepare a mixture which had a higher tensile strength than either clay separately. It is interesting to note that this worker, contrary to many others, considers it incorrect to use the tensile strength as a measure of the plasticity of green clays. (See 'Binding Power,' p. 234.)

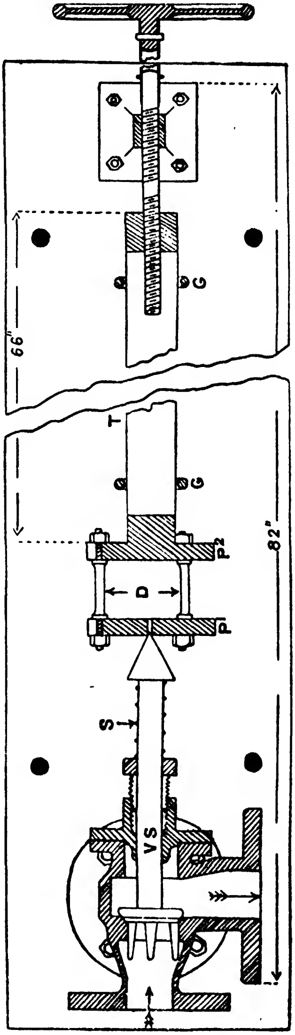

FIG. 41.

Texture varies greatly in various clays, and does not readily admit of numerical comparison, though the results of a careful washing of the clay through a series of sieves of gradually increasing fineness, and drying the residues on each sieve and weighing them (see p. 311), will prove of great assistance. The texture is really best ascertained by observation, with or without a powerful lens, of the polished surface, to which a thin sheet of glass has been cemented with Canada balsam, as suggested by Lomax. The microscopical study of the texture of raw clay has not, up to the present, yielded results of great value to the clayworker. Its chief purpose is to identify various minerals which may be present, and to give some indication of the size of the particles of material.

The texture of the fired ware, on the contrary, well repays careful study, especially where the conditions under which it is used are very severe, as is the case with most refractory materials. The causes of lack of durability, insufficient resistance to corrosion, or the effect of heat or abrasion may often be studied most effectively on a polished sample or on an extremely thin section. The use of a good petrological microscope is often invaluable in this examination, but requires special training and skill.

Thermometers; Thermoscopes.—See 'Temperature,' p. 293.

Volumeters are used for determining the specific gravity and the porosity of fired clay goods (see p. 280).

Waggons, although nominally of a definite size, are notorious for containing different weights of material. Hence if each waggon cannot be weighed at each time of loading, the average weight should be taken from as large a number as possible. This is especially necessary where two different sets of waggons are used for the same material, as when coal is brought from the pit and delivered into bunkers from which it is taken in other waggons as required to the kilns, etc. If, as should be the case, each waggonman reports the weight of coal moved by him, the two weights will often fail to tally when 'stock' is taken of the fuel left in the bunkers, if the weight of it held by the waggons is estimated from an average load, with the result that a chief object of the reports of the men (viz. to prevent stealing of coal) is frustrated. Now that there are several forms of weighing machines on the market which are made for this purpose and do their work automatically, there is no excuse for a discrepancy of this sort.

Warners are used in connection with firing kilns, and are intended to secure a regular attention from the fireman, especially at night, when the temptation to neglect duty is apt to be greater and to be fraught with more serious consequences than during the daytime (see p. 235).

A perfect warner will indicate any serious alteration of temperature, first to the fireman, and then, if he does not attend, to the foreman or some other responsible person. Up to the present, however, no entirely successful warner has been placed on the market. An electrical one used by the author in connection with a Callendar pyrometer has proved entirely satisfactory under his care, but is too delicate for use by those not accustomed to instruments of precision. The warner most favoured abroad is so arranged that a bell rings at definite intervals (usually every fifteen minutes), indicating that it is time for the man to attend to his fires, after doing which he must move a small lever to indicate that he has done his duty. Should he neglect to move this lever (through being asleep or some similar cause) within ten minutes of the ringing of the bell, another alarm is sounded in the manager's or foreman's house, so that the cause of the fireman's neglect can be speedily ascertained. As will be seen, this instrument does not work directly in connection with the kiln, and is to this extent unsatisfactory, but, as already stated, no better means of warning the manager or his deputy of anything going wrong with the firing has yet been devised, which can be placed in the hands of an ordinary foreman, and at the same time cannot be 'fooled' by the fireman should he be so disposed. An electrical connection with a draught-gauge appeared at one time to promise success, but it was found on continued use that draught variations were not always injurious to the contents of the kiln, so that those responsible were often unnecessarily 'warned' at much inconvenience to themselves.

Washing Clay is an operation which needs particular care and oversight. A good test of its efficiency consists in (1) washing a carefully weighed quantity of the clay through a special set of sieves of gradually increasing fineness, and (2) drying and weighing the residue left on each sieve. For this purpose exactly 2 lbs. of the dry clay, or an equivalent amount of the wet, is well mixed with about two quarts of hot water in a gallon basin, a wooden stick half an inch in diameter and with slightly rounded ends being used to rub the clay into the consistency of a thin cream. After standing for a couple of hours about two quarts more of water are added, the mixture well stirred, allowed to settle for five minutes, and the liquid then poured carefully through a No. 40 sieve,[1] as much as possible of the heaviest sediment being allowed to remain in the basin. The contents of the sieve are then brushed gently so as to cause as much of the clay as possible to pass through, the residue in the basin is rubbed up with a fresh quantity of water passed through the same sieve, and the operation repeated until no more clay will go through the sieve and the water used runs through quite clear. The residue on the sieve is then dried and weighed. The sifted clay and water ('slip') is next passed in a similar way through a finer sieve and then through others still finer, until a sieve with, say, 200 meshes per linear inch (No. 200) is reached. For most purposes this is sufficiently fine, but in the case of special work it may be necessary to make a supplementary test by means of Schoene's apparatus. (See p. 270, also Ashby's *How to Analyse Clay.*) It will generally be found in practice that three sieves will be sufficient in testing all but the finest varieties of clay, the precise sizes of mesh of these sieves being dependent, of course, on the particular class of work for which the clay is to be used. It is essential that the clay be not forced through the sieves; on this account a wooden tool is used to break up the 'cakes' of clay in the first instance, and a soft brush is used on the sieve. A sieve of moderate coarseness should always be used first, as this, by preventing hard pieces of material from getting on to the finer sieves, prevents their being so rapidly worn, or torn, as they would otherwise be. 'Standard sieves' (p. 85) are essential for accurate work.

Some investigators consider it necessary to boil the clay with water containing a little alkali (sodium carbonate or ammonia for preference) in order to destroy any cementitious matter and 'deflocculate' the clay. Unless such an addition is to be made to the clay when in actual use, its employment in testing may be misleading.

Water for clayworks purposes does not need to be of the same degree of purity as that applied to towns; at the same time certain impurities should be avoided. Amongst these are an excessive proportion of soluble salts, determined by evaporating a gallon of water (or less, according to the accuracy of the scales available) in a small weighed evaporating dish and

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[1] If there is much coarse material, the series used by the author or that recommended by Mellor (pp. 270, 271) should be used.

weighing the residue after drying it to constant weight (p. 276) at 105° C. or 110° C. It is not possible to fix a limit for the proportion of soluble salts permissible, as so much depends on the temperature and method of firing of the kilns (*i.e.* on the class of goods made); but, as a general rule, waters containing more than 100 grains per gallon should be regarded with grave suspicion.

For use in boilers, it is important to know how much matter will be deposited as scale by the water. This may be estimated by the following method, which will be found, in practice, to be superior to the usual 'soap test,' which is very unsatisfactory with magnesian waters:—

To a convenient volume of the water (say 500 c.c.) which has been carefully measured, a few drops of methyl-orange solution are added, and *decinormal* hydrochloric acid (to be obtained of exactly the correct strength from scientific instrument dealers and some chemists) is then added drop by drop from a burette until the yellow colour of the water has been changed to a distinct pink, which remains after much stirring. Great care must be taken not to add too much acid, and to measure accurately the volume of acid necessary to bring about this change in colour. The number of c.c. of the acid required when multiplied by 350, and divided by the number of c.c. of water taken for the test, will indicate the number of grains of chalk per gallon in the water ('temporary hardness'), and this result divided by 2 will show approximately the number of grains of quicklime which must be added in the form of lime-water to remove this form of hardness from a gallon of the water.

To the pink liquid is added 100 c.c. or more[1] (the exact volume added must be accurately known) of a solution of *decinormal* sodium carbonate solution by means of a pipette, and the liquid is boiled gently for a few minutes and is then filtered through a paper filter. The clear solution is allowed to cool, and *decinormal* hydrochloric acid is run in drop by drop until the colour is again just pink. If only two or three drops of the acid are required, it shows that an insufficient quantity of the sodium carbonate solution has been added, and the test must be commenced afresh, using more of the solution. The number of c.c. of the acid used the second time is deducted from the number of c.c. of sodium carbonate solution used, and the result multiplied by 476 and divided by the number of c.c. of water used gives the number of grains per gallon of 'sulphate of lime' ('permanent hardness') in the water, and this result multiplied by 0·78 gives the number of grains of soda ash needed to remove it from each gallon of the water.

If magnesia is present in the water it will be reckoned as chalk or sulphate of lime, according to its state of combination. This will not, however, affect the proportions of lime or soda needed for softening the water.

It is advisable to occasionally draw samples of water from the boiler and to determine their 'hardness'; in this way the necessity for softening will be made clearer, or the accuracy with which the softening is being carried out will be shown.

It need scarcely be pointed out that when town's water is used to any considerable extent, a careful comparison of the readings of the meter week by week will often prevent any serious waste of water without much trouble; any serious variations in the amount of water used should always be accounted for, if waste is to be prevented. (See also 'Water and Water Supply,' p. 32.)

Weights per Pint.—See 'Density,' pp. 133 and 248.

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[1] Sufficient must be added for the water to remain a decided yellow, even after boiling.

Weights and Scales should be tested periodically by the recognised inspectors, even though they are not used for 'purposes of trade,' as in this way assurance is obtained that serious errors in the weights of glaze materials, etc., are not due to defective appliances.

Whiting may be assayed as chalk (p. 239).

Zinc Oxide is occasionally added to glazes as an opacifier or as an 'anti-craze.' For this purpose the white, light-weight variety is to be preferred to the denser, heavier one. By the method of its manufacture it is obtained so pure that it is scarcely worth assaying if obtained from reliable firms. If assayed by titration with decinormal hydrochloric acid after the manner of chalk (method (*b*), p. 240), it will be found that 1 c.c. of the acid is equivalent to 0 004 gramme of zinc oxide; hence if 0·4 gramme of the sample be used for the assay, each c.c. of acid required will represent 1 per cent. of pure zinc oxide in the sample. A more accurate assay of the material is beyond the powers of one not trained as a chemist and is, therefore, outside the scope of this book.

APPENDIX.

GENERAL INFORMATION.[1]

Metric Weights and Measures.

1 Metre = 100 centimetres (cm.).
1 Centimetre = 10 millimetres (mm.).
1 Gramme of water measures 1 c.c.
1 Kilogramme = 1000 grammes.
1 Litre = 1000 c.c.

Metrical Equivalents of British Weights and Measures.

English.	Metric.
1 Inch = 2·54 centimetres (cm.).	1 Millimetre (mm.). = 0·04 in.
1 Foot = 30·48 centimetres (cm.).	1 Centimetre (cm.). = 0·39 in.
1 Yard = 0·91 metre (m.).	1 Metre (m.) = 39·37 in. 3·28 ft. 1·09 yds.
1 Mile = 1609 metres (m.).	1 Kilometre (km.) = 1093·6 yds.
Area.	
1 Sq. inch = 6·45 sq. cms.	1 Sq. cm. = 0·155 sq. in.
1 Sq. foot = 0·093 sq. metre.	1 Sq. m. = 1·194 sq. yds. or 10·764 sq. ft.
I Sq. yard = 0·836 sq. metre.	
1 Acre = 4040 sq. metres.	
Volume.	
1 Cubic inch = 16·4 c.c.	1 C.c. = 0·061 cb. in.
1 Cubic yard = 0·76 cb. m.	1 Cb. metre = 1·307 cb. yds.
1 Pint = 568¼ c.c.	1 Litre = 1·76 pints = 1000 c.c. 0·035 cb. ft.
1 Gallon = 4·55 litres.	
Weight.	
1 Ounce = 28·34 grammes.	1 Kilogramme (kilo.) 2·20 lbs.
1 Pound avoir. = 453·6 grammes. 0·454 kilo.	1000 Kilos. = 1 ton (nearly).
1 Ton = 1016 kilos.	

Pressure.

1 Lb per sq. in. = 70·3 grammes per sq. cm.
1 Kilo. per sq. cm. = 14·22 lbs. per sq. in.
1 Inch mercury-gauge = 0·0333 atmosphere.
    13·6 in. water gauge.
    0·49 lb. per sq. in.
1 Inch water-gauge = 0·0735 in. mercury gauge.
    0·036 lb. per sq. in.

Power.

1 Horse-power = 0·707 B.Th.U. per second.
    0·178 calories per second.
    0·746 kilowatt.

British Weights and Measures.

1 Pint = 20 oz. of water.
1 Gallon = 8 pints.
    10 lbs. of water.
    277·27 cb. inches.

1 Cubic inch of water weighs 0·036 lb.
1 Cubic foot water = 1000 oz. (nearly).
    6·23 gallons.
    0·028 cubic metre.

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[1] For a large amount of other mathematical information and tabular matter see the author's *Ceramic Industries Pocket-Book* (Pitman).

Formulæ relating to the Circle, etc.

$$\text{The circumference of a circle} = \text{diameter} \times \frac{22}{7} \text{ (or 3·1416).}$$

$$\text{Area of circle} = \text{square of diameter} \times \frac{22}{28} \text{ (or 0·7854).}$$

Area of triangle = half base × perpendicular height.

The capacity of a tank or cistern with straight sides is found in cubic inches by multiplying the length by the breadth and then by the depth (all measured in inches). To convert cubic inches into gallons, divide by 277.

Chemical Calculations.

To find the Percentage Composition having the formula given.—Find the molecular weight by adding the atomic weights of the different elements in the formula, taking care that when more than one atom is present the proper multiple of the atomic weight is used; then

$$\frac{\text{Molecular weight}}{100} = \frac{\text{Weight of constituent in a molecule}}{\text{Percentage of constituent}};$$

or multiply the molecular weight of the constituent by 100 and divide by the molecular weight of the whole substance.

Treat each of the constituents in turn in this manner; the sum of the percentages obtained will then be the percentage composition of the whole substance.

To find the Empirical Formula of a substance from its Percentage Composition.—Divide the percentage of each constituent by the atomic weight of that constituent, and divide all the numbers thus obtained by the lowest; if the numbers thus resulting are not whole numbers, the nearest whole numbers may usually be taken as correct.

In calculating the formulæ of glazes and bodies divide the percentage of each oxide (K_2O, Al_2O_3, SiO_2, etc.) by the molcular weight of that oxide, and divide the numbers so obtained by the number found for the total of the bases and alkalies (K_2O, Na_2O, PbO, CaO, MgO).

Before this calculation can be made, it is obviously necessary to know the percentage composition of each constituent of the glaze or body.

Force Required to Move a Weight.

Along a rough chiselled floor, . .	Two-thirds of its weight.
,, ,, using rollers,	One-thirtieth ,,
Along a wooden floor, ...	Three-fifths ,,
,, ,, using rollers, .	One-fortieth ,,

Fire-resisting Materials Defined.

The first schedule of the London Building Acts (Amendment) Act, 1905, contains the list of materials which are considered fire-resisting by the London County Council, and the following extracts are of interest:—

The following materials shall, for the purposes of the Act of 1894, the Act of 1898, and this Act, be deemed to be fire-resisting materials:

I. For general purposes:

1. Brickwork constructed of good bricks well burnt, hard and sound, properly bonded and solidly put together—
   - (*a*) With good mortar compounded of good lime and sharp, clean sand, hard, clean broken brick, broken flint, grit, or slag; or
   - (*b*) With good cement; or
   - (*c*) With cement mixed with sharp, clean sand, hard clean broken brick, broken flint, grit, or slag.
2. Granite and other stone suitable for building purposes by reason of its solidity and durability.
3. Iron, steel and copper.
4. Slate, tiles, brick and terra-cotta, when used for coverings or corbels.
5. Flagstones when used for floors over arches, but such flagstones not to be exposed on the underside, and not supported at the ends only.
6. Concrete composed of broken brick, tile, stone chippings, ballast, pumice or coke breeze, and lime, cement or calcined gypsum.
7. Any combination of concrete and steel or iron.

II. For special purposes:

In the case of floors and roofs—bricks, tiles, terra-cotta or concrete composed as described in paragraph I. 6 of this schedule, not less than 5 inches thick, in combination with iron or steel.

In the case of floors and of the roofs of projecting shops—pugging of concrete composed as described in the said paragraph I. 6, not less than 5 inches thick, between wood joists, provided a fillet 1 inch square is secured to the sides of the joists, and placed so as to be in a central position in the depth of the concrete or concrete blocks, not less than 5 inches thick, laid between wood joists on fire-resisting bearers secured to the sides of joists.

In the case of internal partitions enclosing staircases and passages, terra-cotta, brickwork, concrete or other incombustible material, not less than 3 inches thick.

Specification for Retort Material.

(*Institute of Gas Engineers*, 1911; *revised* 1922.)

Clause 1. *Constituents.*—The retorts or retort tiles shall be made of—

- (*a*) Suitably prepared raw clay and clean burnt clay or 'grog.' 'Grog' which would pass through a test-sieve having 16 meshes to the linear inch is usually undesirable; or
- (*b*) silica or siliceous material; or
- (*c*) aluminous material; or
- (*d*) carborundum or other refractory material; or
- (*e*) suitable mixtures of the above.

Standard sieves (p. 100) to be used.

Clause 2. *Chemical Analysis.*—A complete chemical analysis of the materials is to be provided when required by the engineer (or purchaser), for his personal information only.

Clause 3. *Refractoriness.*—A piece of the material shall show no signs of fusion when heated to a temperature not less than Seger cone 28 (about 1630° C.), the heat being increased at the rate of about 50° C. per 5 minutes, in an oxidizing atmosphere.

The expression 'sign of fusion' shall be interpreted to mean that, with a test-piece ground to the same shape as a Seger cone 1½ inches high by ¾ inch edge of base, the angular edges begin to lose their angularity, or that the piece shows signs of bending, or that the matrix shows signs of running out.

The new scale of Seger cones (printed on p. 332) is to be used.

The material is to be chipped to the form and size of a Seger cone and tested against Standard Seger cones (small size).

Clause 4. *Surfaces and Texture.*—All surfaces shall be reasonably true and free from flaws or winding, and after burning no 'washing' shall be done without the consent of the engineer or (purchaser). The material shall be evenly burned throughout and shall contain no black core. The texture throughout shall be even and regular, containing no holes or flaws, and the 'apparent porosity' shall not be less than 16 per cent. by volume.

Clause 5. *After-Contraction or Expansion.*—Two representative test-pieces each 2½ to 3 inches long by 1½ to 2 inches wide, with their ends ground flat and parallel, after being heated to a temperature of 1410° C. (cone 14) in two hours in an oxidising atmosphere shall not show (as an average of two tests) an after-contraction or expansion of more than 1 per cent., a tolerance of 0·1 per cent. being allowed for experimental error.

The contraction referred to is lineal and is equal to:

$$\frac{\text{change in length} \times 100}{\text{original length of test piece}}.$$

A pyrometer is required to ensure the temperature being maintained within the proper limits.

Clause 6. *Inspection and Testing.*—The engineer (or purchaser), or his agreed representative, shall have access to the works of the maker at any reasonable time, and shall be at liberty to inspect the manufacture at any stage, and to reject any material which does not conform to the terms of this specification. Pieces may be selected for the purpose of testing, either before or after delivery, but, in either case, a representative of the maker shall, if he choose, be present when such selection is made, and shall be supplied with a similar piece of the retort material to that taken for the purpose of testing.

Complaints to be made before the expiration of ten days after delivery.

The engineer (or purchaser) reserves to himself the right, if the material does not conform to the tests laid down in the specification, to reject any or all the material in the consignment from which the test pieces were taken. An arbitration clause may be included.

The cost of these independent tests and of any retort lengths or tiles damaged before delivery for obtaining test pieces shall be equally divided between the purchaser and the maker if the test proves satisfactory, and if unsatisfactory such cost and that for all other subsequent tests required on this account from the same consignment shall be borne by the makers.

The cost of any tests or of any material damaged for the purpose of obtaining test pieces after delivery, shall be borne by the purchaser in the event of the test being satisfactory, and, if unsatisfactory, by the manufacturers, in a similar manner to that specified for the tests prior to delivery.

Specification for Firebricks.

(*Institute of Gas Engineers*, 1911; *revised* 1922.)

For the purpose of classification, it is understood that this specification applies generally to material made from fireclay containing approximately not more than 75 per cent. (or, in a few instances, 80 per cent.) of silica.

Clause I. Refractoriness.—Two grades of material are covered:—

(1) Material which shows no sign of fusion when heated to a temperature of not less than Seger cone 30 (about 1670° C.).

(2) Material which shows no signs of fusion when heated to a temperature of not less than Seger cone 26 (about 1580° C.).

The test shall be carried out in an oxidizing atmosphere, the temperature of the furnace being increased at the rate of about 50° C. per five minutes. (See *Clause* 3 on p. 316.)

A preliminary trial is first made with a piece of the material chipped into the approximate form of a cone. This should be cemented on to a refractory disc or slab with a mixture of alumina and best china clay, together with Seger cones 28, 30, and 32 (small size). These cones are selected because they cover the range of first-grade clays. Best china clay fuses between cones 35 and 36; and all British fireclays bend below this point. If cones 28 and 30 bend, the furnace should be cooled, and the material under investigation examined. If it exhibits no sign of fusion, the trial should be repeated with cones 31, 32, and 33. When cone 32 squats, the piece should be again examined, and if it shows signs of fusion, the trial should be repeated with cones 30, 31, and 32. By this method of approximation, it is possible to decide whether the piece vitrified between cones 30 and 31 or between cones 31 and 32. A similar method should be adopted when testing second-grade material.

It may be noted that clays and related materials have no sharply defined melting point, and the definition of refractoriness here adopted refers to the temperature at which the angular edges of the material under investigation begin to lose their angularity when heated.

Clause 2. *Chemical Analysis.* (See *Clause* 2 on p. 316.)—The silica should be determined by two evaporations with an intervening filtration; and the alumina, lime, and magnesia by two precipitations. The amount of titanic oxide should be indicated, and not confused with alumina and iron. The potash and soda should be separately determined.

Clause 3. *Surfaces and Texture.*—The material shall be evenly burnt throughout, and the texture regular, containing no holes or flaws. All surfaces shall be reasonably true, and free from flaws or winding.

Clause 4. *After-Contraction or Expansion.*—Two test pieces, when heated to a temperature of Seger cone 14 for two hours, and maintained at that temperature for a further two hours, shall not show more than the following linear contraction or expansion:—

No. 1 grade, 0·75 per cent.
No. 2 grade, 1 per cent.

a tolerance of 0·1 per cent. being allowed.

The test-pieces shall be of the size mentioned in Clause 5 on p. 317, and shall be prepared and tested in the same manner.

Clause 5. *Variations from Specified Measurements.*—In the case of ordinary bricks, 9 inches by 4½ inches by 3 inches or 2½ inches thick, there shall not be more than ± 1½ per cent. variation in length, nor more than ± 2½ per cent. variation in width or thickness, and in all cases the bricks shall work out their own bond, with not more than ⅛-inch allowance for joint. In the case of special bricks, blocks, or tiles, there shall not be more than ± 2 per cent. variation from any of the specified dimensions.

Clause 6. *Crushing Strength.*—The material shall be capable of withstanding a crushing strain of not less than 1800 lbs. per square inch, when applied to whole bricks placed with their long side vertical between the jaws of the machine, giving a vertical thrust.

The most important factors requiring attention are:—

(1) The two ends of the brick which come in contact with the jaws of the machine must be either ground or sawn flat and parallel, so as to receive a vertical thrust.

(2) An average of not less than three bricks must be used, because flaws, etc., may give an abnormal result, which might not be detected if only one brick be used.

Clause 7. *Cementing Clay or 'Fireclay Mortar.'*—This shall be machine ground, and, at the discretion of the manufacturer, may contain a suitable percentage of fine grog; but in all cases the cement clay shall be quite suitable for the purpose of binding together the bricks, blocks, or tiles for which it is supplied, and shall be capable of withstanding the same test for refractoriness.

Clause 8. *Marking of Material.*—All bricks, blocks, or tiles shall be distinctly marked by means of a figure 1 or 2 (not less than 1 inch long) stamped on them to indicate the grade to which they belong, and it shall be understood that any material not so marked is ungraded, and is not purchased in accordance with the terms of this specification.

Clause 9. *Inspection and Testing.*—This is identical with Clause 6, p. 317.

For other specifications of firebricks see the author's *Refractory Materials: their Manufacture and Uses* (Griffin).

Specification for Silica Bricks.

(*Institution of Gas Engineers*, 1912; *revised* 1922.)

The material covered by this specification is divided into two classes:—

(1) That containing 92 per cent. and upwards of silica, and hereinafter called 'silica material.'

(2) That containing from 80 to 92 per cent. of silica, and hereinafter called 'siliceous.'

1. *Refractoriness.*[1]—Test pieces of the material shall show no signs of fusion when heated to the following temperatures:—

'Silica' material, not less than Seger cone 32 (about 1710° C.).

'Siliceous' material, not less than Seger cone 29 (about 1650° C.).

The test shall be carried out in an oxidizing atmosphere, the temperature of the furnace being increased at the rate of about 50° C. in five minutes.

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[1] For table of softening temperature of Seger cones, see p. 332.

2. *Chemical Analysis.*—A complete analysis of the material to be provided when required by the engineer (or purchaser) for his personal information only.

3. *Surfaces and Texture.*—The material should be evenly burned throughout, and the texture regular, with no holes or flaws. All surfaces should be reasonably true and free from flaws or winding.

4. *After-Contraction and Expansion.*—Two test-pieces, when heated in an oxidizing atmosphere to a temperature of Seger cone 14 in two hours, and maintained at that temperature for a further two hours, shall not show, on cooling, more than 0·5 per cent. linear contraction or expansion, a tolerance of 0·1 per cent. being allowed. The test-pieces shall be of the size mentioned in Clause 5 (p. 317), and shall be prepared and tested in the same manner.

5. *Variations from Measurements.*—In the case of ordinary bricks, 9 inches by 4½ inches by 3 inches or 2½ inches thick, there shall not be more than ± 1½ per cent. variation in length, nor more than ± 2½ per cent. variation in width or thickness; and in all cases the bricks shall work out their own bond. Special bricks, blocks, or tiles, shall not show more than ± 2 per cent. variation from any of the specified dimensions.

6. *Cement Clay.*—See p. 319.

7. *Inspection and Testing.*—This is identical with Clause 6, p. 317.

Some of the large firms using great quantities of firebricks and other refractory articles have their own specifications, which differ from and are usually more stringent than those given above. There is a danger lest private specifications become unduly restrictive.

For other specifications of silica bricks, see the author's *Refractory Materials: Their Manufacture and Uses* (Griffin).

Standard Specification for Salt-Glazed Drain-Pipes.

(*Published by the British Engineering Standards Association,* 1914.)

The *dimensions* of various parts of drain-pipes are given in detail in the Standard Specification, which can be obtained from Messrs Crosby Lockwood & Son, London, or through any bookseller, price 5s. net.

Two tests are specified:—

(*a*) *Hydraulic Test.*—The pipes when subjected to the hydraulic test at the manufacturer's works must withstand an internal hydraulic test pressure on the barrels of the pipes of 20 lbs. per square inch without showing any signs of injury or leakage. The pressure shall be applied at a rate not exceeding 10 lbs. per square inch in five seconds. Care shall be taken that all air is extracted before the test is commenced.

The purchaser or his representative shall have the right to be present at the application of the tests.

Should the engineer (or purchaser) so desire, 5 per cent. of the pipes ordered may be selected for testing under the hydraulic test at the manufacturer's works.

If four-fifths of the pipes selected for testing comply with the hydraulic test the whole of the pipes represented (other than those which have failed) shall be accepted.

If less than four-fifths of the pipes selected comply with the test, a further 5 per cent. of the whole pipes represented shall be selected and so on, until the total number of pipes which stand the test amounts to four-fifths of the total number of the pipes tested, when the whole of the pipes represented (other than those which have failed) shall be accepted, or failing this, until the whole of the pipes have been tested, when only such as comply with the test shall be accepted.

All pipes marked 'tested' shall have been subjected to and have withstood the hydraulic test specified in (*a*).

(*b*) *Absorption Test.*—The test pieces selected for testing shall be taken from the body of the pipe and not within six inches of either end. Each test shall be of the whole thickness of the pipe, and shall have two glazed surfaces, each having an area of not less than 8 inches super nor not more than 20 inches super. The test pieces shall be dried at a temperature of not less than 150° C. until no further loss in weight can be detected. They shall be immersed in cold water, and the temperature raised to boiling point (100° C.). The water shall be maintained at that temperature for one hour, and after it has been allowed to cool, the test pieces shall be removed, carefully wiped with a dry cloth, and then re-weighed. The percentage increase in weight of each test piece by absorption of water shall not exceed the figures given in the following Table:—

Thickness of pipe.	Percentage increase in weight.
¾-inch and under.	5 per cent.
Over ¾-inch and up to 1-inch.	6 ,,
,, 1-inch ,, ,, 1½-inch.	8 ,,
,, 1½-inch.	10 ,,

Absorption tests shall be carried out at the manufacturer's works by the engineer or the inspector before the pipes are dispatched.

One absorption test may be made from every 100 pipes ordered if the engineer (or the purchaser) so desires.

All the appliances, pipes to be tested, and other facilities are to be provided by the manufacturer at his sole expense.

An official mark has been designed for use on pipes which conform to the specification.

An arbitration clause is included.

Neither of the foregoing specifications are compulsory, but they are being adopted by an increasing number of gas engineers and other users of refractory goods.

For other specifications in regular use, see the author's *Refractory Materials; their Manufacture and Uses* (C. Griffin & Co., Ltd., London).

TABLES RELATING TO MATERIALS.

Common Chemicals and their Formulæ.

Common Name.		Formula.
Alum,	Potassium or ammonium aluminium sulphate,	$K_2SO_4.Al_2(SO_4)_3.24H_2O$ or $(NH_4)_2SO_4.Al_2(SO_4)_3.24H_2O$
Aqua fortis,	Nitric acid,	HNO_3
Aqua regia,	A mixture of nitric and hydrochloric acids.	
Barytes (heavy spar),	Barium sulphate,	$BaSO_4$
Bauxite,	Impure alumina,	$Al_2O_3.2Al_2(OH)_6$
Biotite (mica),	A complex silicate of potassium, magnesium, and iron.	
Blue vitriol,	Cryst. copper sulphate,	$CuSO_4.5H_2O$
Brown coal (lignite),	Contains 55 to 75 per cent. carbon.	
Calcine,	A heated mixture of lead and tin.	
Chalk,	Calcium carbonate,	$CaCO_3$
Chili saltpetre,	Sodium nitrate,	$NaNO_3$
China clay,	(See Kaolin.)	
Colcothar,	Ferric oxide,	Fe_2O_3
Common salt,	Sodium chloride,	$NaCl$
Copperas (green vitriol).	Ferrous sulphate,	$FeSO_4.7H_2O$
Corundum,	Impure alumina,	Al_2O_3
Crocus martis,	An oxide of iron containing some nitrate.	
Dolomite,	Calcic magnesic carbonate,	$CaO.MgO.2CO_2$
Epsom salts,	Magnesium sulphate,	$MgSO_4.7H_2O$
Felspar,	Usually orthoclase; but anorthite, albite, labradorite, oligoclase, and other similarly constituted minerals in which the potassium is in different proportion or is partially or completely replaced by other metals. See Sodalite.	$K_2O.Al_2O_3.6SiO_2$
Flint,	Amorphous silica,	SiO_2
Fluorspar,	Calcium fluoride,	CaF_2
Galena,	Plumbic sulphide,	PbS
Glauber's salt,	Sodium sulphate,	$Na_2SO_4.10H_2O$
Glucose,	Grape sugar,	$C_6H_{12}O_6$
Gypsum,	Calcium sulphate,	$CaSO_4.2H_2O$
Hæmatite,	Impure iron oxide,	Fe_2O_3
Hausmannite,	Impure manganese oxide,	Mn_3O_4
Heavy spar,	Barium sulphate,	$BaSO_4$
Ilmenite (titaniferous iron ore).		$FeO.TiO_2$
Iron pyrites,	Iron sulphide,	FeS_2
Kaolin,	China clay,	$Al_2O_3.2SiO_2.2H_2O$
Kieselguhr,	A highly porous form of silica,	SiO_2
Labradorite,	A felspar,	$(Na_2Ca)O.Al_2O_3.3SiO_2.$
Lignite,	(See Brown coal.)	
Lime,	Calcium oxide,	CaO
Magnesite,	Magnesium carbonate,	$MgCO_3$
Malachite,	Cupric carbonate,	$2CuCO_3.H_2O$
Marble,	Calcium carbonate,	$CaCO_3$
Mennige,	(See Red lead.)	
Oligoclase,	A soda-lime felspar,	$2(Na_2Ca)O.2Al_2O_3.9SiO_2$
Orthoclase,	A potash felspar,	$K_2O.Al_2O_3.6SiO_2$
Plaster of Paris,	Calcium sulphate,	$2CaSO_4.H_2O$
Pyrites (iron),	Iron sulphide,	FeS_2
Pyrolusite,	Manganese dioxide,	MnO_2
Quartz,	Crystalline silica,	SiO_2
Realgar,	Arsenic sulphide,	AsS
Red lead,	Triplumbic tetroxide,	Pb_3O_4

Common Name.		Formula.
Rock crystal,	Quartz,	SiO_2
Rock salt,	Sodium chloride,	$NaCl$
Rutile,	Titanium oxide,	TiO_2
Rust of iron,	Iron oxide (more or less hydrated),	$Fe_2(OH)_6.Fe_2O_3$
Sal ammoniac,	Ammonium chloride,	NH_4Cl
Saltpetre,	Potassium nitrate,	KNO_3
Salt of tartar,	Potassium carbonate,	K_2CO_3
Smaltite,	A cobalt ore,	$CoS_2.CoAs_2$
Sodalite,	A felspar,	$3Na_2O.3Al_2O_3.12SiO_2$
Spinel,	A magnesium aluminate,	$MgO.Al_2O_3$
Spirits of hartshorn,	Ammonia solution.	
Spirits of salt,	Hydrochloric acid.	
Sugar of lead,	Lead acetate,	$Pb(C_2H_3O_2)_2$
Talc (steatite),	A magnesium silicate,	$3MgO.4SiO_2.H_2O$
Tincal,	Impure borax,	$Na_2B_4O_7.10H_2O$
Tin ash,	A heated mixture of tin, and lead more or less completely oxidized.	
Umber,	An earthy mixture rich in iron and manganese oxides.	
Verdigris,	A basic acetate of copper of somewhat varying composition.	
Vinegar,	Is chiefly used for the acetic acid it contains. Coml. acetic acid (pyroligneous acid) is cheaper, and, for most technical purposes, equally suitable.	
Vitriol, Oil of,	Sulphuric acid,	H_2SO_4
Vitriol, Blue,	Copper sulphate,	$CuSO_4.5H_2O$
Vitriol, Green,	Ferrous sulphate,	$FeSO_4.7H_2O$
Vitriol, White,	Zinc sulphate,	$ZnSO_4.7H_2O$
Wad,	Impure manganese oxide.	
Witherite,	Barium carbonate,	$BaCO_3$
Yellow ochre,	Ferruginous, calcareous clay.	
Zinc spar (spathic zinc ore),	Zinc carbonate,	$ZnCO_3$

Formulæ of some Compounds used in Clayworking.

Name.	Formula.	Molecular Weight
Alum (ammonium),	$(NH_4)_2SO_4.Al_2(SO_4)_3.24H_2O$	904
,, (potassium),	$K_2SO_4Al_2(SO_4)_3 24H_2O$	948
Alumina,	Al_2O_3	102
Aluminium sulphate	$Al_2(SO_4)_3 18H_2O$	665
Antimony oxide,	SbO	287
Arsenic oxide,	As_2O_3	198
Barium carbonate,	$BaCO_3$	197
Barium chloride (cryst.),	$BaCl_2 2H_2O$	244
Barium oxide,	BaO	153
Barium sulphate,	$BaSO_4$	233
Bismuth oxide,	Bi_2O_3	468
Borax,	$Na_2B_4O_7 10H_2O$	382
Boric acid,	H_3BO_3	62
Boric oxide,	B_2O_3	70
Calcium carbonate,	$CaCO_3$	100
Calcium oxide (lime),	CaO	56
Calcium phosphate (bone phosphate),	$Ca_3P_2O_8$	310
Calcium sulphate,	$CaSO_4$	136
,, ,, 'gypsum,' ,, ,, 'plaster,'	$CaSO_4 2H_2O$	172
Carbon dioxide,	CO_2	44
Carbon monoxide,	CO	28
Chromium oxide,	Cr_2O_3	153

Name.	Formula.	Molecular Weight.
Chromium sulphate,	$Cr_2(SO_4)_3 18H_2O$	717·7
Chromium tri-oxide,	CrO_3	100·2
Cobalt carbonate,	$CoCO_3$	118·5
Cobaltic chloride,	Co_2Cl_6	329·4
Cobalt nitrate,	$Co(NO_4)_3 6H_2O$	290·1
Cobalt sulphate,	$CoSO_4 7H_2O$	280·1
Copper oxide (black),	CuO	79·5
Copper oxide (red),	Cu_2O	143·0
Copper sulphate (blue vitriol),	$CuSO_4 5H_2O$	249·5
Ferric oxide,	Fe_2O_3	160
Ferrous oxide,	FeO	72
Ferric sulphide (pyrites),	FeS_2	120
Ferrous sulphate (cryst.),	$FeSO_4 7H_2O$	278
Ferrous sulphide,	FeS	88
Ferroso-ferric oxide,	Fe_3O_4	232
Hydrochloric acid (gas),	HCl	36·4
(The liquid hydrochloric acid only contains about 40 per cent. of the gas.)		
Iron compounds—see Ferrous and Ferric.		
Lead carbonate,	$PbCO_3$	266
Lead, basic carbonate (white lead),	$Pb(OH)_2 2PbCO_3$	773
Lead chromate,	$PbCrO_4$	323
Lead oxide (litharge),	PbO	222·4
Lead, red,	Pb_3O_4	685
Lead sulphate,	$PbSO_4$	302
Lead sulphide,	PbS	238·4
Magnesium carbonate,	$MgCO_3$	84
Magnesium oxide (magnesia),	MgO	40
Manganese carbonate,	$MnCO_3$	115
Manganese oxide (braunite),	Mn_2O_3	158
Manganous oxide,	MnO	71
Tri-manganic tetroxide,	Mn_3O_4	229
Manganese dioxide (pyrolusite).	MnO_2	87
Mennige (see Red lead).		
Nickel oxide,	NiO	75
Nickel sulphate,	$NiSO_4 7H_2O$	280·8
Nitric acid,	HNO_3	63
Potassium alum,	$K_2SO_4 Al_2(SO_4)_3 24H_2O$	948
Potassium antimonate,	$KSbO_3$	206·5
Potassium bichromate,	$K_2Cr_2O_7$	295
Potassium carbonate,	K_2CO_3	138
Potassium carbonate (cryst).	$K_2CO_3 2H_2O$	174
Potassium chrome alum,	$K_2SO_4 Cr_2(SO_4)_3 24H_2O$	999
Potassium iron alum,	$K_2SO_4 Fe_2(SO_4)_3 24H_2O$	1006·5
Potassium hydrate,	KHO	56
Potassium nitrate (nitre),	KNO_3	101
Potassium oxide ('potash'),	K_2O	94
Potassium sulphate,	K_2SO_4	174
Silica,	SiO_2	60
Sodium bicarbonate,	$NaHCO_3$	84
Sodium carbonate ('soda ash')	Na_2CO_3	106
Sodium carbonate (washing soda cryst.)	$Na_2CO_3 10H_2O$	286
Sodium chloride (salt),	$NaCl$	58·5
Sodium hydrate,	$NaHO$	40
Sodium nitrate,	$NaNO_3$	85
Sodium oxide ('soda'),	Na_2O	62
Sodium silicate (water glass),	$Na_2Si_4O_2$ (approx.)	302
Sulphuric acid,	H_2SO_4	98
Tin oxide,	SnO_2	150
Titanium oxide,	TiO_2	80
Uranium oxide,	UO_2	272
Zinc oxide,	ZnO	81

Molecular Weights arranged in Alphabetical Order of the Symbols of the Elements most important to Clayworkers.

Al_2O_3	102	CoO	74·5	$Na_2CO_3.10H_2O$	286
$Al_2O_3.2SiO_2.2H_2O$	258	Cr_2O_3	153	$NaCl$	58·5
$Al_2O_3.2SiO_2$	222	CuO	79·5	$NaNO_3$	85
$Al_2(SO_4)_3.18H_2O$	665	$CuSO_4.5H_2O$	249·5	$Na_2B_4O_7$	202
As_2O_3	198	Fe_2O_3	160	$Na_2B_4O_7.10H_2O$	382
BH_3O_3	62	FeO	72	$Na_2SO_4.10H_2O$	322
B_2O_3	70	$FeSO_4.7H_2O$	278	$Na_2O.Al_2O_3.6SiO_2$	524
$BaCO_3$	197	K_2O	94	NiO	75
$BaCl_2.2H_2O$	244	K_2CO_3	138	$NiSO_4.7H_2O$	280·8
$Ba(OH)_2.8H_2O$	315	$K_2CO_3.2H_2O$	174	PbO	222
BaO	153	KNO_3	101	Pb_3O_4	685
$BaSO_4$	233	K_2SO_4	174	PbS	238
CO	28	$K_2Cr_2O_7$	295	$PbCO_3$	266
CO_2	44	$K_2O.Al_2O_3.6SiO_2$	556	$2PbCO_3.PbH_2O_2$	775
$CaCO_3$	100	MgO	40	Sb_2O_3	287
CaF_2	78	$MgCO_3$	84	SiO_2	60
CaH_2O_2	74	$MgSO_4.7H_2O$	246	SnO_2	150
CaO	56	MnO_2	87	$SrCO_3$	147·5
$CaSO_4$	136	Na_2O	62	UO_2	272
$CaSO_4.2H_2O$	172	Na_2CO_3	106	ZnO	81

Table of Atomic Weights of the Chief Elements.

Name.	Atomic Weight.	Name.	Atomic Weight.
Aluminium,	27·1	Molybdenum	96·0
Antimony,	121·8	Nickel,	58·6
Argon,	39·9	Niobium,	93·5
Arsenic,	74·9	Nitrogen,	14·01
Barium,	137·4	Osmium,	190·9
Beryllium,	9·0	Oxygen,	15·96
Bismuth,	210·0	Palladium,	106·7
Boron,	10·8	Phosphorus,	31·0
Bromine,	79·9	Platinum,	195·2
Cadmium,	112·4	Potassium,	39·11
Cæsium,	132·8	Rhodium,	102·9
Calcium,	40·0	Rubidium,	85·5
Carbon,	11·97	Ruthenium,	101·7
Chlorine,	35·46	Selenium,	79·2
Cerium,	140·2	Silicon,	28·3
Chromium,	52·0	Silver,	107·88
Cobalt,	58·9	Sodium,	23·0
Copper,	63·6	Strontium,	87·6
Erbium,	167·7	Sulphur,	32·07
Fluorine,	19·0	Tantalum,	181·5
Gold,	197·2	Tellurium,	127·5
Hydrogen,	1	Thallium,	204·4
Indium,	114·8	Thorium,	231·5
Iodine,	126·93	Tin,	118·7
Iridium,	193·1	Titanium,	48·1
Iron,	55·9	Tungsten,	184·0
Lanthanum,	139·0	Uranium,	238·2
Lead,	207·2	Vanadium,	51·0
Lithium,	6·94	Yttrium,	88·7
Magnesium,	24·3	Zinc,	65·4
Manganese,	54·9	Zirconium,	90·6
Mercury,	200·6		

Table giving the Weight of 1 Cubic Foot of Various Materials.

	Lbs.
Water,	62
Clay (before digging), rough average,	125
Clay (after digging), ,,	72
Sand (before digging), ,,	119
Sand (after digging), ,,	87–110
Burned bricks (closely piled),	112
Broken bricks (roughly crushed),	150
Coal (unscreened),	45
Coal (slack),	50
Chalk,	85
Portland cement (loose),	85–100
Concrete (varies with the stone used),	110–137
Plaster or stucco (in use),	61
Slate,	168
Glass,	165
Marble or granite,	168
Fir or pine wood,	37–40
Beech or oak wood,	43–50
Cast iron,	380–470
Cast steel,	440–492
Lead,	695
Copper,	550
Zinc,	450
Aluminium,	160
Air,	0·077

When other substances than water are measured, the weight will vary with the specific gravity of the material.

Volume × Sp. Gr. = Wt. (for Metric measure).

Volume (in pints) × Sp. Gr. = Wt. (in lbs.) × 0·8 (for British measures).

Specific Gravity of Various Substances.

Material.	Sp. Gr.	Material.	Sp. Gr.
Cement,	2·7–3·5	Mica,	2·7–3·2
Chalk,	1·8–2·7	Pitch,	1·1
Coal,	1·37	Quartz,	2·5
Coke,	1·5	Salt,	2·1
Clay,	1·8–2·7	Sandstone,	2·2–2·4
Glass,	2·5–3·3	Sand,	1·9
Granite,	2·7	Tiles and bricks,	1·5–2·0
Hæmatite ore,	5·0	Wax,	0·97
Marble,	2·7	Wood,	0·47–0·85.

Water = 1.

Standard Sizes of Bricks in different Countries.

In many countries there is no official standard; when such is the case, the average size is given.

Country.	Length, inches.	Breadth, inches.	Thickness, inches.
Great Britain,	9	$4\frac{3}{8}$	$2\frac{5}{8}$
Germany,	10	$4\frac{3}{4}$	$2\frac{5}{8}$
Austria,	$11\frac{5}{8}$	$5\frac{5}{8}$	$2\frac{5}{8}$
France,	$8\frac{3}{4}$	$4\frac{3}{8}$	$2\frac{3}{8}$
Italy,	9	$5\frac{1}{2}$	$2\frac{3}{8}$
Holland and Belgium,	$9\frac{5}{8}$	$4\frac{3}{4}$	$2\frac{3}{8}$
Switzerland,	10	$4\frac{3}{4}$	$2\frac{3}{8}$
Russia (varies greatly),	$11\frac{1}{2}$	$5\frac{1}{8}$	$2\frac{3}{4}$
United States,	8	4	$2\frac{3}{8}$

The Royal Institute of British Architects standard size lies between—length, $8\frac{7}{8}$ in. and 9 in.; breadth, $4\frac{5}{16}$ in. and $4\frac{3}{8}$ in.; thickness, $2\frac{5}{8}$ in. and $2\frac{11}{16}$ in.

The method of measuring the bricks as set out in the standard is as follows:—

(1) The length of the brick should be double the width *plus* the thickness of one vertical joint.

(2) Brickwork should measure four courses of bricks and four joints to a foot.

Joints should be $\frac{1}{4}$ in. thick, and an extra $\frac{1}{16}$th, making $\frac{5}{16}$th, for the bed joints to cover irregularities in the bricks. This gives a standard length of $9\frac{1}{4}$ in. centre to centre of joints.

The bricks, laid dry, to be measured in the following manner:—

A. Eight stretchers laid square end and splay end in contact in a straight line to measure 72 in.

B. Eight headers laid side to side, frog upwards, in a straight line to measure 35 in.

C. Eight bricks, the first brick frog downwards and then alternately frog to frog and back to back, to measure $21\frac{1}{2}$ in.

A margin of 1 in. less will be allowed as to A and $\frac{1}{2}$ in. less as to B and C.

The standard has been agreed upon between the Royal Institute and the Institute of Clayworkers, and has been drafted in consultation with these bodies and with representatives of the Institution of Civil Engineers.

It was ordered to come into force on 1st May 1904.

The council recommend that members should insert this standard in their specifications under the title of "The R.I.B.A. Standard Size of Bricks."

Composition of Various Fuels.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Coal—						
Lancs.,	79½	5	9	1½	1	4
Newcastle,	83	5	5	2	1	4
Yorkshire, Derbyshire,	80	5	10	1	1	3
Welsh,	85	5	3	1	2	4
Scotch,	78	7	9	1	1	4
Anthracite,	90	2	4	¼	¾	3
Coke,	94	...	...	...	1	5
Dry wood,	50	6	41	1	...	2
Dried peat,	59	6	30	1	...	4
Petroleum,	85	13	2	...	...	...

The above figures are the average of a large number of analyses, but individual samples of any of the fuels may vary greatly from the typical ones quoted; thus, peat may have as much as 30 per cent. of ash, and coal, if small ('slack'), may often be obtained with 10 to 15 per cent. of ash.

Coal Ash varies somewhat in composition according to the seam from which it is obtained, but the following is a fair average:—

Silica,	43 per cent.	Magnesia,	2 per cent.
Alumina,	26 ,,	Alkalies,	1 ,,
Iron oxide,	15 ,,	Sulphuric acid,	5 ,,
Lime,	7 ,,	Phosphoric acid,	1 ,,

Approximate Composition of Various Gases.

	Carbon dioxide.	Oxygen.	Carbon monoxide.	Hydrogen.	Methane.	Nitrogen.
Coal gas,	2	...	15	43	31	2
Producer gas,	5	...	25	12	2	56
Air,	...	21	...	...	...	79

TABLES RELATING TO HEAT.

Conversion of Degrees Fahrenheit into Degrees Centigrade.

In order to calculate the temperature on one of these scales into the corresponding temperature on the other, it is well to remember that

Temperature of melting ice = 0° C. and 32° F.
Temperature of boiling water = 100° C. and 212° F.

Hence

Deg. Cent. = deg. Fah. − 32, divided by 9 and multiplied by 5.
Deg. Fah. = deg. Cent., multiplied by 9 and divided by 5, and 32 added to the result.

Thus, 15½° C. = 60° F., because

Deg. Cent. = 60 − 32 = 28, which divided by 9 = $3\frac{1}{9}$, and this multiplied by 5 = $15\frac{5}{9}$, or 15½° C.
Deg. Fah. = 15½ × 9 = 139½, which divided by 5 = 28 (nearly), to which add 32, giving 60° F.

For most purposes, the Centigrade scale is much more convenient than that of Fahrenheit, and it is, in consequence, more generally used for accurate measurements of temperature.

A third scale, devised by Réaumur, is sometimes used for domestic purposes in Germany, but it is of no value to British clayworkers. Its degrees are exactly 1¼ the value of those on the Centigrade scale.

Melting and Boiling Points.

For Calibrating Pyrometers.

Substance.	Melting Point. °C.	Boiling Point. °C.
Water, ...	0	100
Lead, ...	327	...
Mercury, ...	−40	350
Sulphur, ...	115	445
Tin-copper alloy (Sn_4Cu), .	735	...
Zinc, ...	419	940
Copper, ...	1054	...

(See also p. 303.)

Coefficient of Linear Expansion per Deg. Fahr.

Substance.	*n.*
Brick, ...	0·0000035
Cast iron, ...	0·0000059
Concrete, ...	0·0000075
Glass, ...	0·0000047
Graphite, ...	0·0000044
Oak, ...	0·0000300
Porcelain, ...	0·0000020
Sandstone, ...	0·0000061
Steel medium, ...	0·0000067

Temperature and Pressure of Saturated Steam.

$h + L = H_s =$ Total Heat.

Absolute Press. in lb. per sq. in *	Temp. in deg. F.	Sensible Heat from 32° F. (B.Th.U.) *h*	Latent Heat (B.Th.U.) *L*	Specific Volume in cub. ft. per lb.
1	101·7	69·5	1032·9	333·1
2	126·1	93·9	1019·7	173·5
3	141·5	109·3	1011·3	118·6
4	153·0	120·8	1004·9	90·54
5	162·3	130·0	999·8	73·44
6	170·1	137·9	995·3	61·91
7	176·9	144·7	991·4	53·59
8	182·9	150·8	987·8	47·30
9	188·3	156·3	984·6	42·36
10	193·2	161·1	981·9	38·39
14·689	212	180·0	970·7	26·79
15	213·0	181·0	970·2	26·27
20	228·0	196·1	961·0	20·08
25	240·1	208·4	953·3	16·29
30	250·3	218·8	946·8	13·74
35	259·2	227·9	940·9	11·90
40	267·2	235·9	935·8	10·50
45	274·4	243·3	930·9	9·41
50	280·9	250·0	926·5	8·520
55	287·0	256·2	922·3	7·845
60	292·6	262·0	918·4	7·184
65	297·8	267·4	914·7	6·666
70	302·8	272·5	911·2	6·218
75	307·5	277·2	908·8	5·829
80	311·9	281·9	904·7	5·487
85	316·1	286·2	901·6	5·184
90	320·2	290 4	898·7	4·913
95	324·0	294·4	895·7	4·670
100	327·7	298·3	893·0	4·451
105	331·2	302·0	890·3	4·251
110	334·7	305·6	887·7	4·070
115	338·0	309·0	885·2	3·903
120	341·1	312·3	882·8	3·751
125	344·2	315·6	880·3	3·609
130	347·2	318·7	878·0	3·479
140	353·0	324·8	873·4	3·245
150	358·4	330·5	869·2	3·041
160	363·5	335·9	865·1	2·862
170	368·4	341·1	861·1	2·703
180	373·0	346·1	857·3	2·562
190	377·5	350·9	853·5	2·435
200	381·8	355·5	849·9	2·320
225	391·9	366·3	841·4	2·076
250	401·2	376·3	833·4	1·880
275	409·8	385·6	825·9	1·718
* 300	417·8	394·4	818·7	1·583

* To find the corresponding Gauge Pressure deduct 14·7 lbs. per sq. in.

Total Heat of Superheated Steam.

At a Pressure of 14·7 lbs. per sq. in.

Temperature of Steam.	Total Heat.	Temperature of Steam.	Total Heat.	Temperature of Steam.	Total Heat.
Deg. Fahr.	B.Th.U. per pound.	Deg. Fahr.	B.Th.U. per pound.	Deg. Fahr.	B.Th.U. per pound.
212	1146	370	1219	530	1293
220	1150	380	1223	540	1298
230	1154	390	1228	550	1303
240	1159	400	1232	560	1308
250	1163	410	1237	570	1312
260	1168	420	1242	580	1317
270	1172	430	1246	590	1322
280	1177	440	1251	600	1327
290	1182	450	1256	610	1331
300	1186	460	1261	620	1336
310	1191	470	1265	630	1341
320	1195	480	1270	640	1346
330	1200	490	1275	650	1351
340	1205	500	1279	660	1355
350	1209	510	1284	670	1360
360	1214	520	1289	680	1365

Table of Maximum Flame Temperatures.

The following table of maximum flame temperatures shows the difficulty which exists in the measurement of the highest extent to which clay can be heated. The first part of the table is due to Professor Smithels (whose work on Flames is so well known), and the second part was published by Professor Féry in 1904.

It must be understood that these temperatures cannot be obtained on a commercial scale from the flames mentioned. They are the temperatures at the hottest points in the flames, not that of the flame as a whole.

MAXIMUM TEMPERATURE IN FLAME OF BUNSEN BURNER USING COAL GAS.

Date.		°C.
1860.	Bunsen and Kirchhoff,	1350
1877.	Rosetti,	1360
1892.	Rogers,	1230
1892.	Lewes,	1630
1895.	M'Crae,	1725
1896.	Waggener,	1770
1899.	Berkenbusch,	1830
1902.	White and Traver,	1780
1905.	Féry,	1871

MAXIMUM FLAME TEMPERATURES (FÉRY, 1904).

	°C.	°F.
Bunsen burner, gas fully aërated,	1871	3400
Bunsen burner, insufficient air,	1712	3114
Acetylene flame,	2548	4618
Alcohol flame,	1705	3101
Denayrouze bunsen, alcohol and air,	1862	3384
Denayrouse bunsen, half each alcohol and petroleum spirit,	2053	3727
Hydrogen, free flame and air,	1900	3452
Oxy-coal gas blowpipe flame,	2200	3992
Oxy-hydrogen blowpipe flame,	2000	3632

Calorific Power of Various Fuels.

	Approximate Total Heat of Combustion of 1 lb. of Fuel.	Equivalent Evaporation of Water from and at 212°F. per lb. of Fuel.	Air chemically consumed per lb. of Fuel.	
	B. Th. Units.	lbs.	lbs.	Cubic Feet. @ 62° F.
Coal (average),	13,000	15¼	11	140
Coke,	12,500	14	11	142
Wood (dried),	11,000	11	4½	60
Wood (20 per cent. water),	6,500	6½	4	53
Peat (dried),	12,000	12	7½	100
Petroleum oils,	27,000	28	15	200

The figures given in the last two columns for the amount of air required are the minimum, and in practice twice or more times these amounts must be employed. Thus, ordinary coal usually needs 18 to 25 lbs. of air per lb. of coal in actual practice.

For a method of determining the calorific power of a fuel, see p. 236.

Seger Cones and Thermometer Scales.

The comparison of Seger cones and temperatures given below is that now recognized by the manufacturers. It differs from the original table of comparisons published by Seger, some of the figures in which were found, on further investigations made in Germany, to be erroneous. Some of the cones in the original list are no longer manufactured.

As Seger cones are 'heat-measurers' rather than 'thermometers,' it is not strictly correct to translate the numbers of the cones into 'degrees,' and it is far better to record simply the number of the cone which indicates the particular temperature to be recorded.

Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.
022	600	1112	07*a*	960	1760	9	1280	2336	29	1650	3002
021	650	1202	06*a*	980	1796	10	1300	2372	30	1670	3038
020	670	1238	05*a*	1000	1832	11	1320	2408	31	1690	3074
019	690	1274	04*a*	1020	1868	12	1350	2462	32	1710	3110
018	710	1310	03*a*	1040	1904	13	1380	2516	33	1730	3146
017	730	1346	02*a*	1060	1940	14	1410	2570	34	1750	3182
016	750	1382	01*a*	1080	1976	15	1435	2615	35	1770	3218
015*a*	790	1454	1*a*	1100	2012	16	1460	2660	36	1790	3254
014*a*	815	1499	2*a*	1120	2048	17	1480	2696	37	1825	3317
013*a*	835	1535	3*a*	1140	2084	18	1500	2732	38	1850	3362
012*a*	855	1571	4*a*	1160	2120	19	1520	2768	39	1880	3416
011*a*	880	1616	5*a*	1180	2156	20	1530	2786	40	1920	3488
010*a*	900	1652	6*a*	1200	2192	26	1580	2876	41	1960	3560
09*a*	920	1688	7	1230	2246	27	1610	2930	42	2000	3632
08*a*	940	1724	8	1250	2282	28	1630	2966	...	...	...

It will be noted that there are some gaps in the serial numbers. These are due to the cones bearing the missing numbers being irregular in action.

The figures in this table do not apply to cones made elsewhere than at the Seger-Cramer Laboratory.

Seger Cones and Holdcroft Thermoscopes suitable for Various Classes of Goods.

The following particulars are taken from lists published by Messrs. Seger & Cramer, Holdcroft & Co., etc., and are useful for those who wish to fire a class of goods to which they are unaccustomed or to those who have not previously used Seger cones. It will be understood that the figures are only approximate:—

	Seger Cones.	Thermoscopes.
Glass colours,	022 –021	...
Porcelain colours and lustres,	022 –010*a*	...
Easy enamel kiln,	020 –018	1–4
Medium ,,	017 –016	4–8
Hard ,,	016 –015*a*	8–12
Calcareous bricks and tiles,	015*a*– 01*a*	20–24
Majolica kiln,	010*a*– 05*a*	15–20
White stoneware (soft glaze),	09*a*– 03*a*	13–20
Easy earthenware glost oven,	03*a*– 1*a*	20–22
Hard ,, ,,	2*a*– 3*a*	22–24
Bricks and tiles of clay free from lime and iron,	1*a*– 10	20–24
Clinker, footplates, and similar goods,	1*a*– 14	20–32
White stoneware (hard glaze),	1*a*– 10	23–29
Easy earthenware biscuit oven,	4*a*– 5*a*	24–26
Hard earthenware biscuit and vitreous tiles,	5*a*– 6*a*	26–28
Stoneware and salt glaze,	5*a*– 10	25–30
Glazed bricks,	6*a*– 9	...
Stoneware,	7 – 11	24–30
China biscuit oven,	9 – 10	28–32
Staffordshire blue bricks,	10 – 14	24–28
Fireclay, cement, and porcelain,	10 – 20	25–30
Hard porcelain glaze,	13 – 16	30–40
Silica bricks and steel and water-gas industries,	18 – 26	...
Testing the refractoriness of clays,	26 – 39	...

The approximate temperatures corresponding to these cones and thermoscopes will be found on p. 332 and p. 334 respectively. The thermoscopes and cones recommended above for any particular purpose do not always correspond to the same temperature.

Wedgwood's Pyrometer, Seger's Cones, Colour Scale, and Degrees Cent.

Wedgwood Pyrometer.	Seger Cones.	Deg. Cent. (approx.).	Colours corresponding to Temperature (Pouillet, etc.).
0	022	580	Earliest visible red.
1	021	650	
2	018	710	Dull red.
3	015*a*	800	
4	012*a*	865	Red.
5	08*a*	940	Cherry red.
6	05*a*	1000	
7	01*a*	1080	Orange.
8	4*a*	1155	
9	7	1230	Bright orange or yellow.
10	10	1300	White.
11	12-13	1370	Steel melts about 1350° C.
12	15-16	1445	
13	19	1515	Dazzling white.
14	26-27	1590	Welding heat about 1540° C.
15	30	1670	
16	33	1735	
17	36-37	1810	
18	39	1880	
19	41	1950	Highest Seger cone (No. 42) = 2000° C.
20	...	2020	
21 to 30	...	...	These temperatures have never been accurately ascertained, though the original pyrometer of Wedgwood was arranged to indicate them.

It must be remembered in using the above table that the figures given are at the best but rough approximations, as, when working on a large scale, temperature is of less influence in causing the contraction of clay than the duration of exposure to heat. This latter property of clay is of more importance to the potter and clayworker, so that Wedgwood's pyrometer is of considerable use, although its indications may not be translatable into actual degrees on Fahrenheit's or the Centigrade scale.

Holdcroft's Thermoscopes.

Bar No.	Degrees Centigrade.	Bar No.	Degrees Centigrade.	Bar No.	Degrees Centigrade.	Bar No.	Degrees Centigrade.
1	600	11	890	22	1080	31	1350
2	650	12	905	23	1100	32	1380
3	670	13	920	24	1120	33	1430
4	700	14	935	25	1140	34	1460
5	730	15	950	26	1200	35	1475
6	760	16	960	26*a*	1230	36	1490
7	790	17	970	27	1250	37	1505
7*a*	810	18	985	27*a*	1270	38	1520
8	840	19	1000	28	1280	39	1535
9	860	20	1040	29	1300	40	1550
10	875	21	1060	30	1325		

Melting Points of Various Substances.

The following list of melting points is often useful for lower temperatures than are indicated by cones, and in situations where a thermometer cannot be conveniently employed.

		°C.
Beeswax (yellow), ...	melts at	65
An alloy containing 3 parts of tin, 5 parts of lead, 8 parts of bismuth,	,,	100
Sulphnr (though difficult to see), ...	,,	115
An alloy containing 8 parts of tin, 1 part of bismuth, ...	,,	200
An alloy containing 1 part of tin, 3 parts of lead, ...	,,	250
Zinc, ...	,,	419
Silver, ...	,,	1000

(See also p. 303.)

Various other alloys of tin, lead, and bismuth melt at temperatures varying from 93° to 295° C., but owing to the ease with which they become oxidised their indications are not really reliable. The 'Sentinel' pyrometers, which are of this nature, are, however, relatively free from this defect, as they are coated with a waxy material which protects them until a short time before they melt.

TABLES RELATING TO MACHINERY, ETC.

Strength of Chains for Slings, Cranes, and Haulage.

Diam. of Chain.	Working Strain.		Weight per Yard.	Diam. of Chain.	Working Strain.		Weight per Yard.
Inch.	Tons.	Cwts.	lbs.	Inches.	Tons.	Cwts.	lbs.
$\frac{3}{16}$	0	5	1¼	1⅛	7	18	40
¼	0	8	2	1¼	9	0	50
$\frac{5}{16}$	0	13	3¼	1½	11	0	60
⅜	1	0	5	1⅝	15	6	70
½	1	8	7	1¾	18	10	82
⅝	2	5	10¼	1⅞	21	4	95
¾	3	5	16	2	24	2	112
⅞	5	0	29	$2\frac{1}{16}$	27	2	120
1	6	8	30				

The above table is obtained from actual tests, allowing an ample factor for safety. For intermediate sizes, it is usually sufficient to consider the safe working strain as one-tenth of the square of the diameter of the chain, when the diameter is measured in eighths of an inch. Thus, for a chain of 1 in. diam. ($=\frac{8}{8}$) one-tenth of the square of $8 = 6{\cdot}4$ tons $=$ 6 tons 8 cwts.

Size of Ropes and Tackle for Lifting.

This table gives particulars of pulley blocks used in lifting weights up to just over 4 tons.

	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.
Diameter of sheave in inches, ...	3	3½	4	4½	5	6
Circumference of rope in inches, ...	1	1¼	2	2½	3	4
Average strain on rope in cwts. for full load, .	1	2¼	3¾	6	8½	15
Number of men required for full load, . .	1	3	6	10	crab	crab
Maximum power in cwts.:						
2 and 1 sheave, ...	2¼	4⅓	9	..	..	..
2 ,, 2 sheaves, ...	3	7	12	..	..	..
3 ,, 2 ,, ...	..	8¾	15	25	35	60
3 ,, 3 ,, ...	..	10½	17½	30	42	72
4 ,, 3 ,, ...	..	..	20	30	49	84

Strength of Common Ropes.—Multiply the square of the diameter by 8 and divide the product by 10; this will give the maximum safe working load in tons; thus, with a rope $\frac{3}{4}$ in. diam. the safe working load is $\frac{3}{4} \times \frac{3}{4} \times \frac{8}{10} = 9$ cwts.

Comparative Strengths of Ropes and Chains.

For lifting one ton the following sizes would be required:—

Best patent plough steel rope, ...	$\frac{1}{2}$ in. diam.
Steel (weldless) chain, ...	$\frac{5}{16}$,,
Iron chain, ...	$\frac{7}{16}$,,
Steel eye bolt, ...	1 ,,
Whitworth screwed bolt, ...	1 ,,
Wet hemp rope (single), ...	$1\frac{1}{2}$,,

Factor of safety 6, if load gradually applied.

Strength of Wire Ropes for Hoisting, Hauling, Etc.

Circumference.	Diameter Approximate.	Weight per 100 Feet (Approximate.)	Actual Breaking Stress.			
			Best Patent Steel.	Special Improved Patent Steel.	Best Plough Steel.	Special Improved Plough Steel.
Ins.	Ins.	Lbs.	Tons.	Tons.	Tons.	Tons.
$1\frac{1}{4}$	$\frac{13}{32}$	27	4·5	4·9	5·4	6·0
$1\frac{1}{2}$	$\frac{1}{2}$	40	6·5	7·1	7·9	8·6
$1\frac{3}{4}$	$\frac{9}{16}$	54	8·7	9·8	10·8	11·9
2	$\frac{5}{8}$	72	11·5	12·8	14·2	15·6
$2\frac{1}{4}$	$\frac{11}{16}$	87	14·2	16·9	17·6	19·3
$2\frac{1}{2}$	$\frac{13}{16}$	107	17·7	19·8	21·8	23·9
$2\frac{3}{4}$	$\frac{7}{8}$	132	21·9	24·5	27·1	29·6
3	$\frac{15}{16}$	154	25·6	28·7	31·7	34·7
$3\frac{1}{4}$	$1\frac{1}{32}$	184	30·2	33·7	37·3	41·2
$3\frac{1}{2}$	$1\frac{1}{8}$	217	35·1	39·2	43·3	47·5
$3\frac{3}{4}$	$1\frac{3}{16}$	247	40·4	45·1	49·9	54·6
4	$1\frac{1}{4}$	275	45·4	50·7	56·0	61·4
$4\frac{1}{4}$	$1\frac{3}{8}$	308	51·4	57·5	63·5	69·5
$4\frac{1}{2}$	$1\frac{7}{16}$	350	57·8	64·5	71·3	78·1
$4\frac{3}{4}$	$1\frac{1}{2}$	392	64·4	72·0	79·6	87·2
5	$1\frac{3}{4}$	420	70·7	79·0	87·4	97·7

Strength of Rolled Steel Joists or Girders.—Joists made of steel by the Siemens-Martin open hearth acid process, and rolled to a uniform I section, are cheap, convenient, and readily obtainable.

A safe load for such a joist may be found from the following formula :—

$$W = 0{\cdot}7(w - 0{\cdot}3BH)\frac{H}{L},$$

where W = safe distributed load (tons),
w = weight of joist per lineal foot (pounds),
B = breadth of flange (inches),
H = total depth of joist (inches),
L = clear span (feet).

Horse-Power of Cotton Driving Ropes.

(*C. N. Pickworth.*)

Velocity in feet per minute.	DIAMETER OF ROPES IN INCHES.									
	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	2
2000	5·1	7·0	9·1	11·0	14·2	17·3	20·5	24·1	28·0	36·5
2100	5·3	7·3	9·5	12·1	14·9	18·0	21·4	25·1	29·2	38·1
2200	5·6	7·6	9·9	12·6	15·5	18·8	22·3	26·2	30·4	39·7
2300	5·8	7·9	10·2	13·0	16·1	19·4	23·1	27·1	31·5	41·1
2400	6·0	8·1	10·6	13·4	16·6	20·1	23·9	28·1	32·6	42·5
2500	6·2	8·4	11·0	13·9	17·2	20·8	24·7	29·0	33·7	44·0
2600	6·4	8·7	11·3	14·4	17·8	21·5	25·5	30·0	34·8	45·4
2700	6·6	8·9	11·7	14·8	18·3	22·1	26·3	30·9	35·9	46·8
2800	6·8	9·2	12·0	15·2	18·8	22·8	27·1	31·8	36·8	48·1
2900	6·9	9·4	12·3	15·6	19·3	23·3	27·8	32·5	37·8	49·3
3000	7·1	9·6	12·6	16·0	19·8	23·9	28·4	33·3	38·7	50·4
3100	7·3	9·9	12·9	16·3	20·2	24·4	29·0	34·1	39·6	51·6
3200	7·4	10·1	13·1	16·6	20·6	24·9	29·6	34·8	40·4	52·7
3300	7·6	10·3	13·4	17·0	21·0	25·4	30·2	35·4	41·2	53·8
3400	7·7	10·6	13·7	17·3	21·5	26·0	30·8	36·2	42·0	54·6
3500	7·8	10·7	13·9	17·6	21·8	26·4	31·4	36·8	42·8	55·8
3600	8·0	10·8	14·1	17·9	22·1	26·8	31·8	37·4	43·3	56·5
3700	8·1	11·0	14·3	18·2	22·4	27·1	32·3	37·9	44·0	57·3
3800	8·2	11·1	14·5	18·4	22·7	27·5	32·7	38·4	44·5	58·2
3900	8·3	11·3	14·7	18·5	23·0	27·8	33·1	38·8	45·0	58·8
4000	8·4	11·4	14·8	18·7	23·2	28·1	33·4	39·2	45·5	59·4
4100	8·4	11·5	15·0	19·0	23·5	28·4	33·7	39·6	46·0	60·0
4200	8·5	11·5	15·1	19·1	23·7	28·6	34·0	39·9	46·3	60·4
4300	8·6	11·6	15·2	19·2	23·8	28·8	34·2	40·2	46·6	60·8
4400	8·6	11·7	15·3	19·3	23·9	28·9	34·4	40·4	46·8	61·2
4500	8·7	11·7	15·3	19·4	24·0	29·0	34·5	40·5	47·0	61·4
4600	8·7	11·8	15·4	19·4	24·1	29·1	34·6	40·6	47·1	61·5
4700	8·7	11·8	15·4	19·5	24·1	29·2	34·7	40·7	47·2	61·6
4800	8·7	11·8	15·4	19·5	24·2	29·2	34·7	40·8	47·3	61·7
4900	8·7	11·8	15·4	19·5	24·1	29·2	34·7	40·7	47·2	61·6
5000	8·7	11·8	15·4	19·4	24·1	29·1	34·6	40·6	47·1	61·5
5100	8·7	11·7	15·3	19·4	24·0	28·9	34·5	40·5	47·0	61·2
5200	8·6	11·7	15·2	19·3	23·9	28·8	34·3	40·2	46·7	61·0
5300	8·5	11·6	15·1	19·2	23·7	28·7	34·1	40·0	46·4	60·6
5400	8·5	11·5	15·0	19·0	23·5	28·4	33·8	39·6	46·0	60·0
5500	8·4	11·4	14·8	18·8	23·2	28·1	33·4	39·2	45·5	59·4
5600	8·3	11·2	14·7	18·6	23·1	27·8	33·1	38·8	45·2	58·8
5700	8·2	11·1	14·4	18·3	22·6	27·3	32·5	38·1	44·3	57·8
5800	8·1	10·9	14·2	18·0	22·3	27·0	32·1	37·6	43·7	57·1
5900	7·9	10·7	14·0	17·8	22·0	26·6	31·6	37·0	43·0	56·2
6000	7·7	10·6	13·9	17·6	21·7	26·3	31·2	36·7	42·5	55·5
6500	6·8	9·2	12·0	15·2	18·8	22·8	27·1	31·8	36·9	48·1
7000	5·4	7·4	9·6	12·2	15·0	18·2	21·4	25·4	29·5	38·4

Shafting.

The following tables show somewhat lower transmission powers than many others which have been published, but they are not far from the truth, and err, if at all, on the side of safety.

Diameter of Shafting.

Minimum diameters of shafts for reciprocating engines may be found from the following formula:—

$$D = \sqrt[3]{\frac{W.P. \times L^2 \times S}{B\left(\frac{L^2}{H^2} + 2\right)}} \times C$$

where

D = diam. of shaft in inches, $W.P.$ = working pressure in lb. /sq. in.

S = stroke of piston in inches.

L = diameter of low pressure cylinder in inches, or the equivalent diameter where there are two or more low pressure cylinders.

H = diameter of high pressure cylinder in inches.

B = co-efficient varying from 1,900 to 2,300.

C = 1·05 for crank shafts and for thrust shafts at bottom of collars, and 1·00 for intermediate shafts.

The minimum diameter of shaft for direct coupled and geared turbine engines where $S.H.P.$ = shaft horse-power (maximum), B = co-efficient varying from 58 to 64, R = revolutions per minute at maximum power, C = 1·05 for thrust shafts at bottom of collars, C = 1·00 for intermediate shafts, may be obtained from the formula:—

$$D = \sqrt[3]{\frac{S.H.P. \times B}{R}} \times C$$

The *torsional moment* or resistance of shafts $= \frac{1}{8}fd^3$, where f is the stress per sq. in. to which the shaft is subjected, viz. 8000 lbs. or 10,000 lbs. for wrought iron, or half these values for cast iron.

In the case of a steam engine, the torsional moment is equal to the product of the pressure on the piston in lbs., and the length of the crank in inches.

The *bearings* for shafts may be placed not more than $4{\cdot}8\sqrt[3]{d^2}$ feet apart, the symbol d indicating the diameter of the shaft in inches.

For a 4-inch shaft the bearings should not be more than $4{\cdot}8\sqrt[3]{16} = 12$ feet apart (see also p. 340).

Ball or roller bearings are preferable to plain bearings for most shafting and effect a great saving in power. If well designed and properly enclosed so as to retain the lubricant, they should run for six months with one oiling. Every precaution must be taken to exclude grit. The balls should be made of special alloy steel, containing 1·0 per cent. of carbon and 1·4 per cent. of chromium; they should be extremely accurate in size and of great and uniform hardness.

Thrust-bearings carrying heavy loads, as in pugmills, should have spherical seats for self-aligning.

Bearing Metals.

Common Standard Mixtures for Bearings are as follows:—

Bearings.	Tin.	Lead.	Zinc.	Anti-mony.	Copper.	Bismuth.
Dynamos,	88	...	...	8	3·5	0·5
Marine engines,	77	17	...	3	3	...
Main bearings,	34	44	...	16	6	...
Slides,	63	...	30	2·5	2·5	...
Babbitt (hard),	80	...	...	10	10	...
„ No. 2,	83	...	...	9	8	...
Gun-metal,	10	12	...	...	78	...
Brass,	...	...	34	...	66	...
Bronze,	16	7	...	...	77	...

Horse-Power of Shafting.

As Main Shafting, Carrying Driving Pulleys or Gears.

Diameter of Shaft in Inches.	Number of Revolutions per Minute.										
	60	80	100	125	150	175	200	225	250	275	300
1¾	2·6	3·4	4·3	5·4	6·4	7·5	8·6	9·7	10·7	11·8	12·9
2	3·8	5·1	6·4	8	9·6	11·2	12·8	14·4	16	17·6	19·2
2¼	5·4	7·3	8·1	10	12	14	16	18	20	22	24
2½	7·5	10	12·5	15	18	22	25	28	31	34	37
2¾	10	13	16	20	24	28	32	36	40	44	48
3	13	17	20	25	30	35	40	45	50	55	60
3¼	16	22	27	34	40	47	54	61	67	74	81
3½	20	27	34	42	51	59	68	76	85	93	102
3¾	25	33	42	52	63	73	84	94	105	115	126
4	30	41	51	64	76	89	102	115	127	140	153
4½	43	58	72	90	108	126	144	162	180	198	216
5	60	80	100	125	150	175	200	225	250	275	300
5½	80	106	133	166	199	233	266	299	333	366	400

As Second Motion or Line Shafting.

Bearings 8 feet apart.

Diameter of Shaft in Inches.	Number of Revolutions per Minute.										
	100	125	150	175	200	225	250	275	300	325	350
1¾	6	7·4	8·9	10·4	11·9	13·4	14·9	16·4	17·9	19·4	20·9
1⅞	7·3	9·1	10·9	12·7	14·5	16·3	18·2	20	21·8	23·6	25·4
2	8·9	11·1	13·3	15·5	17·7	20	22·2	24·4	26·6	28·8	31
2⅛	10·6	13·2	15·9	18·5	21·2	23·8	26·5	29·1	31·8	34·4	37
2¼	12·6	15·8	19	22	25	28	31	35	38	41	44
2⅜	15	18	22	26	29	33	37	41	44	48	52
2½	17	21	26	30	34	39	43	47	52	56	60
2¾	23	29	34	40	46	52	58	64	69	75	81
3	30	37	45	52	60	67	75	82	90	97	105
3¼	38	47	57	66	76	85	95	104	114	123	133
3½	47	59	71	83	95	107	119	131	143	155	167
3¾	58	73	88	102	117	132	146	162	176	190	205
4	71	89	107	125	142	160	178	196	213	231	249

For simply Transmitting Power.

Diameter of Shaft in Inches.	Number of Revolutions per Minute.										
	100	125	150	175	200	233	267	300	333	367	400
1½	6·7	8·4	10·1	11·8	13·5	15·7	17·9	20·3	22·5	24·8	27
1⅝	8·6	10·7	12·8	15	17·1	20	22·8	25·8	28·6	31·5	34·3
1¾	10·7	13·4	16	18·7	21·5	25	28	32	36	39	43
1⅞	13·2	16·5	19·7	23	26·4	31	35	39	44	48	52
2	16	20	24	28	32	37	42	48	53	58	64
2⅛	19	24	29	33	38	44	51	57	63	70	76
2¼	22	28	34	39	45	52	60	68	75	83	90
2⅜	27	33	40	47	53	62	70	79	88	96	105
2½	31	39	47	54	62	73	83	93	104	114	125
2¾	41	52	62	73	83	97	111	125	139	153	167
3	54	67	81	94	108	126	144	162	180	198	216
3¼	68	86	103	120	137	160	182	205	228	250	273
3½	85	107	128	150	171	200	228	257	285	318	342

SPACING OF SHAFT BEARINGS.

Table I.—When carrying Own Weight only.

Diameter of Shaft.	in. 1	in. 1½	in. 2	in. 2½	in. 3	in. 3½	in. 4	in. 4½	in. 5	in. 5½	in. 6	in. 6½	in. 7	in. 8
Distance between Centres.	ft. in. 5 0	ft. in. 6 6	ft. in. 8 0	ft. in. 9 8	ft. in. 10 6	ft. in. 11 6	ft. in. 12 6	ft. in. 13 6	ft. in. 14 6	ft. in. 15 6	ft. in. 16 6	ft. in. 17 4	ft. in. 18 4	ft. in. 20 0

Table II.—When carrying Pulleys, etc.

Diameter of Shaft.	in. 1	in. 1½	in. 2	in. 2½	in. 3	in. 3½	in. 4	in. 4½	in. 5	in. 5½	in. 6	in. 6½	in. 7	in. 8
Distance between Centres.	ft. in. 4 8	ft. in. 6 3	ft. in. 7 6	ft. in. 8 9	ft. in. 10 0	ft. in. 11 0	ft. in. 12 0	ft. in. 13 0	ft. in. 14 0	ft. in. 15 0	ft. in. 15 9	ft. in. 16 9	ft. in. 17 6	ft. in. 19 0

RULES FOR THE SPEED OF SHAFTS, AND SIZE OF PULLEYS TO GIVE A DEFINITE SPEED.

1.—*To ascertain the Speed of a Machine.*

Multiply the revolutions per minute of shaft, whose speed is known, by the sum of the multiplication together of diameter in inches of all the *driving* pulleys, and divide by the sum of the multiplication of the diameter in inches of *driven* pulleys. Result is speed of machine.

EXAMPLE.—Engine 120 revolutions per minute, 30-in. driving pulley.

No. 1 Shaft, . . . 12-in. driven pulley, 20-in. driving.
,, 2 ,, . . . 15 ,, ,, 30 ,,
Machine, . . . 6 ,, ,,

$$\frac{120\times 30\times 20\times 30}{12\times 15\times 6}=\frac{2,160,000}{1080}=2000 \text{ revolutions of the machine per minute.}$$

2.—*To calculate Size of Pulleys required for a given Speed.*

Divide speed required by speed of nearest available shaft. Result is the diameter of pulley required to drive one of 1 ft.

If the pulley on machine is less or more than 1 ft., the driving pulley will be proportionately altered, *e.g.* if 6 ins. it will be half the number given.

If this gives too large a driving pulley, a countershaft or shafts may be interposed to reduce the size half or quarter, as convenient.

Example.—Shaft, 90. Speed required 1600 with 3-in. pulley, $\frac{1600}{90}=17\frac{7}{9}$ (say 18), pulley on machine being 3 in. ($\frac{1}{4}$ of 1 ft.), driving pulley required $=\frac{18}{4}$ or $4\frac{1}{2}$ ft.; if $4\frac{1}{2}$ ft. be too large, reduce it by interposing a countershaft, thus:—

36 ins. on 90 shaft to 18 ins. on counter = 180;
27 ins. on counter to 3 ins. on machine = 1620;

Or
36 ins. on 90 shaft to 12 ins. on counter = 270;
18 ins. on counter to 3 ins. on machine = 1620.

Note.—Take *accurately* the speed of the shaft from which the calculation is commenced, as a slight error there may be enormously multiplied.

The maximum speed at which a shaft may be safely driven is:—

$$N=\frac{A}{D}$$

where N = revs. per min.;
D = diameter of the wheel in feet;
A = a constant which depends on the quality of the material;
for good cast iron it is 1530, and for good cast steel it is 2000.

Data for Movement of Liquids.

Water and similar liquids flowing through pipes discharge $16{\cdot}3\sqrt{H}\times D^2$ gallons per minute when H = head in feet and D = orifice of the pipe in inches; but if the aperture is of considerable thickness or the pipe very short, the factor 13 must be substituted for 16·3 in the above formula.

The loss of head (in feet) due to the friction of water in pipes per 100 ft. of pipe is shown in the following table:—

Gallons per Minute.	Diameter of Pipe in Inches.											
	1	1½	2	2½	3	4	5	6	7	8	9	10
5	3·02	·40	·10	..	..	..	..	..	..	..	..	..
10	12·08	1·605	·41	..	..	..	..	..	..	..	..	..
15	27·10	3·64	·90	..	..	..	..	..	..	..	..	..
20	48·3	6·4	1·64	·50	..	..	..	..	..	..	..	..
30	108·0	14·2	3·52	1·13	..	..	..	..	..	..	..	..
40	..	24·9	6·4	2·0	..	..	..	..	..	..	..	..
60	..	36·6	14·0	4·2	1·82	..	..	..	..	..	..	..
80	..	99·8	25·1	8·0	3·24	..	..	..	..	..	..	..
100	..	162·0	38·4	12·6	5·07	1·2	..	..	..	..	..	..
150	..	..	86·7	28·4	11·4	2·71	..	..	..	..	..	..
200	..	..	154·1	50·5	20·3	4·82	..	..	...	..	..	..
250	..	..	..	78·8	31·7	7·58	2·61	·99	·655	·234	...	..
300	..	..	..	113·7	45·7	10·85	3·8	1·43	·943	·333	..	..
350	..	..	..	..	62·2	14·7	5·71	1·93	1·28	·459	..	..
400	..	..	..	..	81·3	19·	6·75	2·53	1·67	·594	..	..
450	..	..	..	..	102·9	24·4	8·55	3·2	2·12	·756	..	..
500	..	..	..	..	126·9	30·1	10·56	3·96	2·62	·936	..	..
550	..	..	..	..	..	36·4	12·77	4·79	3·15	1·18	·816	..
600	..	..	..	..	..	43·3	15·2	5·07	3·77	1·2	·97	..
700	..	..	..	..	..	58·9	20·68	7·74	5·12	1·83	1·3	..
800	..	..	..	..	..	..	26·8	9·8	6·2	2·21	1·724	·68
900	..	..	..	..	..	..	34·5	2·5	8·0	2·45	2·11	·94
1000	..	..	..	..	..	..	..	5·9	10·3	3·3	2·7	1·22
1100	..	..	..	..	..	..	..	8·8	12·52	4·23	3·10	1·47
1300	..	..	..	..	..	..	..	..	17·48	5·90	4·33	2·04
1500	..	..	..	..	..	..	..	..	..	7·5	5·96	3·07
1700	..	..	..	..	..	..	..	..	..	9·63	7·8	3·5
2000	..	..	..	..	..	..	..	..	..	14·9	10·6	4·91
2500	..	..	..	..	..	..	..	..	..	23·4	16·5	7·62
3000	..	..	..	..	..	..	..	..	..	..	..	12·02
3500	..	..	..	..	..	..	..	..	..	..	..	14·92
4000	..	..	..	..	..	..	..	..	..	..	..	17·5

The following equivalents are often useful :—

1 imperial gallon = 277¼ cb. in.
= ⅙ cb. ft. (roughly).
= 10 lbs.

Piping 1 in. inside diam. holds ⅓ lb. of water for each foot length

1 cb. ft. water = 6¼ galls.
= 62⅓ lbs.
1 litre of water = 0·22 gall.
= 61 cb. in.
= 2¼ lbs. (nearly).
1 ton of water = 224 galls. = 35¾ cb. ft.

See also 'Pumps' (p. 112).

TABLES RELATING TO DRYING.

Condensation of Steam in Pipes.

The following table (obtained as the result of a large number of very careful experiments by W. N. Bolam and T. Grieve), shows the number of B.T.U. lost per hour from each square foot of surface for each degree Fah. difference in temperature between the steam and the outside air :—

Thickness of Cover.	Covering.	Steam Pressure.			
		25 lbs.	50 lbs.	70 lbs.	100 lbs.
0	Uncovered, .	2·20	2·95	3·20	3·20
1·25 in.	Slag-wool, .	·52	·58	·62	·66
1·20	Hair and felt, .	·49	·59	·58	·58
·90	Felt, . .	·70	·76	·79	·79
1·5	Magnesia, .	·50	·56	·59	·60

Cellular asbestos, cork, and kieselguhr have an insulating value equal to that of slag-wool.

Vapour Pressure of Water (Proctor).

Temperature °C., .	−10	−5	0	5	10	15	20	25	30	35	40
,, °F., .	14	23	32	41	50	59	68	77	86	95	104
Pressure mm., . .	2·2	3·2	4·6	6·5	9·1	12·7	17·4	23·5	31·5	41·9	54·9
Grammes per cb. m.,	2·4	3·4	4·9	6·8	9·3	12·8	17·2	22·8	30·1	39·2	57·0
Lbs. per cb. yd., .	·004	·006	·008	·012	·016	·022	·029	·039	·052	·067	·097

Grammes per cb. m. is equivalent to ounces per 1000 cb. ft.

Air required in Drying (A. E. Brown).

The following table shows the weight of air required to drive 1 lb. of water from goods, when the air enters and leaves the dryer at the temperatures named, providing it leaves the dryer saturated with moisture, a condition never attained in practice. This table is chiefly of value in showing the much smaller quantities required when the air has a high initial temperature.

Temperature of Air entering Dryer.	Temperature leaving Dryer.	Weight of Air required.	Heat required to dry 1 lb. of Water. in B.T.U.
72 °F.	52 °F.	227 lbs.	2156
98 ,,	62 ,,	125 ,,	1954
130 ,,	72 ,,	77 ,,	1788
170 ,,	82 ,,	50 ,,	1652
220 ,,	92 ,,	34 ,,	1537

In practice, the figures shown in the preceding table must be augmented by 50 to 100 per cent. to allow for the heating of the dryer walls, loss by radiation, and warming of the goods.

Moisture in Air.

$$\text{Grammes per cb. m. of moisture in air} = \frac{288P}{T},$$

where P = pressure of water vapour and T = absolute temperature of air (= temperature in °C + 273).

The pressure of the water vapour in the air is found from the following table, used in conjunction with a 'wet and dry bulb thermometer' or hygrometer (see p. 254).

WET AND DRY BULB HYGROMETER TABLE.

Pressure of Aqueous Vapour in Millimetres.

Dry Bulb Reading.	Excess in Temperature of Dry over Wet Bulb.						
	0° C.	1°	2°	4°	6°	8°	10°
0° C.	4·6	3·7	2·9	1·3	...	...	...
2	5·3	4·4	3·4	1·9	...	...	...
4	6·1	5·1	4·1	2·4	·8	...	...
6	7·0	5·9	4·9	2·9	1·1	...	...
8	8·0	6·9	5·8	3·7	1·7	...	...
10	9·2	8·0	6·8	4·6	2·5	·5	...
12	10·5	9·2	8·0	5·6	3·4	1·3	...
14	11·9	10·6	9·2	6·7	4·4	2·2	...
16	13·5	12·1	10·7	8·0	5·5	3·2	1·0
18	15·4	13·8	12·3	9·5	6·8	4·3	2·0
20	17·4	15·7	14·1	11·1	8·3	5·6	3·1

Thus, to find the mass of moisture in 1 cb. m. of air when the dry bulb thermometer is at 16° C. and the wet bulb at 10° C., it is necessary, first of all, to find the vapour pressure from the above table. As the difference between the wet and dry bulbs is 6° C., line 9 in the table and column 6 shows this to be 5·5 mm. Hence, $\frac{288P}{T} = \frac{288 \times 5\cdot5}{16+273} = \frac{1584}{289} = 5\cdot5$ grammes per cb. m., or 5½ oz. per 1000 cb. ft.

Humidity.

The following extract from Glaisher's tables shows the degree of humidity (percentage of complete saturation) when the dry bulb thermometer is at the reading given in the first column, and the wet bulb is lower by the quantity D:—

Dry Bulb. °F.	Humidity.	Dry Bulb. °F.	Humidity.	Dry Bulb. °F.	Humidity.
D=2°		D=5°		D=10°	
30	69	42	63	60	50
31	72	44	65	62	50
32	75	46	67	64	51
33	78	D=8°		66	52
34	79	46	51	68	52
D=3°		48	52	70	53
35	72	50	53	72	54
36	74	52	54	74	55
37	75	54	55	76	55
D=5°		56	56	78	56
38	62	58	57	80	56
39	63	60	58	82	57
40	63			84	57

The following table, by A. E. Brown, gives the weights and volumes of air at certain temperatures which will contain, when saturated, 1 lb. of water in the form of vapour:—

Temperature. °F.	Weight of Air.	Volume of Mixture.
42	178·18 lbs.	2272 cubic feet.
52	122·17 ,,	1595 ,,
62	84·79 ,,	1135 ,,
72	59·54 ,,	819 ,,
82	42·35 ,,	600 ,,
102	21·98 ,,	333 ,,
132	8·49 ,,	151 ,,
182	1·402 ,,	48·7 ,,

The striking feature of the table is the rapid decrease in the quantity of air necessary as the temperature of it increases.

Table of Gases.

Saturated with Water-vapour at 760 mm. pressure, and at temperatures from 0° to 99° C.

Temperature t° C.	Grammes of Water-vapour absorbed by 1 cubic metre of Dry Air at 0° C. when saturated at t° C. and 760 mm.	Total Volume of Air and Water-vapour resulting from saturating 1 cubic metre of Dry Air at 0° and 760 mm. to t° C.	Temperature t° C.	Grammes of Water-vapour absorbed by 1 cubic metre of Dry Air at 0° C. when saturated at t° C. and 760 mm.	Total Volume of Air and Water-vapour resulting from saturating 1 cubic metre of Dry Air at 0° and 760 mm. to t° C.	Temperature t° C.	Grammes of Water-vapour absorbed by 1 cubic metre of Dry Air at 0° C. when saturated at t° C. and 760 mm.	Total Volume of Air and Water-vapour resulting from saturating 1 cubic metre of Dry Air at 0° and 760 mm. to t° C.	Temperature t° C.	Grammes of Water-vapour absorbed by 1 cubic metre of Dry Air at 0° C. when saturated at t° C. and 760 mm.	Total Volume of Air and Water-vapour resulting from saturating 1 cubic metre of Dry Air at 0° and 760 mm. to t° C.
0	4·866	1·0060	25	25·69	1·1267	50	110·78	1·3468	75	493·04	2·0570
1	5·231	1·0107	26	27·32	1·1327	51	117·25	1·3605	76	527·88	2·1179
2	5·620	1·0144	27	29·03	1·1387	52	124·10	1·3742	77	565·99	2·1843
3	6·035	1·0191	28	30·85	1·1447	53	131·35	1·3892	78	607·81	2·2574
4	6·477	1·0228	29	32·77	1·1518	54	139·03	1·4054	79	653·86	2·3386
5	6·948	1·0275	30	34·80	1·1578	55	147·17	1·4218	80	704·79	2·4268
6	7·448	1·0312	31	36·95	1·1650	56	155·80	1·4394	81	761·36	2·5245
7	7·983	1·0359	32	39·21	1·1722	57	164·97	1·4571	82	824·50	2·6344
8	8·550	1·0407	33	41·61	1·1794	58	174·70	1·4761	83	895·38	2·7566
9	9·153	1·0444	34	44·14	1·1866	59	185·03	1·4963	84	975·45	2·8939
10	9·794	1·0491	35	46·81	1·1939	60	196·02	1·5179	85	1066·5	3·0516
11	10·47	1·0539	36	49·63	1·2023	61	207·72	1·5396	86	1171·0	3·2298
12	11·20	1·0587	37	52·61	1·2096	62	220·18	1·5639	87	1291·9	3·4381
13	11·97	1·0634	38	55·76	1·2181	63	233·46	1·5883	88	1433·4	3·6792
14	12·78	1·0682	39	59·09	1·2266	64	247·63	1·6152	89	1601·0	3·9666
15	13·64	1·0730	40	62·60	1·2363	65	262·77	1·6436	90	1802·7	1·3102
16	14·56	1·0778	41	66·32	1·2448	66	278·97	1·6733	91	2049·7	4·7329
17	15·53	1·0826	42	70·24	1·2545	67	296·32	1·7044	92	2359·1	5·2596
18	16·56	1·0884	43	74·38	1·2643	68	314·92	1·7381	93	2757·5	5·9393
19	17·66	1·0933	44	78·75	1·2753	69	334·91	1·7746	94	3289·6	6·8433
20	18·81	1·0981	45	83·38	1·2863	70	356·41	1·8137	95	4035·4	8·1121
21	20·04	1·1040	46	88·26	1·2974	71	379·59	1·8556	96	5155·2	10·017
22	21·33	1·1099	47	93·43	1·3085	72	404·62	1·9002	97	7022·9	13·192
23	22·70	1·1148	48	98·89	1·3208	73	431·71	1·9488	98	10760·7	19·544
24	24·16	1·1207	49	104·67	1·3332	74	461·09	2·0002	99	21978·4	38·604

Flow of Steam through Pipes.

Gauge Pressure in lb. per sq. in.	Diameter of Pipe in inches (Length of Pipe is 240 times its Diameter).								
	1	2	3	4	5	6	8	10	15
	Weight of Steam per minute in lbs., with 1 lb. Loss of Pressure.								
10	2·57	12·72	31·45	58·05	95·8	143·6	262·0	422·7	996
20	3·02	14·94	36·94	68·20	112·6	168·7	307·8	496·5	1170
40	3·74	18·51	45·77	84·49	139·5	209·0	381·3	615·3	1450
60	4·32	21·38	52·87	97·60	161·1	241·5	440·5	710·6	1675
80	4·82	23·82	58·91	108·74	179·5	269·0	490·7	791·7	1866
100	5·25	25·96	64·18	118·47	195·6	293·1	534·6	862·6	2032
120	5·63	27·85	68·87	127·12	209·9	314·5	573·7	925·6	2181
150	6·14	30·37	75·09	138·61	228·8	343·0	625·5	1009·2	2378

Loss of Heat by Radiation.

This is a quantity which it is almost impossible to determine accurately in practice; several authorities have published figures showing the results of their experiments, but they do not agree well with one another. The following figures, calculated from Box's experiments and compared with others, appear a fair average:—

A 4½-in. brick wall loses ·45 B.T.U. per hour for each sq. ft. of surface, and for each deg. Fah. difference in temperature between the two sides of the wall. Similarly,

a 9-in. wall loses	·36 B.T.U.
13½-in. "	·28 "
18-in. "	·25 "
Window glass,	·75 "
Door of 1-in. board,	·47 " .

Stone walls need only be half the thickness of brick ones to retain the same amount of heat within the walls.

The absolute loss by radiation from a wooden surface being reckoned as unity (= 1), the following are the relative losses from other substances:—

Iron, . . .	291	Concrete, . . .	4
Lead, . . .	145	Sand or earth, . .	2½
Glass, . . .	8	Sawdust, . . .	1¼

Table showing Relative Cost of Progressive Tunnel Dryers (A. E. Brown).[1]

Name.	Bricks easily dried.			Moderately easy to dry.			Difficult to dry.		
	Cost in £.	Area in sq. yds.	Time taken in days.	Cost in £.	Area in sq. yds.	Time taken in days.	Cost in £.	Area in sq. yds.	Time taken in days.
Blackman, with slab heater, ...	100	30	1	...	...	...	...	...	...
Blackman or Sutcliffe, with tubular steam heater, . . .	117	30	1	...	...	...	...	...	...
A. B. C. dryer, .	150	30	1	...	...	...	...	...	...
Blackman 'improved,'	133	30	1	400	90	3	...	...	...
Wolff (without tempering chamber), .	200	·45	2	...	...	...	...	...	...
Wolff (with tempering chamber), . .	...	...	...	330	80	3	...	...	...
Bucyrus, ...	117	25	1	290	63	2½	468	100	4
Möller and Pfeifer, .	278	53	⅔	417	80	1	625	120	1½
Brown, . . .	140	30	1	280	60	2	420	90	3

These figures apply to 1911; the costs should be at least doubled for 1929.

USEFUL RECIPES.

Cements.

A. For steam joints use a mixture of 100 parts of fine iron filings, 2 parts of sal ammoniac, and 10 parts of water. This mixture soon rusts, becomes very strong, and is proof against water and steam.

B. Fireproof cement may be made by mixing into a paste with vinegar 140 parts of iron filings, 20 parts of hydraulic lime, 25 parts of ground flint, and 3 parts of sal ammoniac. When the cement is perfectly solid, the joint may be heated; this will cause it to set stone hard.

Several useful fireproof cements are sold under trade names such as *Purimachos*, *Feusol*, *Pyrolyte*, etc.

C. A handy solder for brass or bronze sieves or lawns is made by melting 2 parts of tin and 1 part of lead together, and casting into fine sticks. This alloy melts at about 300° F.

D. Cement for covering defects in the surface of glazed goods may be made by mixing a saturated solution of zinc chloride into a paste with dense zinc oxide. (The ordinary light oxide is useless.) This cement has an ivory colour; if pure white is required, Keene's or Parian cement should be employed. If properly worked, the above give a fairly glossy surface.

Typical Clays.

District.	Clay.	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Alkalies.	Water, etc.
Stourbridge,	Fire clay,	65	22	2	0·3	0·5	Traces	10
Leeds,	Fire clay,	60	29	2	...	...	...	9
Glasgow,	Fire clay,	50	30	1·5	0·4	0·5	1·5	16
Northumberland,	Fire clay,	60	28	2	·1	0·2	1·8	7
Peterborough,	Red-burning,	62	14	11	2	...	2·0	8
Cambridgeshire,	Marl,	17	7	...	41	...	0·5	34
Medway,	Blue gault,	44	15	6	15	2	0·6	17
Warwickshire,	Blue lias,	38	15	4	18	3	0·5	22
Ruabon (Wales),	Red-burning,	63	20	6	...	...	5·4	5
Wareham (Dorset),	Ball clay,	46	38	0·5	1·5	...	...	14
St Austell,	China clay,	46	40	...	1	...	...	13

STANDARD BOOKS AND JOURNALS DEALING WITH CLAYWORKING.

In the following list, only books dealing directly with some branch of clayworking are included. Allied subjects, as Analytical Chemistry, Book-keeping, Chemistry, Physics, Electricity, Steam and Mechanical Engineering, Building Construction, Geology, etc., are omitted, excepting where they treat specially of the clay industries. Many of the best books are, unfortunately, in French or German, but where English translations exist, these, and not the originals, are given. Volumes which are out of print are omitted. The dates refer to the existing edition and not necessarily to the first one. Many other books are mentioned in Brauner's *Bibliography* and Solon's *Ceramic Literature*, but most of them are not readily accessible.

In column 6 the following abbreviations are employed:—

S. G. = Scott, Greenwood, & Co., Ludgate Hill, London, E.C. 4.
B. C. = Clayworker Press, 43 Essex Street, Strand, London, W.C. 2.
T. = Verlag der Tonindustriezeitung, Berlin.
W. = Wiley & Co., New York, or Williams & Norgate, London.
G. = Chas. Griffin & Co., Ltd., 42 Drury Lane, London, W.C. 2.
H. = John Heywood, Ltd., 20–22 St Bride Street, London, E.C. 4.
C. = Crosby, Lockwood & Co., 7 Stationers' Hall Court, London, E.C. 4.
R. = T. A. Randall & Co , Indianapolis, Ind., U.S.A.
Spr. = "Sprechsaal," c/o Muller u. Schmidt, Coburg, Germany.
B. = The Tradepress Publishing Corporation, 542 South Dearborn Street, Chicago, Ill.

Author.	Title.	Date.	Publisher.[2]
Ackworth, A. T.	Roofing Tiles	1910	H.
Asch, W. & D.	The Silicates in Chemistry and Commerce	1913	Constable.
Ashby, H.	How to Analyse Clay	1898	S. G.
Audley, J. A.	Silica and the Silicates	1921	Baillière, Tindall & Cox.
Auscher, E. S.	Technologie de la Céramique	1901	T.
„	Les Industries Céramiques	1901	T.
„ (Burton)[1]	French Porcelain	..	Cassell.
Baker, E.	Roads and Pavements	1918	W.
Bauer, E. P.	Keramik	1923	Spr.
Beck, A. J.	Ziegeleianlagen u. Fabrikation	1901	T.
Benfey, G.	Die heutige Ziegelindustrie	1908	T.
„	Herstellung feuefester Erzeugnisse	1926	T.
„	Ziegelerzevgung	1926	T.
Berdel, E.	Einfaches Chemisches Praktikum :		
	Teil I. Chemische Versuche und Präparate	1926	T.
	„ II. Vorubungen zur Analyse	..	T.
	„ III. Die qualitative Analyse	..	T.
	„ IV. Ausgewahlte quantitat. Methoden	..	T.
	„ V.–VI. Zusammen in einem Band geb. Anleitung zu keramischen Verschen für Schule und Praxis		
„	Chemisches Praktikum für Tonfal. u. Glastechniker	1913	Spr.
Berge, A.	Blei- und Zinnfreie Schmelzglasuren	..	T.
„	Bleifrei Schmelzglasur mit vermindertem Zinnoxydgehalt	..	T.
„	Bunzlauer Braun	..	T.
„	Gold in Glasuren	..	T.
„	Pinkglasuren	..	T.
„	Rote Chromglasuren	..	T.
„	Titansäure in Unterglasurfarben	..	T.

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[1] The name in brackets is that of the translator or reviser.

[2] In some instances the name of the firm from which the work can be most easily obtained replaces that of the publisher.

Author.	Title.	Date.	Publisher.
Berge, A.	Wasserglasglasuren	..	T.
"	Emaildekor auf Steingut	..	T.
"	Fabrikation der Tonerde	..	T.
"	Keramisches Praktikum, Anleit. z. keram. Laborat.-arbeit auf der chem. Grundlage	..	T.
"	Chemische Technologie der Tonwaren	1925	Spr.
"	Mitteilungen aus der Kgl. Keramischen Fachschule Bunzlau :		
	I. Verschiedenes	..	Spr.
	II. Schmelz- oder Fayenceglasuren	..	Spr.
	III. Frittenglasuren mit Muhlenversatz für Steingut und Irdenware		
Berling, E.	Meissner Porzellan (Geschichte)	..	T.
Binns, C. F.	Manual of Practical Potting	1922	S. G.
"	Ceramic Technology	1897	S. G.
Bischof, C.	Die feuerfesten Tone	1904	T.
"	Gesammelte Analysen	1901	T.
Bock, O.	Ziegelei als landw. Gewerbe	1898	T.
"	Ziegelfabrikation aller Arten	1901	T.
"	Ziegeloefen Konstruktion	..	T.
Bock-Nawrath	Die Ziegelei (5th ed.)	1924	T.
"	Der Ziegelofen (4th ed.)	1921	T.
Bollenbach, H.	Laboratoriumsbuch für Tonindustrie	1910	Knapp, W., Halle a S.
"	Porzellan aus elementarem Bestandteilen	..	Spr.
"	Beispiele zur Berechnung keramischer Massen und Glasuren	..	T.
"	Keramische Rechentafeln zum Gebrauch in den Laboratorien der Ton-, Glas-, und Email-Industrie	.. 1913	T. Spr.
Bolz, C. H.	Die Pyrometer	..	T.
Borrmann, R.	Moderne Keramik	1902	T.
Böttcher	Verflussigung des Tones durch Alkali	..	Spr.
Bourry, E. (Searle)	Treatise on Ceramic Industries	1926	S. G.
Boyer	Manuel du Porcelainier	..	W.
Branner, J.	Bibliography	1906	Amer. Cer. Soc.
Broemse, F.	Lehrbuch d. Tonwarenindustrie	1899	T.
"	Ofen- u. Glasurfabrikation	1896	T.
Brongniart, A.	Colouring and Decoration of Ware	1898	—
Bronn, J.	Elektrische Keram : Ofen	..	T.
Brown, A. E.	Brick-Drying	..	B. C.
"	Hand Brickmaking	..	B. C.
Brüning	Porzellan	1907	T.
Buchholz, P.	Dachziegel Fabrikation	1903	T.
Bük, R.	Der Zieglermeister in Theorie u. Praxis	1908	T.
Burghardt, R.	Inbetriebsetzung Hoffmann. Ofen	1910	T.
Burton, W.	Porcelain	1906	Cassell.
"	English Earthenware and Stoneware	1906	"
Büttner	Chromtrioxyd in Glasuren	..	Spr.
"	Herstellung von Unterglasurfarben n. d. Aufsaugevfahren	..	Spr.
"	Wohlfeile Rohmaterialien für die Porzellanfabrikation	..	Spr.
"	Die Rolle der Chromtrioxyds in Glasuren	..	Spr.
Christoph, J.	Der praktische Toepfer	1895	T.
Clauss, R.	Die Künstlichen Ziegeltrockenanlagen (2nd ed.)	1925	T.
"	Die Schürapparate	1925	T.
Cramer, E.	Ueber feuerfeste Tone u. Quarzite	1901	T.

Author.	Title.	Date.	Publisher.
Cramer, E.	Ueber das Ausschlages im Ofen	..	T.
Crary, J. W.	Sixty Years a Brickmaker	..	R.
Crossley, A.	Tables of Analyses of Clays	..	R.
Davis, T..	Bricks, Tiles and Terra-Cotta	1905	R.
Deck, T..	La Faïence	1887	T.
Delezel, F.	Grundzüge der Tonindustrie	1910	Spr.
Demmin, A.	Keramik-Studien: I. Fayence	1881	T.
	" " II. Porzellan	1883	T.
	" " III. Steinzeug	1885	T.
	" " V. Terrakotten	1884	T.
Dietz, H..	Steinzeug	1907	T.
Dietz, R..	Das Porzellan	1907	Spr.
Dittler, E.	Mineralsynthetisches Praktikum	1915	T.
Dobson, E. (A. B. Searle)	Bricks and Tiles	1911	C.
Dorfner	Verwendung keramischer Rohmaterialien und Zusammensetzung feinkeramischer Massen nach der chemischen Analyse	..	Spr.
"	Zur Bleifrage	..	Spr.
Dubovszky, J.	Majolika-Malerei	..	T.
Dümmler, K.	Handbuch der Ziegelfabrikation	1926	T.
"	Klinker	1926	T.
"	Das Brennen der Ziegelsteine	1919	T.
D. V. Ton Ind.	Zur Frage der Herstellung von Ziegeln grossen Formats	1902	T.
Eckel, E. C.	Building Stones and Clays	1912	W.
Eckhart, A.	Bei Anlage periodischer Ziegelöfen	1883	T.
"	Technik des Verblendsteins (2 vols.)	1884	T.
Eisenlohr	Färbeversuche mit Zahnporzellanmassen	..	Spr.
Eyer	Email-Wissenschaft	..	T.
"	Die Zusammensetzung der Emailleglasuren	..	T.
"	Die Eisenemaillierung	..	T.
"	Anlagen und Einrichtungen eines Emaillierwerkes	..	T.
"	Naturgeschichte der Emailfehler	..	T.
Fairie, J.	Notes on Pottery Clays	1901	S. G.
Falke, H.	Majolika	1907	T.
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Fiebelkorn	Entstehung unserer Tongesteine	..	T.
Fischer	Bearbeitung der Steine, Glas- und Tonwaren	..	Spr.
"	Verwertung und Verarbeitung vin alten Gipsformen und Gips sowrie Verwertung von Abfallen aus der keramischen Industrie	..	Spr.
Fleck	Photokeramik	..	T.
Friese	Porzellan als Isoliermittel	..	T.
Furnival, W. J.	Leadless Glazes for Tiles and Faience	1904	W. J. Furnival, Stone, Staffs.
Gentelles.	Lehrbuch der Farbeniafabrikation:		
	I. Die Erdfarben	..	T.
	II. Die Mineralfarben	..	T.
	III. Die Lackfarben	..	T.
Graesse-Jaennicke	Guide de l'amateur de Porcelaines	1901	T.
Granger, A.	La Céramique Industrielle	1905	W.
"	Fabrication et Emploi des Materiaux et Produits Refractaires utilisés dans l'Industrie	..	Spr.

Author.	Title.	Date.	Publisher.
Greaves-Walker	Clay Plant Construction	1919	B.
Greiner, R.	Steingutfabrikation	1903	T.
Griffen, H. R.	Clay Glazes and Enamels	1896	W.
Grimm	Fabrikation des Feldspatporzellans	1901	T.
Grünwald, J.	Raw Materials in the Enamel Industry. Translated by H. H. Hodgson	1914	G.
,,	Theorie und Praxis der Blech- u. Gussemail-Industrie	..	T.
,,	Abhandlungen aus der Eisenemail- u. Verzinnungtechnik	..	T.
,,	Chem.-Tech. der Email-rohmaterialien	..	T.
Hainbach, R.	Pottery Decorating	1924	S. G.
Harris, G.	Science of Brickmaking	1897	B. C.
Harvard, F.	Refractories and Furnaces	1913	B.
Hasluck, P.	Bricks and Brickmaking	1906	Cassell.
Hausbrand, E.	Trocknen mit Luft und Dampf	1903	T.
Hecht, H.	Untersuchungen über Porzellan	..	T.
,,	Ueber verschiedene Chamottesteine	1900	T.
,,	Rohstoffe der Tonindustrie	1900	T.
,,	Die Tonreiniger	..	T.
,,	Die Beschicker	..	T.
,,	Lehrbuch der Keramik.	1923	T.
Hegemann, H.	Herstellung des Porzellans	..	T.
Heim, M.	Steingutfabrikation	1910	T.
Heinecke, H.	Neuere Brennöfen derk. Porzellan-Manufaktur zu Charlottenburg	..	T.
,,	Versuchsöfen mit Gasheizung und Pressluft für Laboratorium	..	T.
Heinrich, H.	Mergel	1908	T.
Hermann, F.	Von Steingut, Faience, Majolika	..	T.
,,	Glass, Porcelain and Enamel Painting	1897	S. G.
Hertwig-Möhrenbach	Der Praktische Keramiker :		
	Part I.	1921	Spr.
	Part II.	1924	Spr.
	Part III.	1922	Spr.
Heubach, R.	Chromrote Glasuren	..	T.
Heusinger, E.	Ziegel und Rohrenbrennerei	1901	T.
Hillebrand, Dr	Analysis of Silica-earths	1898	W.
Hirsch, H.	Die Erweichungsversuch	1925	T.
,,	Der Silikastem beim Druckerweichungsversuch	1926	T.
Hölzgen, F.	Herstellung holländisch. Dachziegel	..	T.
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Jackson, W.	Ceramic Calculations	1904	Longmans.
Jaennicke, F.	Geschichte der Keramik	1900	T.
,,	Grundriss der (Kunst) Keramik	1880	T.
,,	Marken auf Fayence, etc.	..	T.
,,	Handbuch der Porzellan-, Steingut-, und Fayence-Malerie uber und unter Glasur	..	T.
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,,	Chemische Analyse als Massstab der Feuerbeständigkeit	..	T.
,,	Grenzen der Feuerbeständigkeit	..	T.
,,	Edeltone. Die chem. Analyse als Massstab der Feuerbeständigkeit der Edeltone u. der Einfluss der Mahlfeinheit auf die für die Formgebung feuerfester Fabrikate wertvollsten physikal. Eigenschaften	..	T.

Author.	Title.	Date.	Publisher.
Keller	Fabrikation feuerfester Ziegel	1906	T.
Kerl, B.	Handbuch der gesam. Tonindustrie	1907	T.
Kissling, J.	Photokeramik	1893	T.
Klassen, L.	Fabrikanlagen	1896	T.
,,	Kontroll-Apparate für Ziegeleien	1896	T.
Kloes, J. A. van der (A. B. Searle)	Manual for Masons	1914	Churchill.
Krüger, J.	Photokeramik	1893	T.
Lang, Prof.	Schornsteinbau (3 vols.)	1901	T.
Lange, G.	Ofen-fabrikation bes. für Emaille	..	T.
Langenbeck, C.	Chemistry of Pottery	1895	W.
Langer, W.	Abziehbilder-Herstellung	..	T.
Le Chatelier, H.	Mésure des températures élevées	1900	T.
,,	La Silice et les Silicates	1914	W.
Lefévre, L. (Bird & Binns)	Architectural Pottery	1900	S. G.
Liebold, B.	Kontinuierlichen Brennöfen	..	T.
,,	Trockenanlagen	1877	T.
Liesegang	Photogr. Schmelzfarbenbilder auf Email, Porzellan, und Glas	..	T.
Litinsky, L.	Schamotte und Silika	1925	Spr.
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,,	Untersuchungs Methode	1905	T.
,,	Chemischen u. physikalischen Konstitution der Tone	1906	T.
,,	Naturliche Zusammensetzung der Tone	1906	T.
,,	Kalkhaltige Tone	1906	T.
,,	Die Schmelzvorange der Segerkegel	..	T.
,,	Der Tunnelofen in der Porzellan-industrie. (Feinkeramische Brennofen, II. Teil)	..	T.
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,,	Aufsuchen Abbodren und Bewertung von Lehm-, Ton-, und Kaolinlagern	..	T.
,,	Kritische Betrachtung einiger Untersuchungsmethoden der Kaoline u. Tone	..	T.
,,	Feinkeramische Brennofen ein Beitrage zur Kenntnis verschiede der Systeme	..	T.
,,	Die Brennfarber der Tone	..	T.
,,	Kalkhaltige Tone ihre Eigenschaften Verhalten und Färbungen im Feuer	..	T.
Lovejoy, E.	Burning Claywares	1920	R.
Ludwig	Beziehungen zwischen Schmelzbarkeit und Zusammensetzung	1904	T.
Mäckler, H.	Ausblühungen	1904	T.
Malepeyre, F., et Romain, A.	Manuel du Briqueteer, tuiler, fabricant de carreaux et de tuyaux de drainage	1914	W.
Marr, O.	Das Trochnen und die Trockner	..	T.
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,,	Formen und Modellieren	1900	T.
,,	Technische Zeichnen	1903	T.
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,,	Quantitative Inorganic Analysis	1913	G.
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Mercator, G.	Photokeramik und Imitationen	1900	T.
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Author.	Title.	Date.	Publisher.
Michel, G.	Ueber die keramischen Verblendstoffe	..	T.
Müller, Dr	Fabrikation der Farben	1880	T.
,,	Prüfung von Ziegeltonen	..	T.
,,	Die Tonofenfabrikation	..	T.
Munby, A. E.	Chemistry and Physics of Building Materials	1910	Constable.
Morrison, R. B.	The Brickmaker's Manual	..	R.
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Parkert, O.	Die Irisationstechnik	1925	Spr.
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Petrik	Bleifrage in der keramischen Industrie	..	Spr.
Pickworth, C. N.	Indicator Diagram	..	Emmott, Manchester.
Pinkl, V.	Die Herstellung der Dramröhren	1926	T.
Plenske	Über Mikrostruktur und Bildung des Porzellans	..	Spr.
Post	Chemisch-technische Analyse von Kalk, Zement, Tonwaren, Glasuren und Glas	..	Spr.
Pukall, W.	Krystallglasuren	1908	T.
,,	Keramische Rechnen	1907	T.
,,	Anorganische Synthesen (aus Silikat-Zeitschrift)	..	Spr.
,,	Beiträge zur Lösung der Bleifrage	..	Spr.
,,	Grundzüge der Keramik	1922	Spr.
,,	Keramische Arbeitsmassen	..	Spr.
Probst, E.	Deutsche Porzellan u. Steingut-industrie	..	T.
Quaglio, J.	Feuerfeste Materialen	1886	T.
Raes, E. L.	The Glazer's Book	1910	H.
Randau, P.	Fabrikation der Emaille	1900	T.
,,	Enamels and Enamelling	1900	S. G.
Rauter	Die Industrie der Silikate, der künstlichen Bausteine u. des Mörtels :		
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	II. Künstl. Bausteine und Mörtel	..	T.
Reboulleau	Peinture sur Porcelaine et Faïence.	..	W.
Richardson, W. D.	Burning Brick	..	R.
,,	Kiln Records	..	R.
Richters, Dr	Untersuchungen ueber Feuerbest.	1897	T.
,,	Feuerbeständigkeit	1897	T.
Rieke	Die Arbeitmethoden der Silikatchemie	..	T.
,,	Das Porzellan	..	Spr.
Rieke und Steger	Einfluss des Tondere- Kieselsaure-Verhaltnisses auf das Verhalten von Porzellanglasuren	..	Spr.
,,	Warmeausdehnungskoeffizient von Glasuren	..	Spr.
Ries, H.	(American) Clays, their Occurrence, Properties and Uses (3rd ed.)	1927	W.
Rischer, A.	Das Glazieren der Ziegel	1904	T.
Rodgers, N.	Filters and Filter Presses	1915	Norman Rodger.
Rohland, P.	Die Tone	1910	T.
,,	Ursachen der Plastizität, das Bindevermogens usw. der Tone	..	T.
Rösler, M.	Keramische Tagesfragen	1888	T.
Romanoff	Behandlung der Schmelzfarben	1887	T.
Rudolph	Die Tonwarenerzeugung (allgemeine Keramik) mit besonderer Beruksichtigung der chem Grundlagen	1923	T.

Author.	Title.	Date.	Publisher.
Ruff	Über die Fabrikation dichten Steinzeugs aus watepreussischen Tonen	..	Spr.
Rzehulka	Die Tone und ihre Verwendung für den Hüttenveitrieb	..	T.
Salvetat	See Brongniart.		
Sandemann, E.	Manufacture of Earthenware	1901	Virtue & Co.
Schamberger, J.	Keramische Praxis	1901	T.
Scherer	Der Magnesite	..	T.
Schimm	Herstellung von Dräntöhren (Sonderabdruck der T.I.Z.)	..	T.
,,	Magnesitbrennerei und Magnesiaziegelherstellung	..	T.
Schlesinger, J.	Bau der Ziegel Brennöfen	1866	T.
Schmatolla, E.	Gaserzeuger und Gasfeuerungen	..	Dr Max Jaenecke, Hannover.
,,	Rauchplage u. Brennstoffverschwendung	1902	,,
,,	Was muss man von Feuerungstechnik wissen ?	1901	,,
,,	Die Brennöfen	1926	T.
Schnurpfeil, H.	Tonindustrie im Glashuttenbetrieb	1908	T.
Schom, Dr	Kunsterzeugnisse aus Ton	1887	T.
Schumacher, Dr	Die keramischen Tonfabrikate	1884	T.
Schwarz, R.	Feuerfeste und hochfeuerfeste Stoffe	1922	Spr.
Searle, A. B.	Bricks and Artificial Stones	1915	Churchill.
,,	Refractories for Furnaces, Crucibles, etc.	1923	Pitman.
,,	Chemistry and Physics of Clays, etc.	1924	Benn.
,,	Clay and What We Get from It	1925	S.P.C.K.
,,	The Making and Burning of Glazed Ware	1928	B. C.
,,	Clayworker's Hand-book	1929	G.
,,	Modern Brickmaking	1920	S. G.
,,	British Clays, Shales and Sands	1912	G.
,,	Natural History of Clay	1912	Camb. Univ. Press.
,,	Cement, Concrete, and Bricks	1912	Constable.
,,	Kilns and Kiln-building	1915	B. C.
,,	Refractory Materials: their Manufacture and Uses	1917	G.
,,	Ceramic Industries Pocket-book	1920	Pitman.
,,	Clays and Clay Products	1915	,,
Seger, H.	Collected Writings	1903	W.
,,	Gesammelte Schriften	1908	T.
Selch	Der Einfluss der basischen Flussmittel auf die Haarrissigkeit und den Schmelzpunkt von borsaurefreien Bleiglasuren	..	T.
,,	Aufschliessende Wirking des Kalkes in keramischen Massen	..	T.
Sexton, H.	Fuel and Refractory Materials	1913	Blackie.
Shaw, S.	History of the Staffordshire Potteries (re-issued 1900)	1829	S. G.
,,	Chemistry of Pottery Materials (re-issued 1900)	1837	S. G.
Singer, F.	Ueber künstliche Zeolithe und ihren Konstitutionellen Zusammenhang mit anderen Silikaten	..	T.
,,	Die Keramik im Dienste von Industrie	1923	Spr.
Solon, M.	Ceramic Literature	1910	G.
Sommerfield	Die Kristallglasuren	..	T.
Stark, J.	Die physikalisch-technische Untersuchung keramischen Kaoline	1922	Spr.

Author.	Title.	Date.	Publisher.
Steger, W.	Die Bedeutung des Wärme-ausdehnungskoeffizenten für die Beständigkeit von keramischen Massen gegen Temperaturwechsel	1924	Spr.
Steinbrecht, G.	Steingutfabrikation	1891	T.
Stephenson, H. H.	Ceramic Chemistry	1913	Davis Bros.
Stoermer, Dr	Untersuchungsmethoden	1902	T.
Stöffler	Die Kalksand Steinfabrikation	..	T.
Strele, C..	Porzellan- und Glas-malerei	..	T.
,,	Fabrikation des mit stark feuerfarben dekorierten Feldspat-Porzellans	1868	T.
,,	Handbuch der Porzellan-Malerei	1883	T.
Swoboda, C. B.	Farben zur Dekoration von Majolika	1891	T.
,,	Grundriss der Tonwaren Industrie.	1894	T.
Tenax, B.	Steingut- und Porzellan Fabrikation	1879	T.
Toldt, F..	Ueber künstlichen Zug	..	T.
Tostmann	Blei-, borsaure- und natronfreie Steinglasuren	..	T.
Treadwell	Studien über die Porosität keramischer Massen	..	T.
Tscheuschrer, E.	Bewertung von Tongruben	1906	T.
,,	Handbuch der Metalldekorierung, oder Dekorieren und Verfeinern von Metallwaren, Glas, Porzellan, und Gewerbe im Feuer, sowie auf Chem. und Wege	..	T.
Uhlenhuth, E.	Formen und Giessen	1899	T.
Ulke, R.	Katechismus de Porzellan Malerei.	1894	T.
Vogt, G.	La Porcelaine	1893	T.
Vogt, J.	Die Silikatschmelzlösungen (2 vols.)	1903	T.
Weber	Handbuch der Ziegeleitechnik	1923	T.
Werner, P.	Die feuerfeste Industrie	1910	T.
Wernicke	Die Herstellung der feuerfesten Steine	1921	Spr.
Wernicke und Wildschrev	Untersuchung der Quartzite und die festellung ihrer Verwendbarkeit in der feufesten Industrie, besonders zur Herstellung von Dinassteinen. Eine petrographische-technische Studie	..	T.
Wheeler, H. A.	Vitrified Paving Brick.	..	W.
Willert	Berechung Keramischer Massen	..	T.
Winkler	Lehrbuch der tech. Gasanalyse	1901	T.
Wipplinger, L.	Keramik	1897	T.
Wilson, H.	Ceramics: Clay Technology.	1927	M'Graw-Hill.
Wolf	Das Giessen freistehender Klosetts	..	T.
Zacharias, A.	Die Ziegeleitechnik in modernen Fabrikbetrieben	1926	T.
Zimmer, G. F.	Mechanical Handling and Storing of Material	1917	C.
Zoellner	Natur des Porzellans	1909	T.
Zschokke, B.	Untersuch. über Plasticität	..	T.
,,	Untersuch. zur tech. Analyse der Ton	..	T.
Zwick	Natur der Ziegeltone und Fabrikation	1894	T.
Anon.	Clay Glazes and Enamels	..	B.
,,	Clays, Tables of Analyses	..	B.
,,	Practical Brick and Tile Book	..	B.
,,	Scumming and Efflorescence	..	B.

New books on Clayworking and allied subjects—including Geology, Mineralogy, Chemistry and Engineering—are constantly being published. The most important ones are reviewed in the Journals mentioned on the next page.

JOURNALS.

The following are the leading periodicals dealing with Clayworking so far as the manufacture of bricks, tiles, terra-cotta, sanitary ware, and other pottery is concerned.

Title.	Issued.	Address.
British Clayworker	Monthly	B. C.
Brick and Pottery Trades Journal	Monthly	M.
Pottery Gazette and Glass Trade Review	Monthly	S. G.
English Ceramic Society Transactions	Annually	North Staffs. Tech. College, Stoke-on-Trent.
Journal of the Iron and Steel Institute	Bi-annually	28 Victoria Street, Westminster.
Society of Glass Technology	Quarterly	The Glass Dept., The University, Sheffield.
Journal of the Society of Chemical Industry	Fortnightly	Central House, Finsbury Square, London.
China Clay Trade Review	Monthly	Ernest Benn, Ltd., Bouverie House, Fleet Street, E.C. 4.
Pottery and Glass Record	Monthly	324–5 High Holborn, London.
Bulletin of National Association of Clayworks Managers	Monthly	6 Blenheim Road, Moseley, Birmingham.
Refractories Journal	Monthly	9 Paradise Square, Sheffield.
Ceramic Industry	Monthly	B.
The Ceramist (continued since Dec. 1926 as Ceramic Age)	..	224 Market Street, Newark, N.J.
The Ceramic Age	Monthly	170 Roseville Avenue, Newark, N.J.
American Ceramic Society Transactions	Annually	Columbus, Ohio, U.S.A.
American Ceramic Society Journal	Monthly	Rutger's College, New Brunswick, N.J.
Brick and Clay Record	Fortnightly	Plymouth Court, Chicago, Ill., U.S.A.
The Clayworker	Monthly	R.
Tonindustrie Zeitung[1]	Thrice weekly	T.
Keram. Rundschau	Monthly	T.
Deutsche Toepfer Ztg.	Twice weekly	19 Muehlweg, Halle a S.
Mittl. deutschen Tonwarenfabrikanten	Annually	T.
Tonwarenfabrikant	Fortnightly	J. Bührer, Konstanz, Germany.
Zentralblatt	Weekly	Porzellangassen 49A, Wien ix, i.
Feuerfest	Monthly	Thiemstrasse 6, Leipzig, O 27.
Kolloid Zeitschrift	Monthly	T. Steinkopff, Residenzstrasse 12 B, Dresden-Blasewitz.
Berichte der deutschen Keramischen Gesellschafts	Every two months	Wegelystr. 1, Berlin, N.W. 87.
Sprechsaal	Weekly	Coburg, Germany.
Taschenbuch für Keramiker	Annually	T.
Silikat Zeitschrift	Monthly	Sprechsaal, Coburg.
Revue des Matériaux de Construction	Monthly	148 Boulevard Magenta, Paris.
Revue Générale de Céramique verriere et Chaufournerie	Annually	51 Rue de Paradis, Paris.
La Céramique	Monthly	Paris.

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[1] An Index to the *Tonindustrie Zeitung* from 1876–1926 was published by T. in 1927 under the title of *Literatur Verzeichnis*.

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