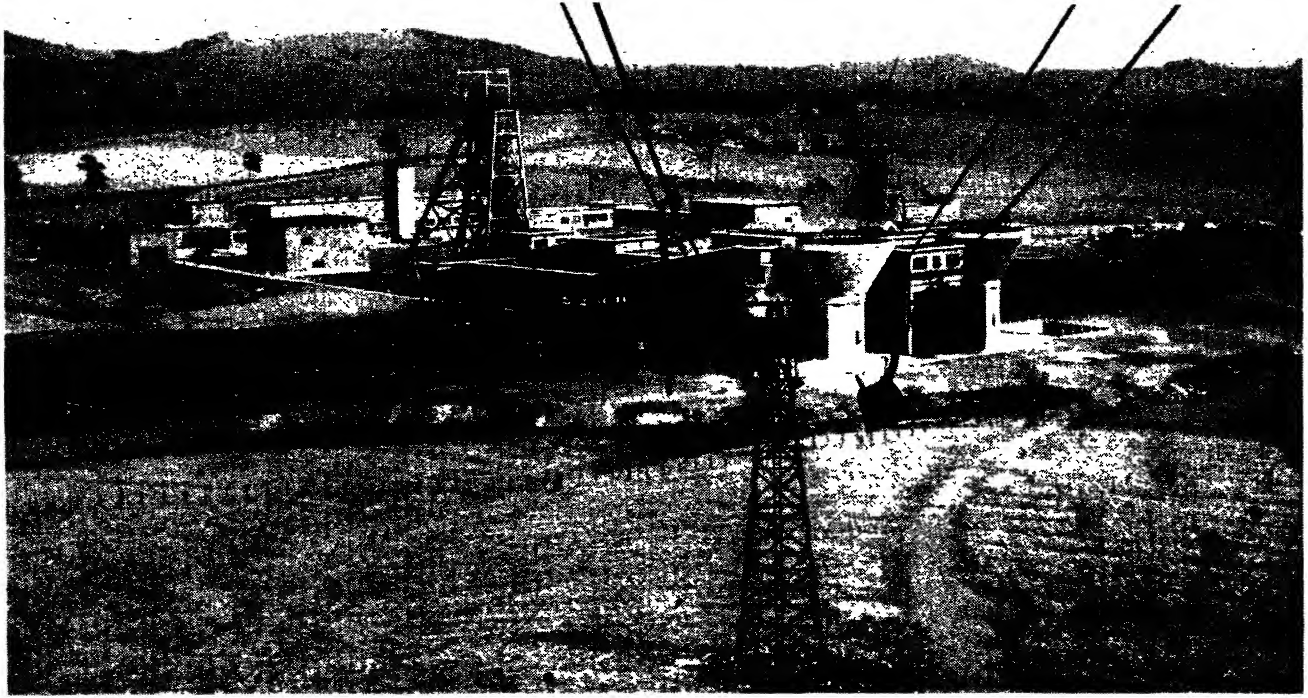
COAL

Production • Distribution
Utilisation



GENERAL VIEW OF COMRIE COLLIERY

This photograph was taken by *The Scotsman* on behalf of the Fife Coal Co. Ltd.; it is now published with the kind permission of the Scottish Division of the National Coal Board

COAL

Production · Distribution Utilisation

THIS BOOK HAS BEEN PRODUCED BY
THE COAL INDUSTRY SOCIETY AND
THE INSTITUTE OF FUEL IN
RESPONSE TO A GENERAL REQUEST
FROM ALL SECTIONS OF THE INDUSTRY

Edited by P. C. Pope

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PREFACE

AFTER the termination of hostilities in 1945 the Coal Industry Society on resuming its educational activities realised the need for the issue of a book similar in character and scope to that published jointly with the Institute of Fuel in 1931 entitled " The Preparation, Selection and Distribution of Coal."

Accordingly, a Committee was formed to decide the contents of a new book, choose the authors and carry out the necessary work. The personnel of this Committee was as follows:—

THE COAL INDUSTRY SOCIETY

L. L. Irwin, *Chairman.*
L. A. Dinnin.
A. Jackson, *Hon. Secretary.*

THE INSTITUTE OF FUEL

P. C. Pope, *Editor.*
R. W. Reynolds-Davies.
A. Coe.

THE FUEL RESEARCH STATION

Dr. A. Parker.
Dr. D. T. Davies.

The whole work has been completely re-written and extended, including particularly a section on Analysis of Coal.

A glance at the contents will indicate that the book is in no way a purely technical one. It gives a survey of the Industry from the coal face to the industrial and domestic appliances designed for the use of coal, electricity and gas. The authors are acknowledged experts each in his own branch of the subject. Their contributions are in plain language easily understandable to the student or stranger to the Industry.

It is hoped that this book will prove useful to members of the Trade who may be following one or other of the educational courses now available, to business men and women who wish to know more of the Coal Industry, and to users of coal both in this country and abroad.

The thanks of the Coal Industry Society and the Institute of Fuel are due to all who have helped in the production of this publication, and especially to the Director and Staff of the Fuel Research Station who have been responsible for a large part of the contents, and to Mr. P. C. Pope who has had the arduous task of editing the work.

Signed

HYNDLEY,
President, Coal Industry Society

D. T. A. TOWNEND,
President, Institute of Fuel

Chapter I

THE FORMATION, COMPOSITION AND CLASSIFICATION OF COAL

by A. C. MARIES*

COAL is a natural fuel, occurring in layers in the earth's crust, composed mainly of plant material that has suffered partial decay and has been further altered by the agencies of heat and pressure. This definition excludes carbonaceous shales and oil-shales, in which inorganic or incombustible material predominates. Strictly, it also excludes peat, which does not satisfy the latter part of the definition, but as peat was the parent material from which most coals were formed it is often regarded as coal in an immature condition.

Coal is not adequately described by this definition, however. The different kinds of plant material vary in their proportions in different coals, and the decay and subsequent alteration of the material proceeded to different degrees. As a result, coals show great variety in their chemical and physical properties, and, because of this, in their behaviour in practical use. Much of the present chapter is an elaboration of the definition given above, describing the origin, nature and composition of coal, and showing that the many different varieties of coal are closely related in a continuous series.

FORMATION OF COAL

Accumulation of Plant Material

The impressions of leaves and of the bark of trees, often seen in shale bands associated with coal seams, show that trees were abundant when the coal seams were formed. Microscopical examination of the coal itself, however, shows the association to have been much closer, and that coal consists of the compressed and altered remains of tree fragments. How the trees were transformed into coal is largely a matter of conjecture, but the following account is in accordance with the evidence from the coal seams and their associated strata, as well as from a study of possible coal-forming conditions existing in certain parts of the world today.

About 250 million years ago, much of the area now occupied by Great Britain was covered by a large shallow lake or swamp surrounded by low-lying land, which, here and there, extended as promontories far into the

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* *Principal Scientific Officer, Fuel Research Coal Survey, D.S.I.R.*

lake and sub-divided it into several parts. The climate at this time is considered to have been warm and humid, with a heavy rainfall, so that conditions were favourable to the growth of luxuriant vegetation. Large trees, many resembling giant ferns, grew in dense forests on the low-lying land or in the shallow waters of the lake, and succeeding generations of trees as they died accumulated on the floor of the lake, forming a vegetable sludge.

Two opposing theories regarding the method of accumulation were very much argued in the past. According to one, the trees grew on dry land and in times of flood were carried in large floating masses by the rivers into the lake; this is called the "drift" theory, and its supporters pointed to the same phenomenon occurring in modern times in the Mississippi and other large rivers. The other theory, known as the "growth *in situ*" theory, maintained that the trees grew in shallow water and accumulated where they fell; this condition can also be seen at the present time in the Great Dismal Swamp of Virginia and North Carolina, and in the coastal swamps of the tropics. The view now generally held, as will be seen later, is that both methods probably operated in the formation of British coal seams.

From time to time sinking of the floor of the lake or swamp drowned the forests, and sediments (sand and mud) carried by rivers were deposited in layers above the vegetable sludge. Eventually, with a halt in the sinking, the water became shallow again, trees re-established themselves, and the whole cycle was repeated. This occurred many times over, so that there accumulated twenty or thirty or even more layers of vegetable sludge separated by layers of sand and mud. The last two materials, with little more change than hardening, eventually formed sandstone and shale, but the conversion of the plant material into coal involved a considerable change in composition.

Conversion of Plant Material to Coal

Many theories have been put forward to explain this change, or "coalification" as it has been called, but it is now generally agreed that the main agencies were bacteria, heat and pressure. Although, according to one theory,(1) the first of these is considered to have been the most important cause of coalification, the most widely held view is that bacterial action occurred only in the early stages of coalification and was very limited in effect. Certain plant substances were rapidly broken down by the bacteria to simpler substances, while others persisted in a modified form, the total effect being that the vegetable sludge was converted into a form of peat. The subsequent changes, which were more profound, were caused by heat and pressure resulting principally from the burial of the coal swamps. These changes, as will be explained later, resulted in a gradual alteration of the composition and properties of the plant materials, and the stage of coalification or the maturity of a particular coal depends on the heat and pressure developed and on the length of time during which they were effective.

The coal seams and the intervening rocks form a series known as the Coal Measures (see p. 24), which reach a maximum thickness of over 8,000 ft. in Great Britain. In later geological periods many hundreds, and sometimes thousands, of feet of other rocks were deposited above the Coal Measures in some districts, so that the coal seams were very deeply buried. Since the temperature, as is well known from shaft sinkings, increases from the surface towards the centre of the earth, a direct effect of this burial was to raise the temperature of the rocks, including the coal seams. The temperature reached was probably not very high, and it is doubtful if it exceeded 200° C., at which temperature peat would be little affected. There were two other factors to be taken into account, however; firstly, the great pressure of the overlying rocks, amounting to about 120 lb. per square inch for every 100 ft. of cover, and secondly, the enormous length of time during which the temperature and pressure could operate.

Support for this explanation of the conversion of peat to coal is obtained from the observation, commonly referred to as Hilt's " law,"* that at a given point in a coalfield successively deeper seams tend to exhibit progressive differences, such as increase in carbon content and decreases in volatile matter content, which indicate an increasing degree of coalification. Though many exceptions occur between successive seams, the " law " applies fairly generally if widely-spaced seams are considered.

The effect of the time factor is demonstrated by the generalisation that, in various parts of the world, the coal seams in younger geological formations tend on the whole (though there are important exceptions) to be less mature or less coalified than those in older formations. The coal seams of Great Britain, with a few unimportant exceptions, all occur in one geological formation, but those exceptions agree with this generalisation—viz., the exceptions, being young coals, are all immature.

While the main course of coalification was probably decided by the heat and pressure resulting from burial of the coal swamps, two other factors in some instances played a part in bringing about the changes. The first of these was pressure, accompanied by heat, occurring in regions of intense earth movements—i.e., in regions where stresses and strains in the earth's crust were being eased by folding or sideways movement of the rocks. The effect was to increase the degree of coalification of the seams towards the region of most intense disturbance. The best-known example of this type of regional change in Great Britain is in the South Wales coalfield, where the lateral change in the properties of the coal seams is very marked (see p. 42).

The second factor was the heat from the molten igneous rocks that were sometimes intruded into the Coal Measures. These occurrences were usually very localised, and in this country they are mainly confined to a few districts in Scotland (p. 29).

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* *Actually, this is simply a generalisation based on observation, and not in the scientific sense a law. It is also of interest to record that, though attributed to the German Hilt, who recorded the observation in 1873, the same observation had previously been made by Dumont (French) in 1832, by De la Beche (English) in 1846, and by Dormoy (French) in 1867.*

METHODS OF EXAMINATION OF COAL

The following descriptions of the methods of examination of coal adopted by different workers give only brief outlines of the aims of the methods and of some of the procedures adopted. They are intended simply to explain some of the technical terms used in this book, but they also give some idea of the scientific work that is being carried out in order to obtain a fuller knowledge of coal and so to enable better use to be made of the country's coal resources.

Fuller accounts must be sought in text-books, some of which are mentioned in the References at the end of this chapter.

Chemical and Physical Analysis

The principal chemical and physical methods of examination used by the coal chemist are described in Chapter IX.

Study of Coal Constitution

The original vegetable matter from which coal was formed consisted of cellulose, lignin, resins, and other complex substances composed mainly of carbon, hydrogen and oxygen. In the process of coalification these were partially or completely changed, with the formation of other complex substances known as ulmins. The ultimate analysis (see p. 126) gives the composition of coal as percentages of carbon, hydrogen, oxygen, nitrogen and sulphur, but it throws no light on how these elements were combined—i.e., on the chemical constitution of the ulmins and other substances in the coal. Until comparatively recently practically nothing was known about the constitution of coal, but during the past twenty or thirty years much research work has been carried out on the subject, because it is believed that when the constitution is fully known many problems of coal utilisation will be brought nearer to solution.

The results already obtained go some way to explaining the behaviour of different coals during combustion, carbonisation and other methods of utilisation.

The main lines of investigation into the constitution of coal(2) can be summarised as follows: —

(1) Decomposition of the coal over a wide range of temperatures, beginning at about 200°C., followed by chemical examination of the products obtained at each stage of decomposition. Some workers carry out the experiments in a high vacuum.

(2) Separation of coal into fractions by the action of solvents, of which benzine and pyridene are the most commonly used, followed by examination of the materials extracted.

(3) Degradation or breaking down of the coal by the controlled action of chemical reagents, with chemical examination of the simpler compounds so produced. The chief method adopted by workers using this method is mild oxidation of the coal.

Microscopical Examination of Coal

The use of the microscope to examine coal is a method confined almost entirely to the research laboratory, but this does not mean that the method is without practical value. By identifying the different kinds of plant material the method has given a clearer understanding of the formation of coal; it has helped to distinguish the banded constituents and other coal types (see pp. 9–13); it has helped to explain the differences in behaviour of these types—for example, why cannels and bogheads have higher volatile-matter contents and oil yields than other coals; and it is widely used as a means of correlating seams—i.e., of identifying the same seams in different parts of a coalfield.

For microscopical examination(3), three general methods of preparing the coal are available—viz., thin sections, polished and etched surfaces, and maceration. The procedure adopted by different workers varies greatly in details, but the following brief descriptions will explain the general principles.

To prepare a thin section, one surface of the coal specimen is ground flat and polished and then affixed to a small piece of glass sheet, using a special transparent cement. With a fine-toothed saw a cut is made so as to leave a layer of coal about ⅛in. thick adhering to the glass. This slice is next ground thin by rubbing it on wet carborundum on glass plates, using successively finer grades of carborundum and finally a smooth-grained hone held in a stream of water. The section is usually polished with a suitable powder, such as is used by jewellers, before cementing on to it a thin glass slip for protection. The thickness of the section varies according to the opacity of the coal, but it is frequently less than 1/5000in.

With increasing coalification, coals become more opaque, so that with anthracites and Welsh steam coals it is impossible to prepare sections thin enough to pass light. For such coals the method employed is to examine polished, or polished and etched surfaces. One face of the coal specimen to be examined is ground flat and polished, as already described, and the surface is then etched by treatment with a strong acid, or polished with certain materials in such a way as to bring the tougher parts of the plant material into relief.

Some workers achieve the relief effect by burning the polished surface with a hot flame.

Maceration, or softening of the coal by chemical treatment, is employed when it is desired to study the more resistant plant remains, such as the spore exines or outer cases of the small spherical bodies that serve, in flowerless plants, as seeds. The larger female megaspores can be examined in thin sections, and, although in a flattened condition, different types can be recognised by their shape and thickness. The smaller male microspores are too minute for this, however, and to study their shape and surface markings they are separated from the coal by maceration. The same method is sometimes adopted for the study of megaspores.

CHEMICAL COMPOSITION OF COAL

All coals contain greater or lesser amounts of moisture and mineral matter which, since they are incombustible, are commonly referred to as "inerts." In discussing the composition of the coal, these will be treated separately from the combustible part, or pure coal substance.

Coal Substance

Plants grow by the action of sunlight, stimulated by minute quantities of mineral salts, upon carbon dioxide (CO_2) and water (H_2O), which are built up to form the cellulose and other complex substances of the plant. The vegetable sludge of the original coal-forming swamp therefore consisted mainly of carbon, hydrogen and oxygen, and the composition of the coal substance eventually formed can best be considered by outlining the changes that occurred during the process of coalification.

The exact course of these changes is not known, but all the evidence points to a gradual loss of carbon, hydrogen and oxygen, most probably by the elimination of water, carbon dioxide, and methane (CH_4). Thus the whole substance suffered wastage, but as the hydrogen and oxygen were lost at proportionately higher rates than the carbon, the net result was that the carbon content of the maturing coal increased with the degree of coalification. The extent of these changes is shown by the following analysis of wood, representing the starting material, and anthracite, which is the most mature form of coal: —

	Wood	Anthracite
Carbon, per cent.	50.0	96.0
Hydrogen ,,	6.2	3.0
Oxygen ,,	43.8	1.0

The alteration was gradual and continuous, and coals of all degress of coalification are found in different parts of the world. The maturity or stage of coalification reached by a coal is referred to as its rank. Rank is not measured in percentages, or other units, though it is judged by composition, particularly the carbon or the oxygen content of the coal; the term is used only in a comparative sense, in such expressions as high rank, medium rank and low rank. It does not imply any superiority or inferiority of quality, and low-rank, for example, does not mean poor quality.

As a result of the changes in the relative proportions of carbon, hydrogen and oxygen, other characteristics also change. With increasing coalification —i.e., increase of rank—the volatile content of the coal decreases, mainly because of the decrease in the proportion of hydrogen to carbon. The calorific value or heating power rises as the oxygen falls, though in the highest rank coals it becomes slightly lower owing to the sharper decline in hydrogen at that end of the scale. The caking properties, which confer on a coal the ability to yield coke on carbonisation, show a change that has not yet fully been explained in terms of composition of the coal: they are nil in the lowest rank coals, rise to a maximum in the medium-rank coals, and fall to nil again in the high-rank coals (see p. 20). Other characteristics that are modified as a result of change of rank are mentioned at the end of this chapter.

Two elements—nitrogen and sulphur—which enter into the composition of the coal substance have not so far been mentioned. They each amount to about 1 or 1½ per cent., and show no marked variation with change in rank. The part they play in the chemistry of coal is not fully understood, but compared with carbon, hydrogen and oxygen they are relatively unimportant.

Moisture

The moisture in coal can be considered to occur in two parts, though the dividing line between them is not absolutely definite. One part, called the " free " moisture, occurs on the surface of the coal and in its cracks and joints. It is easily lost by evaporation, and except during unusually wet and cold weather the amount of free moisture in sized grades of coal is generally small when it reaches the consumer, but washed smalls, which sometimes drain badly, may retain considerable quantities. Large amounts of free moisture are clearly undesirable in the coal as purchased, since they have to be paid for at the same price as coal. On the other hand, a limited amount of free moisture is not always unwelcome in the coal as eventually used, and water is often added to dry smalls to assist combustion.

The other part, called the air-dried or inherent moisture, is more intimately held in the fine pores of the coal, and under normal atmospheric conditions it is not removed by evaporation; it is in fact so much a part of the coal, varying characteristically with different types of coal, that the percentage of air-dried moisture can be used as a broad indication of the rank of a coal. The amount retained, however, while dependent mainly on the rank of the coal, is to some extent affected by the atmospheric conditions existing at the time of air-drying. For these reasons the conditions under which coal is air-dried in preparation for laboratory examination are carefully specified (see p. 124).

Mineral Matter and Ash

The terms mineral matter and ash, as applied to coal, are not synonymous. Mineral matter refers to the various impurities as they exist in the coal, whereas the ash is the solid residue remaining after the coal has been completely burned. Although the ash is obviously derived from the mineral matter, it has not the same composition nor is it the same in amount as the mineral matter (see p. 125). On the average, the weight of ash is about 9/10 of the weight of the mineral matter.

The mineral matter in coal is derived from several sources. A very small part of it comes from the mineral constituents that formed an essential part of the original plant material. The second and main source is the clay and silt washed into the coal-forming swamp. This material was in part distributed throughout the vegetable sludge, but occasionally it formed layers with but little plant material admixed. These shaly layers are in some instances only a fraction of an inch in thickness, but in others they may reach several inches. A third source of mineral matter was infiltration by water carrying salts dissolved from overlying strata. The golden grains or nodules of pyrites often seen in the coal were formed this way, as well as the thin plates of ankerite or spar found in the vertical joints and cleavages.

The average ash content of British coal seams as they occur in the ground is between 4 and 5 per cent., but the amount in the coal as worked is often higher, owing to the inclusion of bands of shale or other " dirt " bands occurring in many seams.

The composition of the ash(4) is often of great importance, because of its effect on the fusibility or clinkering tendency of the ash. The relationship between the composition and fusibility is not fully understood, but the following partial explanation is generally accepted. The principal constituent of coal ash is aluminium silicate, or clay admixed with the coal during its formation. This substance by itself is highly-refractory or infusible. Most coal ashes also contain iron, however, and when this is appreciable in amount, especially if lime and magnesia are also present, complex silicates with lower fusibilities are formed during the combustion of the coal.

The laboratory examination of a coal often includes the determination of the melting point or fusion temperature of the ash, in order to give some indication of the clinkering tendency of the ash. A single fusion temperature is of little value, however, for clinkering is greatly affected by the nature of the atmosphere in which the coal is burned—for example, clinker generally forms at a lower temperature in zones where there is insufficient air for complete combustion (reducing atmosphere) than in zones where there is adequate air (oxidising atmosphere); both reducing and oxidising conditions can exist in different zones in the same appliance. It is, therefore, now usual to record the ash fusion temperatures as determined in a mildly reducing atmosphere and in an oxidising atmosphere, and to give two temperatures for each atmosphere—viz., the initial fusion temperature, at which softening can just be detected, and the final fusion temperature (often called the squatting point), at which the sample being tested loses its original form and becomes more or less fluid. The following fusion temperatures (for a mildly reducing atmosphere) indicate broadly the clinkering tendencies of coal ash:—

Final fusion temperature	
Over 1400°C.	Little or no clinker.
1200—1400°C.	Clinker formation probable, but not serious
Under 1200°C.	Clinkering likely to be serious

The temperature difference between the initial and the final fusion temperature is also of importance in judging the fusibility of an ash. For ashes having about the same final fusion temperature, those with small differences such as 50°C. will have a greater tendency to form clinker than those with differences of 100°C. or more.

Bases of Reporting Analyses

Before leaving the subject of the " inerts " (moisture and ash), some consideration must be given to the bases of reporting coal analyses. Most analytical determinations are carried out using air-dried coal, since as already mentioned, the coal in this state is fairly stable and represents the coal with the proportion of moisture properly belonging to it, without added or free moisture. Analyses are therefore usually reported on the air-dried basis, and the consumer converts this by calculation to any other basis he requires.

For accurate measurement of the efficiency of coal utilisation, such as boiler trials or the preparation of weight balances of carbonisation yields, the analyses must relate to the coal exactly as it exists at the time of use. This is achieved by re-calculating the air-dried analysis figures to take account of any moisture in excess of the air-dried moisture; the analysis is then said to be on the " as received " or " as fired " basis. To enable this calcuation to be made, the total moisture content must be determined in a sample of coal specially taken at the time the trial is carried out (p. 122).

In some instances, consumers prefer to use analyses recorded on the dry coal basis—i.e., analyses calculated on the assumption that all the moisture has been removed from the coal. The main advantage of using this basis is that it facilitates direct comparison of the ash contents of coals having different inherent moisture contents.

For comparison or classification of the coal substance, analyses on the dry ash-free basis are used—i.e., analyses are re-calculated on the assumption that the coal has been completely freed of its moisture and ash contents. The aim of comparing the pure coal substance is not really achieved by using this basis, however, for as already stated, the percentage of ash remaining after the coal has been burned is not the same as the percentage of mineral matter in the unburnt coal, and it is the latter quantity that must be removed—in theory—from the coal by calculation. For very accurate investigations and comparisons, therefore, analyses must be calculated to the dry mineral-matter-free basis (see also p. 126).

All analytical figures quoted in this chapter are on the dry ash-free basis, unless otherwise stated.

BANDED STRUCTURE OF COAL

The fact has long been recognised that many coal seams are not uniform throughout their thickness but consist of more or less parallel layers varying in appearance and hardness. From early times miners have distinguished three kinds of layer—" brights " or " softs," dull coal or " hards," and mineral charcoal or " mother-of-coal," a soft, powdery material occurring only in occasional thin layers.

A careful examination of the different layers in a number of coal seams led Dr. M. C. Stopes in 1919 to the conclusion that there were in fact four distinct types of coal layer or " banded constituents," which she defined according to their appearance as seen by the unaided eye, and to which she gave the names, vitrain, clarain, durain and fusain(5). Since that date the banded constituents have been studied by many workers. They have been carefully separated and examined by means of the microscope, as well as by chemical analysis and the special methods used to elucidate the nature of the compounds in coal (p. 4). Much controversy has ranged over the subject, both as to the nature of the banded constituents and as to the naming of them. The focusing of attention on the banded constituents has thrown considerable light on the probable methods of deposition of coal, and the results have not been without benefit to the consumer, for they have helped to explain the behaviour of different kinds of coal during carbonisation and combustion. In the following paragraphs descriptions are given of the main characteristics of the four types, and of the less common cannel and boghead types.

Description of Banded Constituents

Vitrain occurs in thin layers, seldom more than ¼in. in thickness. It has a black glassy lustre and breaks with a conchoidal or shell-like fracture, though sometimes it tends to form small cubes. When viewed in thin section under the microscope it is orange-red in colour. Though originally considered to be devoid of recognisable plant remains, improvements in the methods of examining coal microscopically have shown vitrain to possess obvious traces of cell structure, sometimes preserved in the finest detail, the cell cavities being generally filled with ulmin substances. In many instances the layer is seen to consist of a single piece of bark which in well-preserved specimens can be referred to a particular species of tree. Bark fragments are in fact very common in coal seams, the reasons being that the cell tissue of bark is tougher and more resistant to decay than that of the softer wood, and that, in contrast to modern trees, bark formed the greater part of the Coal Measure trees.

Clarain is not so uniformly bright as vitrain. To the naked eye it has a silky lustre, and on a vertical face it is seen to be finely laminated. It breaks usually with a splintery fracture. Examination under the microscope shows the laminations to be due to thin streaks of vitrain interbanded with more opaque layers composed of highly fragmented plant remains; among these may be identified, in addition to cellular plant material, the tough outer layers of leaves and spore exines. Clarain in fact should be regarded not as a separate constituent, but as a mixture of vitrain and durain. Compared with other constituents about to be described, it includes relatively large plant fragments, particularly in the vitrain bands, and it seems reasonable to assume that the bright coal or clarain was formed from material that was not transported into the swamp but came directly from the trees growing there.

Durain is black or greyish black in colour, with a dull lustre. It is appreciably harder than clarain and vitrain, and has less vertical jointing or cleavages, so that in thick bands it tends to form large blocks on mining. As will be noted in the second part of this chapter, in some seams the durain bands are very thick and are persistent over wide areas. In thin section durain is much more opaque than bright coal. The nature of the plant remains composing it is very variable, but there can be seen, in varying proportions, spore exines, leaf cuticle, beads of resin and shreds of vitrain set in an opaque mass of finely-divided plant material. The fragmentary nature of the plant material in durain suggests that it results from the deposition of a sort of vegetable mud carried by rivers into the coal-forming swamp, and this view is strengthened by the fact that durain generally contains a higher proportion of clayey impurities than is usual in bright coal. By increase of the impurities, durains merge into carbonaceous shales. With increasing amounts of spore material, on the other hand, durain merges into cannel.

Fusain occurs in layers which are usually not wide in extent and seldom exceed $\frac{1}{8}$in. in thickness, though exceptionally the layers are thicker and cover a wider area. It is normally a soft, powdery charcoal-like material, which is largely responsible for the dustiness of coal, and it can be readily identified on lumps of coal along the surfaces that were originally parallel to the roof and floor of the seam. Under the microscope fusain is seen to consist of opaque cellular tissue, with empty cell cavities. Sometimes, however, fusain is dense and hard, and microscopical examination then shows the cells to be filled with mineral matter. Several theories have been advanced to explain the formation of fusain; its charcoal-like appearance suggests forest fires, but another theory is that the occasional drying out of the surface layer of the swamp caused different conditions of decay.

Cannels and Bogheads

Cannels are compact fine-grained coals with a satiny lustre. They have no cleats, or vertical jointing, and they break with a conchoidal or shell-like fracture. Under the microscope they are seen to consist of finely-divided plant material in which are often embedded large numbers of spore exines. The ash content of cannel is usually high.

Bogheads, also known as torbanites, are similar to cannels in appearance, except that they tend to be browner in colour. Examination under the microscope, however, shows them to contain, in addition to the constituents of ordinary cannels, large numbers of round flattened yellow bodies, which are considered to be the remains of algae. In some bogheads the algae constitute the greater part of the coal. As regards their origin, it seems probable that cannels and bogheads accumulated in pools or lagoons within the coal-forming swamp.

Composition of Banded Constituents

The foregoing descriptions indicate that the banded constituents, as well as cannels and bogheads, are each characterised by appreciably different proportions of the various kinds of plant material, resulting from different methods of accumulation in the coal-forming swamp. As a result, there are important differences in the composition and other characteristics of the constituents. In general, the bright coal (clarain) has a lower carbon

TABLE 1

Analyses of Banded Constituents (Silkstone Seam, Yorkshire) and Torbanite (Fifeshire)

	Vitrain	Clarain	Durain	Fusain	Torbanite
Proximate analysis air-dried basis (per cent.) :—					
Moisture	1.1	1.0	0.8	0.8	1.1
Volatile matter less moisture	33.0	35.8	34.5	16.3	55.6
Fixed carbon	65.4	61.1	58.9	64.4	17.5
Ash	0.5	2.1	5.8	18.5	25.8
Volatile matter on dry ash-free basis	33.5	36.9	36.9	20.2	76.1
Ultimate analysis dry ash-free basis (per cent.) :—					
Carbon	87.3	86.7	88.9	89.6	78.5
Hydrogen	5.5	5.6	5.8	3.4	9.8
Nitrogen	1.5	1.6	1.3	0.5	1.1
Sulphur	1.0	1.5	0.7	5.6	4.0
Oxygen	4.7	4.6	3.3	0.9	6.6
Caking properties	Strongly caking	Strongly caking	Weakly caking	Non-caking	Non-caking

content and a higher hydrogen content than dull coal (durain) from the same seam, and its volatile matter content is in consequence higher. When the durains are rich in spore remains, however, the hydrogen and volatile contents are higher than those of clarain and vitrain. In seams that exhibit caking properties, the bright coal is more strongly caking than the dull.

The composition of cannels and bogheads is markedly different from that of normal coals: the carbon content is lower, while the hydrogen content is higher, especially in bogheads with large concentrations of algae. As a result the percentage of volatile matter is high, being usually well over 50, whereas in normal coals it does not exceed 45 and is often much less. On carbonisation the yields of gas and oil are high, the latter being from 40 to over 100 gallons per ton, compared with 10 to 20 from a normal coal. The gas has also a high illuminating value, and it was for this reason, as well as the high yields, that cannels and bogheads were once so much in demand for gas-making, since gas of high candle-power was required for burners of the batswing type. With the introduction of the incandescent gas mantle the demand for cannel declined, and nowadays when it is present as a layer in a coal seam it is usually sold in admixture with the remainder of the coal.

Mineral Matter in Banded Constituents

The mineral matter and ash content of coal can also be related broadly to the method of accumulation of the various constituents. Vitrain, consisting of single plant fragments, is characterised by a low ash content, usually less than 1 per cent. Clarain, which includes considerable proportions of vitrain, also tends to be low in ash, which usually amounts to between 2 and 3 per cent. Durain, cannels, and bogheads, on the other hand, contain appreciable quantities of clay material carried into the swamp with the plant mud; their ash contents are seldom less than 3 per cent., and are often very much higher. The ash content of fusain is occasionally low, but because of the filling of the empty plant cells with infiltered mineral matter, it is more often high, sometimes exceeding 20 per cent.

Analyses of the four banded constituents, separated from the same seam, are given in Table 1, together with an analysis of torbanite.

CLASSIFICATION OF COAL

General

The function of a coal classification system, if it is to be of practical value, is to group into separate categories the coals that are suitable for particular purposes or appliances. Even more important, it must exclude from any category coals that are not so suitable as other coals in the same category.

The best approach to formulating a practical system of classification would appear to be to define the requirements of different processes in a series of well-considered specifications, and to use these as the basis of classification. Unfortunately, this is not simple. By trial and error during the development of industrial coal utilisation, certain types of coal came to be recognised by their suitability for particular processes—e.g. coking coals (for the manufacture of metallurgical cokes), gas coals, steam coals and navigation coals. Though not accurately specified by analysis, these names were attached to certain coals and for a time served well enough as a guide to the consumer. Later improvements in plant design and in the technique of plant operation, far from narrowing the ranges of coal to which these names can be applied, has in fact widened them. At the present time, for instance, the coals used in gasworks include not only the strongly-caking coals that were once considered the only suitable type, but also medium and weakly-caking coals; the term gas coal, in fact, now lacks precise meaning. Similarly, the development of mechanical stokers for boilers and other furnaces has greatly widened the range of coals that can be efficiently used for steam-raising.

The formulation of a practical classification is further complicated by the fact that the size and purity of the coal have to be taken into account. For example, a vertical gas retort can operate successfully with weakly-caking coal if this is supplied in nut size, but for smaller sizes the coal must be more strongly caking; and for steam-raising the amount and nature of the mineral matter or ash must be considered in relation to the design of the boiler and its equipment, and may be of much greater importance than the burning characteristics of the coal substance.

No comprehensive classification covering the nature of the coal substance, the size grading, and the ash content has yet been evolved, and most existing classifications are based on consideration of the coal substance alone. Some of the systems used to classify British coals will be reviewed in the following paragraphs.

During the nineteenth century certain main classes of coal became recognised, such as lignite, bituminous, semi-bituminous, anthracite, and certain sub-divisions of these classes. Although these classes are now considered to be inadequate for grouping different types of coal, several of the terms have passed into general use, and the main features of each class will be described. The descriptions are in order of increasing rank.

Peat is not coal in the strict sense, but it is included here because it represents broadly the starting point of the coal series. It varies in colour from light brown to nearly black, this range of colour being often seen from top to bottom of the peat bed. The darker varieties are denser and show less evidence of plant remains than the lighter varieties. The moisture content of newly-won peat is very high (about 90 per cent.) and even when the peat has been air-dried it is about 30 per cent. This fact, coupled with a high oxygen content, results in the calorific value being lower. An analysis is given in Table 4.

Lignites mark the transition from peat to coal—i.e. they are the lowest rank of true coals. They include the brown coals, which have an obviously woody texture, as well as black varieties that more closely resemble normal coals. Though common in many parts of the world, the only notable occurrence in Britain is in the small Bovey Tracey basin in Devon. Here beds of lignite occur among the pottery clays, but though they are excavated during the mining of the clays they are seldom used as fuel, except to a limited extent in the clayworks boilers. Lignites have high inherent moisture contents (15 per cent. or over), high volatile contents (40 per cent. and over) and low calorific values (10,000 B.Th.U. per lb.). They readily break down to smalls on weathering.

Sub-bituminous coals are properly a group intermediate between the lignites and bituminous coals, though the name is also sometimes applied to coals near the anthracitic end of the series. In the former sense the coals are black, and show the banding common to bituminous coals, though the durain or dull coal bands are not so pronounced. They have high moisture, volatile matter and oxygen contents, and low carbon contents, all indicating the low rank of the coal.

Bituminous coals are black, with a well-banded structure—i.e. the bright and dull bands are distinctive in appearance. They cover a wide range of coals; their carbon contents vary between 75 per cent. for a coal containing about 45 per cent. of volatile matter, to about 90 per cent. for a coal containing about 20 per cent. of volatile matter; and they range from non-caking to very strongly caking. Their uses are many, including the manufacture of metallurgical cokes, gas making, steam generation, and other industrial processes. The bituminous coals, in fact, are the general purpose coals which constitute about 90 per cent. of Great Britain's coal output, and it is not surprising that most of the attention paid to coal classification is directed to this wide group.

Semi-bituminous coals form a group between the bituminous coals and the anthracites. They have between 10 and about 20 per cent. of volatile matter, and carbon contents ranging from about 90 to 93. Banding is less marked than in the bituminous coals. In this country, apart from local occurrences in Scotland, they are found only in South Wales, where they include the caking steam coals (14 to 20 per cent. of volatile matter) and the dry steam coals (10–14 per cent. of volatile matter). The caking properties decrease progressively with decrease in volatile content, and the dry steam coals are non-caking.

Anthracites form the highest rank coals—i.e. they represent an extreme stage of the conversion of the original coal-forming swamp. They have a semi-metallic lustre, and no banding is apparent to the unaided eye, though it can be detected under the microscope. The carbon contents are over 93 per cent., the volatile matter content is less than 10 per cent., and the caking power is nil. A group known as the semi-anthracites, with volatile matter between 9 and 11 per cent., is now little recognised in this country.

Classification of Coal Substance

The variations in the composition and properties of the coal substance have been mentioned in previous pages, and two causes have been discussed. Firstly, there was the change due to the process of coalification, the stage of alteration reached by a coal being known as its rank (p. 6). Secondly, there were the differences in composition due to the variations in the nature of the plant materials composing the primary coal types or banded constituents; despite the great changes in composition due to coalification, these differences persist in coals of all ranks, though they become less pronounced in the higher ranks coals. The variation in hydrogen content, though relatively small in amount, was found to have appreciable effects on the nature of the coal (pp. 6 and 11).

The results of these two causes of variation can be clearly shown by means of graphs, which also form the simplest approach to the subject of coal classification. When pairs of analytical factors, such as carbon and hydrogen, carbon and calorific value, or volatile matter and caking properties, are plotted graphically for a large number of coals, the points fall within a relatively narrow belt, often called "the coal band." Figure 1 shows the coal band obtained by plotting the carbon content against the oxygen content.(6) Here the rank of a coal is judged by its position along the length of the band. The distance from the heavy diagonal line indicates the combined percentages of hydrogen, nitrogen and sulphur; since the nitrogen and sulphur are fairly constant (averaging together about 3 per cent.), the width of the coal band is a rough measure of the variation in hydrogen contents resulting from the fact that most coals are mixtures of layers formed from different types of plant material.

The problem of classification can now be re-stated: it is to divide one or other form of the coal band into a number of sections, such that the coals falling in each section will give similar performances in the same appliances. In the form shown in Figure 1 the band is easily divided along its length, but its narrowness, due to the scales used, does not allow of easy differentiation between coals of different hydrogen content.

A classification that is well known in Great Britain, evolved by Dr. C. A. Seyler, overcomes this defect. It was first produced by Seyler as a classification based simply upon the carbon and hydrogen contents of coal, and was published in the form shown in Table 2. It will be noted Seyler had in mind the practical application of his classification, and included the "use" names of the more important classes of coal. Sub-division according to hydrogen content is an important feature of this classification.

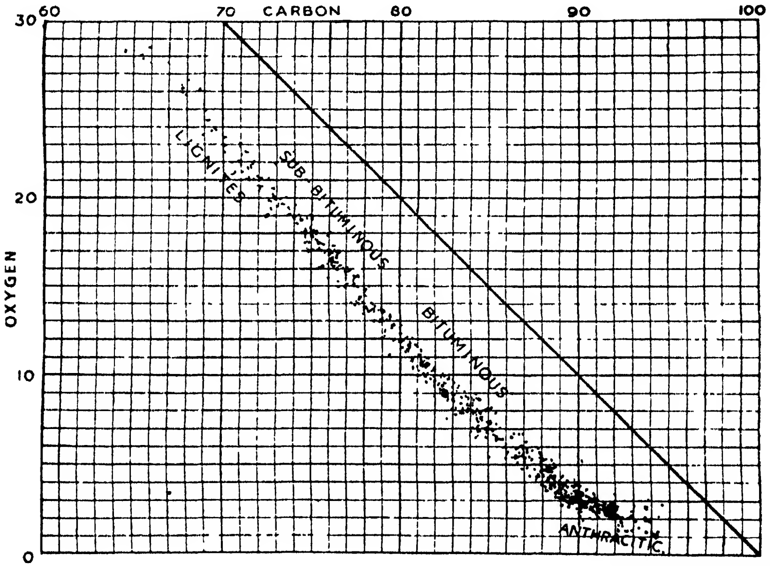

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Figure 1.

Later, Seyler produced a more comprehensive system in the form of a chart on which he depicted such characteristics as the inherent moisture content, calorific value and volatile matter content, in addition to the carbon and hydrogen ranges, which still remain the basis of the classification. A simplified form of the chart is shown in Figure 2. Only the principal coal types of Table 2 are named. The chart deserves careful study, for it gives a useful picture of some of the effects of increase in rank (right to left).

A classification of bituminous coals recently put forward and recommended

TABLE 2

Seyler's Classification of Coal[3]

Carbon	Anthracite.	Carbonaceous.		Bituminous		Lignitous.	
			Meta-	Ortho-	Para-	Meta-	Ortho-
	Carbon over 93.3 per cent.	93.3—91.2	91.2—89.0	89.0—87.0	87.0—84.0	84—80	80—75
PER-BITUMINOUS GENUS Hydrogen over 5.8 per cent.	—	—	PER-BITUMINOUS (Per-meta-bituminous) *Long flame steam coals*	PER-BITUMINOUS (Per-ortho-bituminous) *Bastard cannels gas coals*	PER-BITUMINOUS (Per-para-bituminous) *Cannels* *Long flame steam coals*	PER-LIG	NITOUS
BITUMINOUS GENUS Hydrogen 5.0—5.8 per cent.	—	(Pseudo-bituminous species)	**Meta-bituminous** *Welsh coking coal*	**Ortho-bituminous** *Durham coking coals* *Smithy and gas coals*	**Para-bituminous** *Long flame steam coals* *Coking coals* *Best gas coal*	**Ligni** (Meta-)	**tous** (Ortho-)
SEMI-BITUMINOUS GENUS Hydrogen 4.5—5.0 per cent.	—	**Semi-bituminous** SPECIES (Ortho-semi-bituminous) *Steam Coals (coking)* *Higher Index blended for coke*	SUB-BITUMINOUS (Sub-meta-bituminous) *House coals* *Continental coking when Index high*	SUB-BITUMINOUS (Sub-ortho-bituminous) *Coking and steam*	SUB-BITUMINOUS (Sub-para-bituminous)	SUB-LIG (Meta-)	NITOUS (Ortho-)
CARBONACEOUS GENUS Hydrogen 4.0—4.5 per cent.	*Semi-anthracitic* species *Dry (non-caking) steam*	**Carbonaceous** SPECIES (Ortho-carbonaceous) *Welsh smokeless steam (slight caking)*	Pseudo-carbonaceous (Sub-meta-bituminous) *Steam coals*	Pseudo-carbonaceous (Sub-ortho-bituminous)	Pseudo-carbonaceous (Sub-para-bituminous)		
ANTHRACITIC GENUS Hydrogen under 4 per cent.	**Ortho-anthracite** *True anthracite*	Pseudo-anthracite (Sub-carbonaceous)	Pseudo-anthracite (Sub-meta-bituminous)	Pseudo-anthracite (Sub-ortho-bituminous)	Pseudo-anthracite (Sub-para-bituminous)		

N.B.—The various genera are arranged in column I. vertically according to the hydrogen. The species in each genus are arranged horizontally according to the carbon.

(From Analysis of British Coals and Cokes, 1924) for general use by the Education Sub-Committee of the Fuel Efficiency Branch of the Ministry of Fuel and Power(9) is reproduced in Table 3. This classification is based upon the carbon content and calorific value, as shown by the fact that the ranges set down for these do not overlap for the different groups. Certain other data are included in the table, but these do no more than indicate the general characteristics of the coals in each group. For example, coals falling within the carbon and calorific value ranges of a particular group will not in all cases lie within the limits stated for each of the other characteristics.

During recent years, for certain investigations in which it was necessary to designate different types of coal, members of the Fuel Research organisation (Department of Scientific and Industrial Research) have used a simple classification, the basis of which is shown in Figure 3. The aim of describing this classification here is simply to show the relationship between the amount of volatile matter, used broadly as a measure of rank, and the caking properties, which largely decide the uses to which the coal can be put. A clear understanding of this relationship is of considerable importance in practice.

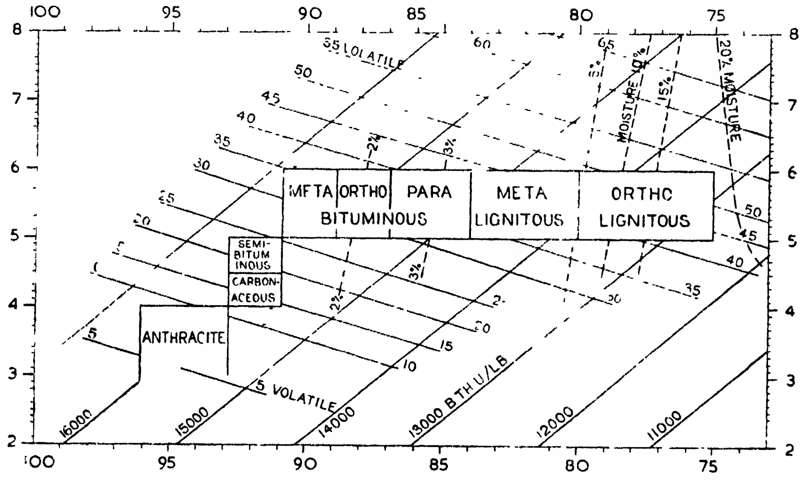

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Figure 2.

The diagram shows the maximum development of caking properties in the 20-30 per cent. volatiles range, and the decrease in these properties on both sides of this range. Even more important is the shape of the coal band in the lower volatile range compared with that in the higher volatile range. In the lower volatile range the band is narrow, showing that the caking properties are closely related to the volatile matter content. Classification in this range is in fact simply a matter of dividing the length of the coal

TABLE 3

Fuel Efficiency Classification of Bituminous Coal

Description	Group 1	Group 2	Group 3	Group 4
	Freeburning or non-caking	Slightly caking	Medium caking	Strongly caking
Analysis of dry ash-free coal :—				
Carbon, per cent.	78–81	81–82.5	82.5–84	84–89
Hydrogen, „ „	5.1–5.6	5.2–5.6	5.2–5.6	4.5–5.5
Volatiles, „ „	45–41	42–38	39–35	37–25
Calorific value :—				
B.Th.U./lb. ..	13,860–14,400	14,400–14,670	14,670–15,030	15,030–15,660
Cals./gm. ..	7,700–8,000	8,000–8,150	8,150–8,350	8,350–8,700
Inherent moisture, per cent. ..	16–10	10–7	7–4	4–2
Type of coke, Gray-King assay ..	A B	C D E	F to G_5	G_2 to G_9
W–D Swelling test	1	1½–2½	3–4½	5–9

" It may prove desirable to divide group 4 into two groups, as follows :

Carbon, per cent	84—86.5	86.5—89
Volatiles, „ ..	37—32	32—25
Calorific value		
B.Th U /lb	15,030—15,550	15,550—15,660
Cals /gm . .	8,350—8,650	8,650—8,700

Group 5 would contain coals used for making coke with a high shatter test and generally non-reactive."

band into a number of sections, and in the diagram this has been done for certain well recognised classes of coal.

In the higher volatile range on the right of the diagram, on the other hand, the band is wide. A broad relationship between volatile content and caking properties is evident, the higher rank coals (volatile matter about 30 per cent.) being strongly caking and the low rank coals (volatile matter 40 per

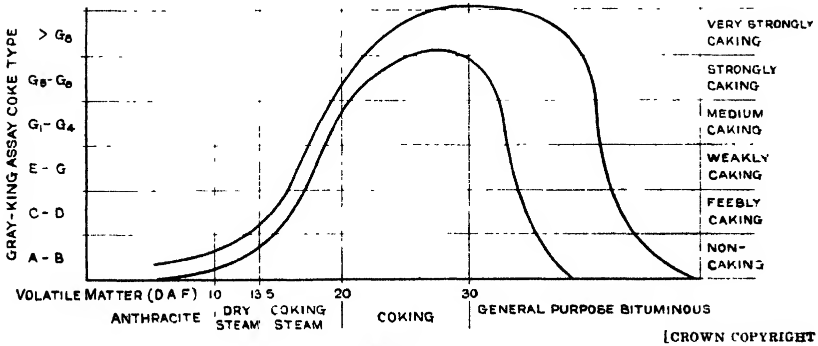

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Figure 3.

cent. and over) weakly-caking or non-caking. Between these extremes, however, the relationship is almost non-existent: coals of 36 per cent. volatiles, for instance, range from non-caking to very strongly-caking, while coals of medium caking character may give between 30 and 40 per cent. of volatile matter. This diagram, in fact, again emphasises the point that the main difficulties in classifying coal lie in suitably dividing the bituminous or lower rank types. In the particular form of coal band in Figure 3, one method of formulating a classification would be to divide the broad part of the band horizontally into four or five ranges of caking properties, and to divide each of these slices into two or more ranges of volatile matter by vertical lines. This method was in fact adopted in the Fuel Research investigations already mentioned, code numbers being used to designate each "compartment."

Many other systems of classification have been proposed, but none has found universal acceptance. Although many of the systems appear to be unrelated, they are in fact simply different forms of expressing the variations due to rank and the nature of the original plant material. A clear conception of these variations will go far towards explaining the suitability of different coals for different purposes, and to conclude this chapter the changes will be listed.

Increasing rank is accompanied by:—

(1) Increase in carbon content.
(2) Decrease in hydrogen content, particularly at the high-rank end of the series. (See Figures 1 and 2.)
(3) Decrease in oxygen content.
(4) Decrease in volatile content.
(5) Decrease in the inherent moisture content to a minimum in the caking steam coals of South Wales, with a slight increase in the anthracites.
(6) Increase in caking power from nil to a maximum in the middle of the range (the caking coals), and a decrease to non-caking in the dry steam coals and anthracite.
(7) Increase in calorific value to a maximum about the middle of the range, and then a slight decrease with further increase in rank.

These statements should be confirmed from the analysis of the series of coals, arranged in order of increasing rank, in Table 4.

Other changes worth noting, the first two being of some practical importance, are:—

(8) Minimum hardness in the caking steam coal range.
(9) Less tendency to break down and form smalls on weathering. This applies particularly to the low-rank end of the series, and the "slacking" tendency is used in America as one of the criteria for classifying low-rank coals.
(10) Change in colour from brown to black (lignite to bituminous).

TABLE 4

Analyses of British Coals, illustrating Change of Rank

	Ultimate Analysis (dry ash-free basis)					Proximate Analysis					Calorific Value	Caking Properties
						(Air-dried basis)				(Dry ash-free basis)	(dry ash-free basis)	Coke type (see Fig. 39)
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Moisture	Volatile matter	Fixed carbon	Ash	Volatile matter	B.Th U. per lb.	
Wood	49.8	6.2	43.4	0.3	0.3	16.7	71.8	10.9	0.6	86.8	8,400	—
Peat (Devon)..	61.8	6.0	30.1	1.6	0.5	13.4	58.1	26.5	2.0	68.6	9,500	—
Lignite (Devon)	66.8	5.6	24.0	1.3	2.3	16.0	46.2	31.8	6.0	59.2	11,500	A
Leicestershire non-caking coal ..	78.6	5.2	11.7	1.6	2.8	13.1	36.3	45.5	5.1	44.4	13,990	B
Yorkshire weakly-caking coal ..	82.6	5.2	9.2	1.8	1.2	4.1	35.2	57.4	3.3	38.0	14,510	E
Yorkshire medium-caking coal .	84.8	5.2	7.6	1.7	0.7	2.7	33.4	61.3	2.6	35.3	15,090	G_2
Durham coking coal	88.5	5.0	4.1	1.6	0.8	0.9	28.5	66.8	3.8	29.9	15,630	G_9
South Wales caking steam coal ..	90.5	4.8	2.3	1.5	0.9	0.3	17.7	77.3	4.7	18.6	15,710	G
South Wales dry steam coal .	92.5	3.9	1.4	1.5	0.7	0.9	10.8	84.7	3.6	11.3	15,610	B
South Wales anthracite . .	93.5	3.5	1.0	1.2	0.8	1.9	7.5	87.6	3.0	7.9	15,590	A

(11) Increasing lustre, which also changes from glassy to metallic at the anthracite end of the series.

(12) Contrast between the banded constituents reaches a maximum in medium rank coals (bituminous), and becomes less noticeable with further increase in rank.

(13) Increased opacity in thin section, and plant remains become less easily distinguished under the microscope.

Apart from the variations due to rank, the following generalisations can be made regarding bright coal (vitrain and clarain) and dull coal (durain, or " hards "): —

(14) Dull coal is harder and less jointed, and so breaks in larger lumps.

(15) Dull coal is generally higher in ash, but the fusion temperature of the ash is higher.

(16) Dull coal is less strongly caking than bright coal from the same seam.

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Chapter II

THE COALFIELDS OF GREAT BRITAIN

by A. C. MARIES*

General

THE coal seams of Great Britain are all—with a few unimportant exceptions—contained in a great series of rocks known to geologists as the Carboniferous formation. These rocks are not all coal-bearing, but, for a proper understanding of the disposition and structure of the British coalfields, it is necessary to consider briefly the whole formation and to touch upon its geological history.

In Britain the Carboniferous rocks were laid down over a vast area, extending from the Midland Valley of Scotland to southern England and including most of Ireland. Changing conditions of deposition, varying from deep water to deltaic or swamp conditions, caused variations in the nature of the rocks formed, and at times tracts of dry land were raised above the surface of the water, so that the rocks were not deposited continuously over the whole area. There were three main phases of deposition, and as a result the Carboniferous rocks show a three-fold division into the Carboniferous Limestone in the lowest part, followed by the Millstone Grit and then the Coal Measures, and though these divisions are not each geologically the same in all parts of the country, they form a convenient basis for a simple description of the formation.

The Carboniferous Limestone is variable in thickness, but is commonly about 3,000 ft. Over most of its area of occurrence in England and Wales it consists of massive limestones, deposited under marine conditions and devoid of any trace of coal. In Northumberland, however, some of the rocks of this division show evidence of shallow-water conditions of formation, and occasional coal seams are present. This change becomes more marked northwards, and in the Scottish area the rocks are mainly sandstones and shales, with coal seams developed on such an important scale that about two-fifths of the coal output of Scotland is obtained from them.

The Millstone Grit is in general a series of massive sandstones with grits and some shales, varying from a few hundred feet to over 3,000 ft. in thickness. They were deposited under shallow coastal conditions, and the highest rocks of this division show the gradual onset of the deltaic and swamp conditions that were to be dominant during the succeeding Coal

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Measure period. Coal seams were in fact occasionally developed in the later stages of the Millstone Grit period, but they are too localised and sporadic to be of much economic importance.

The Coal Measures—the third and topmost division of the Carboniferous formation—are by far the most economically important rocks of Great Britain, for they provide over 95 per cent. of the country's output of coal, besides fireclay, ironstone and other materials. Of variable thickness, reaching a maximum of over 8,000 ft. in South Wales, they consist of a varied succession of sandstones, shales, fireclays and coal seams. They were deposited mainly in fresh water, under the conditions described in Chapter I, but the occasional break-in of the sea is shown by several marine bands (beds rich in the fossilised remains of sea-living creatures), which are of value to the geologist and mining surveyor in determining the identity of nearby seams.

The coal seams vary from streaks of no economic importance to 8 or 10 ft. in thickness, though occasionally—as in the Thick Coal of Warwickshire and South Staffordshire—a thickness of 30 ft. is reached. Seams 18 in. or less in thickness have occasionally been worked in some coalfields, but in general the minimum thickness for mining is considered to be 2 ft. Though some seams can be traced over many hundreds of square miles, they seldom maintain a uniform thickness and structure over more than comparatively small areas: they may locally increase to two or three times their usual thickness, or they may become thinner and, if the reduction is continued, eventually disappear; a seam may in one district consist of solid coal, but in another be so interleaved with shale bands as to be valueless; and two or more seams, that are separate and distinct in one part of a coalfield, may become united into a single seam in another part by the thinning out of the intervening strata.

The Coal Measures were originally deposited in six main basins, of which two can be dismissed at once—that of Devon and Cornwall, because it contains no workable seams, and that of Ireland, because, in addition to its paucity of good seams, it lies outside the scope of this book. The remaining areas can be defined as enclosing the following coalfields (see Figure 4):—

(1) Scottish group: Fife and Clackmannan, the Lothians, Central (or Lanarkshire), and Ayrshire.
(2) Northern group: Northumberland and Durham, and Cumberland.
(3) Midland group: Lancashire and Cheshire, North Wales, North Staffordshire, Shrewsbury, Coalbrookdale, Forest of Wyre, Cannock Chase and South Staffordshire, Warwickshire, Leicestershire and South Derbyshire, and Yorkshire, Nottinghamshire, and Derbyshire.
(4) Southern group: South Wales, Forest of Dean, and Bristol and Somerset. Kent has also been included in this group.

The Carboniferous era ended with a period of great earth movements: the strata were slowly forced into great archfolds (anticlines) with intervening

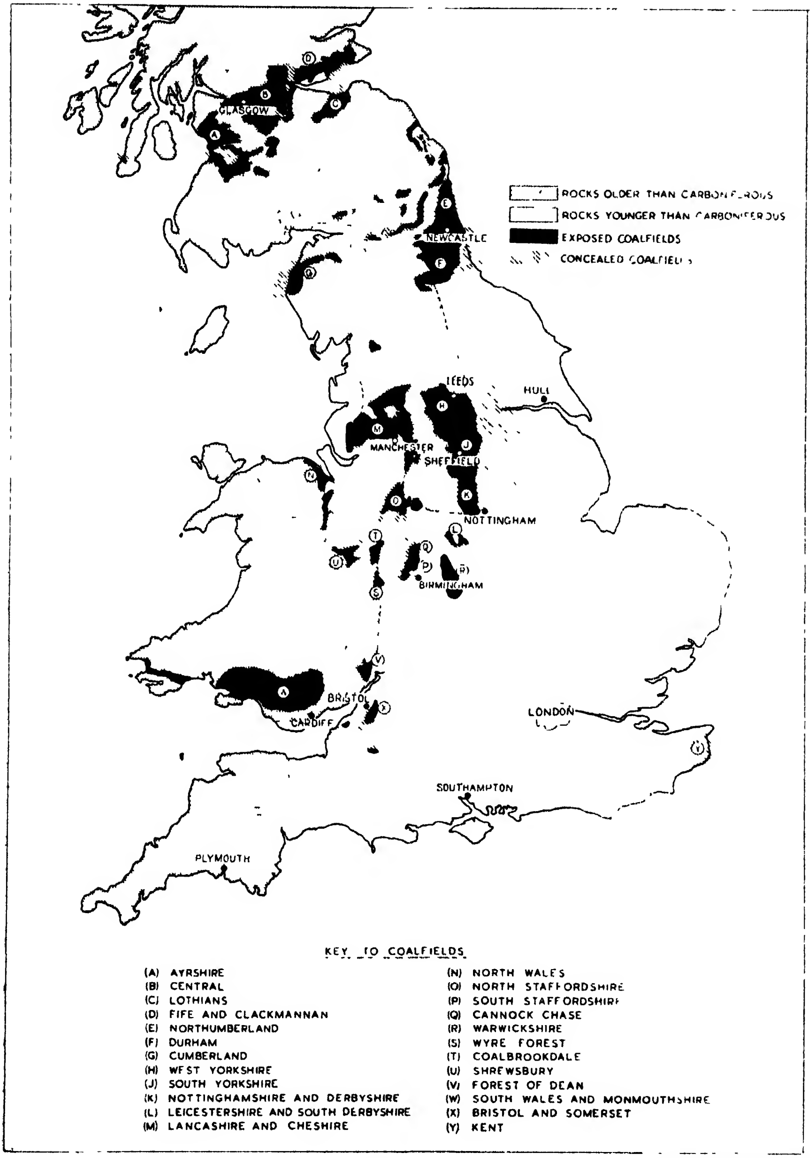

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Figure 4.

trough-folds (synclines), and were fractured and broken by faults; the Coal Measures on the crests of the rising anticlines were worn away by weathering, often until the underlying Millstone Grit or even the Carboniferous Limestone was exposed, while over the lower-lying synclines they were covered, at least in parts, by newer rocks. As a result, the four original basins were broken into about forty separate areas, of which some twenty are actually coal-producing. Moreover, because of this folding and wearing away of the arch-folds, most of these areas are essentially synclinal or basin-shaped, as will be noted in the descriptions of the individual coalfields given later in this chapter. Coalfields in which the Coal Measures lie at the surface are called exposed coalfields, to distinguish them from the concealed coalfields, in which the Coal Measures are covered by newer rocks. It is unnecessary to consider these newer rocks in any detail here, but it may be mentioned that those most frequently named in descriptions of coalfields and of mining operations are the Permian rocks, which were deposited immediately after the Coal Measures, and the Triassic rocks which followed them.

The possibility of discovering new coalfields is a matter of the greatest importance, and it will be discussed briefly in relation to the coalfield map (Figure 4). In this country coal-forming conditions occurred on a major scale only during the Carboniferous period; in the older rocks (i.e. rocks deposited before the Carboniferous period) there are no coals, and though in other parts of the world coal seams are abundant in some of the newer rocks, they are rare and insignificant in Great Britain. It follows, therefore, that in areas where older rocks lie at the surface, as in the western and northern parts of Great Britain, there is no prospect of finding new coalfields. On the other hand, there is at least a possibility that areas of Coal Measures with workable coal seams may underlie the newer rocks covering the Midlands and southern and eastern England. Several such areas are already known, and in the following accounts of the coalfields reference will be found to several extensions of coalfields under these rocks; the entire Kent coalfield also lies buried beneath them. In certain other areas the absence of buried Coal Measures has been proved by deep borings, or has been deduced with some certainty by geologists. There remain large areas, however, particularly in the South Midlands and southern England, where the presence of Coal Measures is considered to be a distinct possibility. Systematic boring in these areas is required to discover whether buried Coal Measures do in fact exist, and whether they contain workable seams.

The thickness of the overlying rocks is also an important consideration in relation to buried coalfields. The maximum depth at which coal can be economically mined today is commonly accepted to be 4,000 ft.; though coal seams have in fact been proved to exist below this depth in some of the known coalfields, none of them has been worked. Unless, therefore, workable coal seams are found well within this limit, it is unlikely—judging by present standards—that any new discoveries will be exploited until the shallower reserves are much nearer exhaustion. Metalliferous mining is carried on at much greater depths in some parts of the world, however, so that there is always a possibility that new developments in coal-mining technique may lead to the deeper seams being worked sooner.

COAL RESERVES

The possible exhaustion of great Britain's coal resources has for a long time been the subject of anxious speculation, and during the past 80 years several estimates have been made of the coal remaining unworked. Only the more recent of these estimates will be mentioned here.

For the Twelth International Geological Congress, held at Toronto in 1913(1), Sir Aubrey Strahan of the Geological Survey prepared estimates of the coal reserves in each coalfield, based largely upon a revision of the figures published by the Royal Commission on Coal Supplies in 1905(2). Strahan's figures, which relate to coal seams 12in. and more in thickness lying within 4,000ft. of the surface, are given in the first column of Table 5. It should be clearly understood that these figures include both the proved reserves and those whose existence is only probable, though certain doubtful reserves have been omitted in preparing this table.

In 1944, Regional Survey Committees of the Ministry of Fuel and Power were appointed to enquire into the position and prospects of the various coalfields in England and Wales, and in the course of their work they made

TABLE 5

Reserves of Coal in Great Britain

Coalfield	Strahan (million tons)	Regional Survey Committees (million tons)
Fife and Clackmannan	6,180	4,135
Lothians	3,143	1,230
Central Scotland	5,795	901
Ayrshire	1,338	1,146
Northumberland and Durham	13,541	5,102
Cumberland	3,398	584
Lancashire and Cheshire	5,636	2,089
Yorkshire, Nottinghamshire and Derbyshire	55,108	13,391
North Wales	2,536	815
North Staffordshire	15,858	1,686
Cannock Chase and South Staffordshire		1,233
Shrewsbury, Coalbrookdale and Forest of Wyre	365	126
Warwickshire	1,445	878
Leicestershire and South Derbyshire	2,494	783
Forest of Dean	200	60
South Wales	36,209	8,200
Bristol and Somerset	4,266	198
Kent	2,000	1,000–3,000

estimates of the reserves of workable coal(3). These Committees did not all use the same methods, so that the individual figures given in the second column of Table 5 are not strictly comparable. In general, however, these figures relate to seams of 18in. or more in thickness, within a depth of 4,000ft. The figures for Scotland were prepared by a Committee of the Scottish Home Department(4).

The great differences between the two sets of figures in Table 5 are explained by the fact that Strahan included all proved and probable reserves, whereas the Regional Survey Committee, with practical mining experts among their numbers, concentrated their attention mainly on seams they considered to be economically workable.

The Regional Survey Committees in some instances made separate assessments of the amounts of gas and "non-gas" coals, but in general, in these and all earlier estimates, no account was taken of the wide range of coal types available. It is not enough, however, to know the total amount of coal in each district or coalfield for the future planning of the country's dwindling resources, it is also necessary to know the amounts of the different kinds and qualities of coal in each district. This information has recently been provided by the Fuel Research Coal Survey of the Department of Scientific and Industrial Research. The Coal Survey has been for many years engaged upon a survey of the physical and chemical properties of the country's coal seams, only in 1944 the information so collected was combined with figures relating to the quantities of coal in each seam in every coalfield. As a result, it is now possible to state the amounts of the different kinds and qualities of coal in each coalfield. A report giving the first results of this work was published in 1946(5).

COALFIELD DESCRIPTIONS

The four original Coal Measure basins, though not completely separated from one another during the whole period of accumulation, were yet sufficiently isolated to allow of the deposition of a somewhat different succession of strata in each. To simplify description, and to bring out any relationship between them, the coalfields are grouped in relation to these basins in the following pages.

The types of coal mentioned are described in simple terms, mainly relating to the volatile matter content and caking properties, which determine broadly the uses to which the coal is put. "Typical" analyses are not given, because it is impossible to select analyses that will cover the wide ranges of types of coal that are found in many coalfields. Moreover, the composition of coal is greatly affected by the treatment it receives during preparation for the market; for example, the different commercial grades from the same seam at the same colliery may have ash contents ranging from less than 2 per cent. to over 20 per cent.

To indicate the relative importance of the coalfields, the descriptions conclude with a statement of the amount of saleable coal produced in 1945.

Scottish Group

The Carboniferous rocks of Scotland were all deposited, with negligible exceptions, within the great Midland Valley—a tract of relatively low-lying ground about 50 miles wide extending east-north-eastwards across the country from Ayrshire to the North Sea (Figure 5). A land barrier separated this basin from the North of England basin, though the occurrence of Carboniferous rocks in Haddingtonshire and Berwickshire shows that the basins were connected to the east of this barrier.

Earth movements and denudation later divided the original area of deposition into three main basins, Ayrshire, the central coalfield, and Fife and Midlothian. The last-named has since been divided by the Firth of Forth into two coal-producing areas.

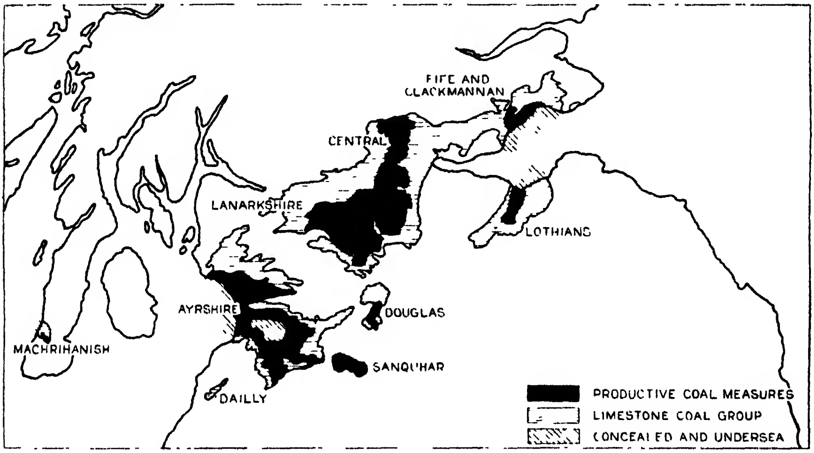

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Figure 5.

The Scottish coalfields differ in two important respects from those of England and Wales; firstly, as already mentioned (p. 23), workable coal seams occur not only in the Coal Measures but also in the Carboniferous Limestone, and secondly, in certain localities some of the seams have been greatly altered by the heat from nearby igneous intrusions.

The Limestone coals, as they are called, occur at intervals throughout almost the whole thickness of the Carboniferous Limestone, but they are most frequent, most persistent, and of greatest economic importance near the middle. About 45 per cent. of the total coal output in Scotland is obtained from them. All are normal bituminous coals, similar to those in the higher division (in Scotland distinguished by the name Productive Coal Measures), and some of them yield the best coking coals produced in Scotland.

Where, as is commonly the case, the Carboniferous strata lie in a syncline or basin fold, the Productive Coal Measures are exposed in the central area of the coalfield, and the Carboniferous Limestones in the marginal areas (see Figure 5). For this reason the Limestone coals are also known as the Edge coals. Mining of the Limestone or Edge coals has therefore been developed in the marginal areas (except in Fife and Clackmannan, where the main structure is not a simple basin). It would seem at first sight that there is considerable scope for mining extensions towards the centres of the coalfields, but two factors may severely limit this development; firstly, to reach the Limestone coals in the central parts of the field great thicknesses of productive Coal Measures and Millstone Grit will have to be penetrated, and secondly, some recent deep borings have shown that, at least in certain parts of the Scottish coalfields, the Limestone coals are poorly developed at the deeper levels.

The alteration of coal seams by igneous rocks is of localised occurrence. In certain districts in Ayrshire, the Central coalfield, and Fife and Clackmannan, molten igneous rocks have penetrated from below into the Carboniferous rocks as sheets or layers long after the formation of the coal seams. The heat from these " intrusions," as they are called, has affected the nearest overlying and underlying seams to different degrees, depending on the thickness of the intrusions and their distances from the seams. When the heating was slight, this " natural carbonisation " caused only some reduction in caking properties, but with increasing degrees of heating there was a progressive loss of volatile content accompanied by other chemical changes, until in extreme cases the coal was burnt and completely destroyed. The result is that the originally high-volatile coals now yield medium-volatile non-caking navigation coals and steam coals, semi-anthracites or anthracites, according to the degree of alteration.

Thick hard bands of splint coal, consisting mainly of dull coal or durain and comparable with the " hards " of Yorkshire, occur in several of the Scottish seams. On mining they yield large lumps which are often segregated and marketed separately for use in locomotives or other hand-fired boilers.

Fife and Clackmannan

The Fife and Clackmannan coalfield occupies a coastal belt on the north side of the Firth of Forth from a little west of Alloa to beyond Leven on the east, a distance of over 40 miles; the maximum width is about 10 miles. Only the Limestone coals are present over the greater part of the field, but folding and faulting have preserved small areas of the Productive Coal Measures around Dysart, Wemyss and Leven on the east and in Clackmannan on the west. The rocks of this coalfield extend southwards under the Forth, and they may be continuous with those of the Lothians field.

The coals of this field are for the most part normal bituminous coals with high-volatile contents and moderate or weak caking properties. They serve as general-purpose coals, being widely used in industry as well as for domestic purposes. Although not strongly caking, many are used in Scottish gas works, where it is the practice to carbonise coals of lower coking power than are generally favoured in English works. The more free-burning (i.e., weakly-caking) varieties are in demand as bunker coals, and large quantities are sent from the Forth ports to London and other southern ports, mainly for use in power stations.

Cannel or parrot coal is associated with the seams more frequently than in most other coalfields; it is not usually segregated and marketed separately, but many gas works appreciate the benefit of its presence in the coal, because of its effect in enriching the gas made. Splint is also found in several seams.

In some localities the seams yield anthracite and other low volatile coals as a result of heating by nearby igneous intrusions.

The output of saleable coal in 1945 was 5.9 million tons.

Lothians

The Lothians coalfield, lying in the counties of Midlothian and East Lothian, extends from the Firth of Forth just east of Edinburgh for a distance of up to 15 miles south-westwards. The structure of the field is that of a double basin fold running in a north-easterly direction and carrying the Carboniferous rocks under the Firth of Forth, where they may be continuous with those of Fifeshire. Productive Coal Measures occupy a central tract in the deeper western basin, but the greater part of the output comes from the surrounding area in which the Limestone coals are worked.

With the exception of cannel bands found in association with several seams, the coals are all of the bituminous type; anthracitisation by igneous intrusions is unknown in this coalfield. High in moisture content (about 10 per cent.) and volatile content (about 40 per cent.), the coals have only moderate caking properties. The inherent ash is usually low, and the sulphur contents are commonly below 1 per cent., and seldom exceed 1.5 per cent.

The output of the field, besides finding a considerable market for household purposes, is used in general industry, especially in gas works, where the high-volatile and low sulphur contents are desirable features. Splint coals are used on the railways and for general steam-raising purposes.

The output of saleable coal in 1945 was 3.3 million tons.

Central or Lanarkshire

The Central Coalfield of Scotland lies mainly within the county of Lanarkshire, but parts of it extend into Renfrewshire, Dumbartonshire, Stirlingshire, Midlothian and West Lothian. It extends from Johnstone and Barrhead, west of Glasgow, to Wilsontown and Bathgate on the east, a distance of over 30 miles, and has a similar maximum width from north to south. Structurally the Central Coalfield consists of several subjoined basins. The principal of these—the Lanarkshire basin—with its full development of Productive Coal Measures, containing a long sequence of thick and high quality seams, has long provided the greater part of the output of the coalfield. As a result, many of the seams have been largely worked out, and within the next 50 years a rapid decline in output from this area is anticipated(4). The reserves in the Stirling basin to the north-east, however, are considered sufficient to provide, with more intensive mining, a higher output to compensate for the decline in Lanarkshire. A third important area of Productive Coal Measures is the Shotts-Armadale basin to the east of the main basin.

The coals of the Productive Coal Measures are in the main medium-caking general purpose coals, but some have caking properties comparable with those of the Yorkshire seams, and the smalls should therefore be suitable for the manufacture of metallurgical cokes. The hard splint of durain bands developed in some of the upper seams are often marketed separately. They were at one time extensively used in Scottish blast furnaces, and though, with their approaching exhaustion and a change in blast-furnace practice, they have now been displaced by metallurgical cokes, they are still in demand for locomotives and for general steam-raising.

The Limestone coals are worked chiefly on the northern, eastern and south-eastern margins of the coalfield, around Kilsyth and Twechar, Bannockburn and Plean, also between Bathgate and Wilsontown. Some of the seams yield coking coals which, though of lower rank than those of Durham and South Wales, are widely used in coke ovens.

In several localities in the northern half of the coalfield some of the seams, both in the Carboniferous Limestone and in the Productive Coal Measures, have been affected by igneous intrusions. They are worked to provide navigation coals, semi-anthracites and anthracites, the last-named being in particular demand for breweries because of their low arsenic contents.

Bands of cannel occurring in some of the seams are seldom separated, but are sold in admixture with the remainder of the seam.

The Douglas coalfield is a small field lying to the south of the Lanarkshire basin. Both the Limestone Coal Series and the Productive Coal Measures are present, but they include fewer workable seams than in the main field.

The output of saleable coal in 1945, including that from the Douglas field, was 8.75 million tons.

Ayrshire

The Ayrshire coalfield extends from Ardrossan and Ayr, lying about 15 miles apart on the Firth of Clyde, eastwards to Cumnock and Muirkirk, and south-eastwards to Dalmellington. Detached areas include the small Sanquhar coalfield to the south-east and the smaller South Ayrshire or New Dailly coalfield to the south-west. Productive Coal Measures occupy the greater part of the area of the main coalfield, though they are partly covered by newer rocks. In the narrow marginal fringe of Carboniferous Limestone the coal seams are poorly developed and of little economic importance.

In general the Ayrshire coals are of weakly-caking type. The normal coals have high volatile and moisture contents of about 40 and 10 per cent. respectively. The ash fusion points tend to be low, except in the splint or durain bands developed in some seams; in these bands (which are often marketed separately) the ash fusion temperatures are exceptionally high. On account of their free-burning nature, coupled with the fact that many leave a brown-coloured ash after burning, the Ayrshire coals are widely used in the Scottish domestic market. Those with sufficient caking power are used to some extent in gas works, and the weakly-caking varieties, with relatively infusible ashes, provide excellent producer fuels. The splint coals are used for locomotives.

Locally some of the seams have been altered by igneous intrusions, and they are worked at a few collieries to produce navigation coals and anthracite.

The output of saleable coal in 1945 was 3.4 million tons.

Northern Group

The northern group includes the Northumberland and Durham coalfield on the east of the Pennines and the Cumberland coalfield on the west. During the Coal Measure period, land areas separated this basin from Scotland and the Midlands. The eastern and western boundaries of the original basin are not known, but as will be seen later they must have lain far beyond the present coastlines. The basin was divided into the two coalfields by the uplifting of the Pennines.

Three divisions of the Coal Measures—Lower, Middle and Upper—are recognised; the Middle Coal Measures contain all the workable seams.

Northumberland and Durham

The Northumberland and Durham coalfield, also known as the North-eastern coalfield, covers a triangular area of about 900 square miles extending from Amble on the north to within a few miles of Hartlepool on the south. The coals outcrop on the west and the general eastward dip carries the Coal Measures under the North Sea. In the Durham part of this seaward extension, workable coal seams are believed to continue for at least three and perhaps six miles from the coast. In Northumberland, though workings at one point have been carried to a distance of one and a half miles seawards, the geological evidence of folding and faulting suggests that in general the area of workable undersea coal is more limited than in Durham. In the south-east the Coal Measures extend some distance under Triassic rocks, forming a small area of a concealed coalfield.

The seams of Northumberland and Durham change progressively across the coalfield, with the result that the field can be divided broadly into areas producing different types of coal. Figure 6 shows the disposition of the general types of coal, but to emphasise that the changes from one type to another are gradual, boundaries of the different areas are omitted.

Soft, bright, metallurgical-coking coals, with between 26 and 30 per cent. of volatile matter, occur in West Durham in an area lying west of the longitude of Durham and between the Tyne and Wear. From here northwards, eastwards and southwards, a gradual increase in hardness and volatile content, accompanied by a reduction in caking power, carries the coals successively through the coking-gas and gas coals of the central and southern parts of the field, and eventually to the weakly-caking steam and house coals

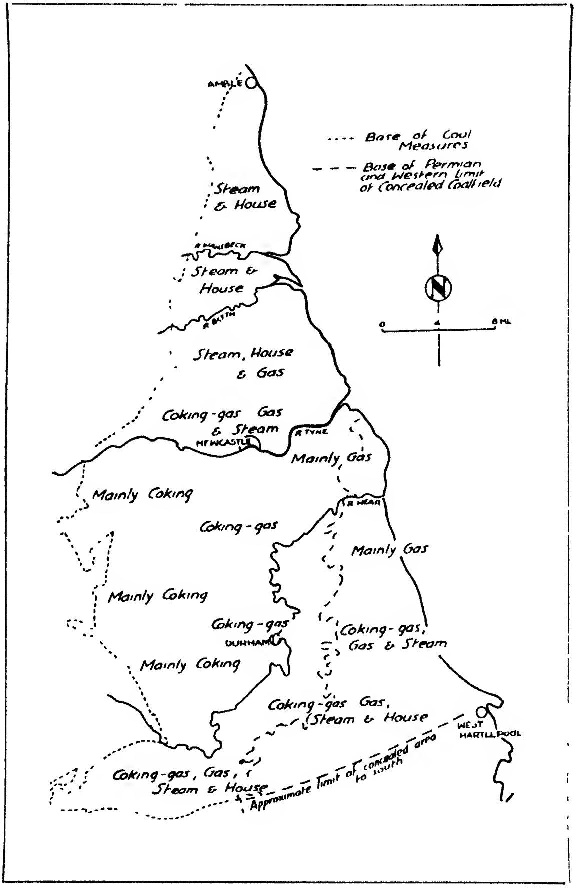

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Figure 6.

of the north. The River Tyne does not, as has often been stated in the past, mark a line of abrupt change north of which all the coals are of weakly-caking type: the caking properties of the seams are maintained with only gradual diminution for a considerable distance north of the Tyne, and much of the coal produced in Northumberland south of Blyth is used in gas works and some would even be satisfactory for coke-ovens.

The best metallurgical cokes, particularly those for use in foundries, have in the past been obtained almost exclusively from the lowest three seams (the Victoria, Busty and Brockwell) in West Durham. The reserves in these seams are now seriously depleted and at the present rates of consumption are considered unlikely to last for more than another 50 years. Fortunately, the reserves lying to the east, particularly in the coastal area, are sufficient to support an increased output to make good the decline in the west; though at present these coking-gas and gas coals are considered inferior to the West Durham coals for coke manufacture, improvements in coke-oven practice and design should eventually overcome any deficiencies in their coke-forming properties.

In the wide area of Carboniferous Limestone lying to the west of the Northumberland field, the local development of occasional coal seams foreshadows the economically important development of the Limestone coals in Scotland. These seams are being worked at a few small collieries.

The output of saleable coal in 1945 was 9.5 million tons from Northumberland and 22.1 million tons from Durham.

Cumberland

The exposed Coal Measures in the Cumberland coalfield form a coastal strip about six miles wide lying between Whitehaven and Maryport, with a narrower extension continuing some miles north-eastwards from the latter place. The area of the coalfield is about 85 or 90 square miles. A general westerly dip carries the measures under the sea, giving rise to a large undersea coalfield. The western limit of this field is not known; coal is at present being mined to a distance of about five miles from the coast, and it is considered possible that the seams extend for at least 12 miles. The area of undersea coal is therefore at least as great as that of the landward coalfield, and the reserves—mainly untapped—are probably considerably greater.

About twenty coal seams of workable thickness exist in the exposed coalfield, but practically all the present output comes from eight of them. No marked lateral variations are noticeable in the seams, which all yield high-volatile strongly-caking coals. Large quantities of smalls are used in coke-ovens, and the large sizes go mainly to the domestic market. General industrial users take a large tonnage in all sizes, and gas works use mainly the graded sizes.

The output of saleable coal in 1945 was 1.0 million tons.

Midland Group

The coalfields of Lancashire and Cheshire, Yorkshire, Nottinghamshire and Derbyshire, North Wales, North Staffordshire, Shrewsbury, Coalbrookdale, Forest of Wyre, Cannock Chase and South Staffordshire, Warwickshire, and Leicestershire and South Derbyshire are all parts of one vast area in which the Coal Measures were deposited in a continuous sheet. The upward thrusting of the Pennines completely separated the Lancashire and Cheshire coalfield from the Yorkshire, Nottinghamshire and Derbyshire field; folding and faulting connected with that great uplift also formed the other coalfields named, but their separation is not so complete since in the intervening areas the Coal Measures were not destroyed but now lie deeply buried beneath later rocks. The coalfields of Lancashire and Cheshire, North Wales, North Staffordshire, the Welsh Borderlands and Cannock Chase, for example, can be regarded as the marginal exposures of Coal Measures which lie buried at great depths under the Cheshire Plain. The fact that the Coal Measures were originally continuous is also confirmed by the fact that certain seams and marine bands have been identified in Lancashire, North Staffordshire and Yorkshire.

Three divisions of the Coal Measures are recognised. The chief seams occur in the Middle Coal Measures; two or three workable seams are sometimes present in the Lower Coal Measures, but the Upper Coal Measures have only a few thin and unworkable seams.

Lancashire and Cheshire

Roughly triangular in shape, and covering an area of about 500 sq. miles, the Lancashire and Cheshire coalfield lies in a great basin fold on the western flank of the Pennine uplift. A large arch-fold within the coalfield brings the Millstone Grit to the surface in the Rossendale area and almost completely separates a northern coalfield, around Burnley and Blackburn, from the main or South Lancashire coalfield. The latter field, as has already been noted, extends southwards under the Triassic rocks of the Cheshire Plain, but colliery explorations have not proceeded very far in this direction. The coalfield as a whole is more folded and faulted than most other British coalfields.

All the coals in Lancashire are bituminous, with volatile matter contents mainly between 30 and 40 per cent., but within this class they yield a wide variety of types, ranging from low rank non-caking coals to medium rank strongly-caking coals, some of the latter approaching Durham coking coals in type. They also show considerable variations in hardness, both from seam to seam and within the same seam; where hard dull bands of sufficient thickness are developed, they are often separated and marketed for railways or other special uses.

As would be expected from Lancashire's dense industrial population, the greater part of the output of this coalfield is taken by the general industries, mainly as smalls, and for domestic use, mainly as large coal. Considerable quantities also go to electricity stations and the carbonising industries.

The output of saleable coal in 1945 was 10.5 million tons.

Yorkshire, Nottinghamshire and Derbyshire

The Yorkshire, Nottinghamshire and Derbyshire coalfield, also known as the East Midlands coalfield, is a large Coal Measure basin lying between Leeds on the north and Nottingham on the south. On the western side of this basin the Coal Measures lie at the surface, forming an exposed coalfield, but the general easterly dip in this part of the field carries the measures below the later Permian and Triassic rocks to form an even larger concealed coalfield.

The eastern boundary of the Coal Measures is not known, but recent deep borings for oil have shown that it may lie beyond Lincoln. The eastward thickening of the overlying rocks must set a practical limit to the workable field, however, for in the neighbourhood of Lincoln they reach a thickness of 4,000ft. The area so far proved, including the exposed coalfield, is 2,400 sq. miles.

The western part of the field has long been extensively worked, and as the best seams approach exhaustion new mines are being sunk in the concealed field, which is of more recent discovery. So far, however, these new workings have penetrated only a few miles into the concealed field.

The Coal Measures contain over thirty workable coal seams. These are in general thickest on the west, and become gradually thinner to the east. In the unworked eastern part of the concealed coalfield there is some evidence from borings that the number of workable seams is considerably reduced, so that the reserves of coal in this part may not be so great as has previously been thought.

The seams in the known coalfield are of unusually high quality; they seldom contain shale bands, and the amounts of inherent ash (i.e., impurities dispersed through the coal) are usually small. An important feature of some seams—notably the Barnsley and Parkgate of Yorkshire and their equivalents the Top Hard and Deep Hard of Nottinghamshire and Derbyshire—is the presence of thick bands of " hards " consisting mainly of durain. These " hards " are more weakly-caking than the bright portions of the seams (which are called " brights " or " softs "), and their ashes have high fusion points. On mining, they produce a high proportion of large lumps, which are separated for sale to special markets such as the railways.

All the seams consist of bituminous coal, with volatile contents of over 30 per cent. and often in the neighbourhood of 40 per cent., but they have a wide range of caking power, which varies from very strongly-caking to non-caking. There is a general tendency for the volatile matter and moisture contents to increase southwards, while the coking power decreases. These changes are slight and far from regular, but they have an appreciable influence on the types of coal available in the north of the field as compared with the south. For example, a bigger proportion of the output from Yorkshire goes to gas works (graded sizes) and coke-ovens (smalls) than from Nottinghamshire and Derbyshire. The latter area, on the other hand, provides large tonnages of free-burning coals (in all sizes) for general industrial use, some being particularly suitable for use in gas producers.

Large coals of the bright varieties go mainly to the domestic market, and the large " hards " to railways. Electricity stations consume large quantities of the smalls.

The output of saleable coal in 1945 was 36.7 million tons from Yorkshire and 27.0 million tons from Nottinghamshire and Derbyshire.

North Wales

The North Wales coalfield lies within the counties of Flintshire and Denbighshire, covering an area of about 90 sq. miles. In Flintshire the Coal Measures are exposed in a narrow strip on the south-west side of the Dee Estuary. The general north-easterly dip of the measures carries them under the estuary, and they appear again over a small area near Neston in the Wirral Peninsula. In Denbighshire the dip is in general to the east, and the Coal Measures pass under the Triassic rocks of the Cheshire Plain. As mentioned earlier, the North Wales coalfield is in fact only a marginal outcrop of a great Coal Measure basin underlying this plain.

Folds and faults are fairly numerous, and a large fault practically severs the Flintshire field from that of Denbighshire. The former field has been extensively mined in the past; many of the better seams have been largely worked out, and the present output of the coalfield is small.

The coalfield as a whole produces medium and strongly caking coals of high volatile content. Some of the seams are of outstanding quality, but they are not widely known because most of the coals are consumed within the coalfield area. Besides being used for general industrial purposes and as household fuels, considerable quantities are taken by the carbonising industries and railways.

The output of saleable coal in 1945 was 1.9 million tons.

North Staffordshire

Lying at the southern extremity of the Pennine uplift, with which its folded structure is closely connected, the North Staffordshire or Potteries coalfield covers an area of about 100 sq. miles. The Coal Measures lie in two major folds, a syncline or basin on the east and an anticline or arch-fold on the west. These folds converge northwards, and as a result the basin is narrow in the north and widens southwards. The anticline over much of its range is steep-sided, in places so much so that the seams on its flanks stand almost vertically and cause great difficulty in mining. The southward tilt of the folds carries the Coal Measures down below a cover of newer rocks

On the east the coalfield is bounded by the outcrop of the Millstone Grit and, on the west, by a series of large faults which carry the seams to considerable depths, though it is possible that some remain within workable depth. Westward of these faults the Coal Measures extend under the Cheshire Plain, as already mentioned.

There is a long sequence of Coal Measures in this relatively small coalfield, with a large number of workable coal seams. Many of the seams are above average in thickness, especially those in the lower part of the Middle Coal Measures. A marked lateral variation in the character of the coal results in a regional distribution in the types of coal produced. On the east of the field all the seams are weakly-caking in character, but westwards towards the deeper parts of the syncline there is a pronounced increase in the caking properties, accompanied by an increase in carbon content and calorific value, and other features indicating an increase in rank. This change markedly affects all the important seams in the lower part of the Coal Measures, but is only slight in the upper seams. On the western side of the field, as a result, all the lower seams are strongly caking. In the deeper parts of the syncline, as yet unworked, coal samples from a recent deep boring have shown that some of the lower seams are similar in type to the best Durham coking coals.

North Staffordshire is thus able to satisfy the requirements of a wide variety of consumers. Large tonnages are used for general industrial and household purposes, and, in the medium and strongly caking varieties, for gas-making and coke-ovens.

The output of saleable coal in 1945 was 5.6 million tons.

Cannock Chase and South Staffordshire

The coalfields of Cannock Chase and South Staffordshire occupy a continuous tract of Coal Measures about 150 sq. miles in area, lying to the west of Birmingham. A broad belt of faulting, a little to the north of a line joining Wolverhampton and Walsall, divides the area into two distinct parts—the Cannock Chase field in the north and the South Staffordshire or Dudley field in the south.

The combined coalfields have the form of a complex and faulted basin, tilted downwards to the south. The eastern and western boundaries are for the most part formed by large faults, which carry the Coal Measures down to considerable depths, though it is possible that in some districts, just outside the present limits of working, the coal seams are within reach of mining. To the north and south the Coal Measures extend some distance under the newer Triassic rocks, which entirely surround the coalfield.

Up to twenty seams are present in some parts of the field, several being of more than average thickness and quality. A striking feature of the South Staffordshire field is the Thick Coal, consisting of 20 or 30 ft. of coal, formed by the thinning of the measures between six or seven seams which to the north are widely separated.

All the coals in this field are of low rank; they have high moisture, volatile matter and oxygen contents, and caking properties are only feebly developed. Bands of different hardness occur in the seams, however, and these allow of some differentiation in the grades marketed to suit the varied requirements of consumers. The large grades provide excellent house coals, and some of the harder varieties are used by railways. Next to the domestic market, however, the largest tonnage is taken by general industrial users.

The output of saleable coal in 1945 was 5.2 million tons.

Shrewsbury, Coalbrookdale and Forest of Wyre

To the west of the Cannock Chase and South Staffordshire coalfield lie the small coalfields of Shrewsbury, Coalbrookdale, and Forest of Wyre. The first of these, in which only three thin seams are present, is not now being actively worked.

The coals from these fields are mainly weakly caking, with high moisture and volatile contents; they are sold for electricity generation (smalls), household purposes (large), and general manufacturing (mainly smalls).

The output of saleable coal in 1945 was about half a million tons.

Warwickshire

The Coal Measures of the Warwickshire coalfield lie in an elliptical basin about 24 miles long from north to south and reaching a maximum width of about 8 miles. The basin pitches or tilts to the south, so that in that direction the coal-bearing Lower and Middle Coal Measures become covered with an increasing thickness of the barren Upper Coal Measures. A subsidiary anticline or arch-fold in the middle of the basin, however, brings the coal seams within easily workable depths.

The eastern boundary of the coalfield is formed partly by older rocks, and partly by faults. The western boundary is a series of faults which carry the seams down to depths too great for mining. Here—i.e. between this coalfield and the South Staffordshire field to the west—the Coal Measures lie deeply buried beneath a cover of newer rocks. This area has not been proved by boring, and it is not known whether the measures include good coal seams.

The sequence includes fifteen or more coal seams of good workable thickness and quality. Over the central and southern part of the field a number of these seams become united into a single seam (the Thick or Hawkesbury) varying from 20 to 30 ft. in thickness.

All the seams are of low rank—i.e. weakly-caking or non-caking, with high percentages of moisture, volatile matter, and oxygen. Thick bands of hard dull coal of unusual purity occur in some seams, and these are marketed separately (as " spires ") for special purposes such as annealing and biscuit baking.

The output of saleable coal in 1945 was 4.3 million tons.

Leicestershire and South Derbyshire

The Leicestershire and South Derbyshire coalfield occupies an area of about 100 sq. miles, with Ashby-de-la-Zouch at its centre. An anticline or arch-fold running N.W.–S.E. divides the field into two separate coal-producing areas, that to the north-east known as the Leicestershire coalfield and the other as the South Derbyshire coalfield, though they do not lie entirely within those counties. The Coal Measures dip north-eastwards and south-westwards from the anticlinal axis; in the neighbourhood of the axis they are exposed over an area of about 24 sq. miles, until the dip carries them beneath the surrounding Triassic rocks and gives a concealed coalfield of considerable extent. The boundaries of the field are fairly exactly known, except on the west, where it still remains to be proved whether or not faulting has carried the seams down to unworkable depths.

In this coalfield the seams, about a dozen of which are worked, are relatively thick; their average thickness is about 3½ ft. and some reach 15 ft. locally. Most are composed of bright and rather soft coal, but some contain bands of " hards," though these are not so distinctive as their counterparts in the Yorkshire coalfield. The coals are all of low rank, with high moisture and volatile contents (10–14 and 40–45 per cent. respectively). They are feebly-caking or non-caking, and the larger sized grades form excellent free-burning house coals, though the " hards " are sometimes picked out for railways and steam-raising. The smalls are used by electricity undertakings and for general industrial purposes.

The output of saleable coal in 1945 was 5.7 million tons.

Southern Group

The coalfields of South Wales, the Forest of Dean, and Bristol and Somerset were originally united in a Coal Measure basin which was separated from the Midlands basin by a land area running from Mid Wales to East Anglia. The relationship of the Kent coalfield to this basin is uncertain, but if as some think it was originally connected with it, then there is a possibility that other buried coalfields may exist in southern England between Somerset and Kent.

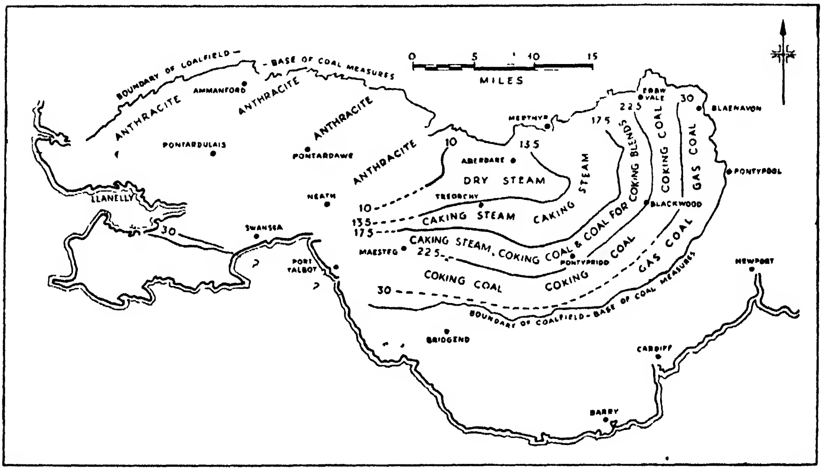
A characteristic feature of the South Wales and neighbouring coalfields is the division of the Coal Measures into an upper and a lower productive (i.e. coal-bearing) series, separated by up to 1,000 ft. of sandstones and shales called the Pennant Series, in which coal seams are less numerous.

South Wales

The main part of the South Wales and Monmouthshire coalfield is an oval-shaped basin about 56 miles long from east to west, with a width of about 15–20 miles. A smaller area, in effect a westward continuation of the main basin, extends as a belt about 4 miles wide across the south of Pembrokeshire. Except where broken by the sea, as in Carmarthen Bay, the boundaries of the field are formed by older rocks—i.e. there are no buried extensions.

The broad basin fold of the coalfield is disturbed by smaller folds. In general the southward dip from the northern margin is gentle, and this has facilitated mining in the northern half of the field. More intense folding in the southern part of the field, particularly near the southern margin, has rendered mining more difficult.

The coalfield, particularly in the eastern part, is crossed by several deep and narrow valleys running N.N.W.–S.S.E., penetrating deep into the Coal Measures and having important effects on mining development. To a greater extent than in other British coalfields, the seams are worked by means of "slants" instead of vertical shafts, and despite the great thickness of the Coal Measures (in some places exceeding 8,000 ft.), the lower seams are accessible over most of the field. The latter point is fortunate, for the Lower Coal Series contains the most important seams and provides almost the whole of the South Wales output. The overlying Pennant Series is barren of coal seams except in the west, where one or two seams are worked. The Supra-Pennant Series, forming the topmost division of the Coal Measures, occurs only in a few isolated patches, and though some of the seams are worked on a small scale at several small collieries, the total output from them is small.



[CROWN COPYRIGHT

Figure 7.

The coal seams change markedly in properties as they are traced across the field. In Figure 7, the property selected for illustration is the volatile matter content, and the change is shown by plotting isovols, or lines of equal volatile matter content. Just as the contours on a topographical map show increases and decreases in the height of the ground, these isovols show the progressive decrease in volatile matter from the south and east towards the north-west. Figure 7 relates to one seam, but all other seams in the coalfield show a similar change. In South Wales the volatile matter is closely related to other characteristics, such as the carbon, hydrogen and oxygen contents, and the caking properties. The isovol map is therefore a record of the geographical distribution of the different kinds of coal, and the names of some of these have been inserted.

The anthracites (volatile matter less than 10 per cent.) and dry steam coals (volatile matter 10–13 per cent.) are non-caking. They are used for gas producers and for slow-combustion domestic stoves; anthracites with low arsenic contents are also used for malting and hop-drying, and for the treatment of other materials for human consumption. At about 13 per cent. of volatile matter the coals begin to develop caking properties, which reach a maximum at about 25 per cent. of volatile matter. Coals with between 13 and 20 per cent. of volatile matter form the caking steam group; they are widely used for steam-raising, as well as in other appliances designed to burn low-volatile coals, and they are highly satisfactory in several types of domestic appliance. Coals with between 17 and 30 per cent. of volatile matter are carbonised in coke-ovens, either alone or suitably blended with coals from outside this range. With over 30 per cent. of volatile matter up to the maximum of 36 per cent. found in this field, there is a slight fall in caking properties. Coals within this range are widely used in gas producers, particularly in South Wales steel works, and in gas works.

The output of saleable coal in 1945 was 20.5 million tons, of which 2.7 million tons was anthracite.

Forest of Dean

The Forest of Dean coalfield is situated in Gloucestershire on relatively high ground between the Rivers Wye and Severn. The Coal Measures lie in two subjoined basins, the main basin on the east being about 9 miles long from north to south and about 3 miles wide at its maximum. The smaller western basin, separated from the main basin by a complex belt of faulting, is shallow and only the lower coal seams are present.

The coalfield has about twelve workable coal seams totalling between 25 and 30 ft. or more. The most important of these is the Coleford High Delf, which yields over 95 per cent. of the current output of the field. It lies low in the Coal Measures, and is therefore present in the shallow western basin as well as in the main basin.

The seams all consist of high-volatile bituminous coals, but the caking properties are variable. The lower seams are in general more strongly caking than the upper seams, but there is also a lateral variation in individual seams. The Coleford High Delf, in particular, shows a steady change from non-caking type near the margins to very strongly caking type in the middle of the field. There is thus considerable variation in the type of coal produced, though as the larger collieries are situated in the central part of the field, the bulk of the output is of strongly-caking type. General industries are the biggest group of consumers, but large tonnages also go to gas works, electricity stations and the domestic market.

The output of saleable coal in 1945 was 0.9 million tons.

Bristol and Somerset

In the Bristol and Somerset coalfield the Coal Measures occupy over 250 sq. miles, but most of this area is covered by Triassic and later rocks, and the Coal Measures are exposed at the surface only in a few isolated areas totalling about 70 sq. miles. The structure of the coalfield is complex: folding and faulting have divided the area into several separate basins, and these earth-movements have in some places been so severe that the strata have been doubled back upon themselves. Mining has up to the present been limited to the neighbourhoods of the exposed areas of Coal Measures. In the concealed areas the coal seams are in places deeply buried, for the overlying rocks sometimes exceed 2,000 ft. in thickness.

The Coal Measures are divided into a Lower and an Upper Coal Series by the Pennant Sandstone, which is 2,000–2,500 ft. thick. The Lower Coal Series contains about 25 seams, including the most valuable seams in the field, but because of their depth in some parts of the field and the disturbed condition of the measures in others, they are not widely worked and contribute less than 10 per cent. of the present output of the field. The Pennant Sandstone contains one or sometimes two coal seams, but these are not worked. The Upper Coal Series contains about 15 seams, which yield the bulk of the output. The seams in both the Upper and the Lower Coal Series are in general thin, and seams of less than 2 ft. are worked to a greater extent here than in any other coalfield.

All the seams yield bituminous coal, with from 23 to 40 per cent. of volatile matter. A few—the higher volatile coals—are weakly caking, but for the most part they are of metallurgical coking and gas coal type. Large tonnages go to gas works in the southern and south-western counties, and the general industries form the next largest group of consumers.

The output of saleable coal in 1945 was 0.6 million tons.

Kent

The Kent coalfield lies entirely concealed beneath younger rocks varying from 1,200 to 3,500 ft. in thickness, so that no evidence of coal is to be found at the surface, or in relatively shallow excavations such as well-sinkings. The possible existence of buried Coal Measures was deduced by geologists, however, and proved by deep boring in 1890. Although the field has not yet been fully proved, its known area under land is about 190 sq. miles, and as the Coal Measures extend under the sea to the east and south the workable area may be much larger.

The Coal Measures lie in a basin fold which is elongated in a N.W.–S.E. direction and dips south-eastwards. Over a dozen persistent seams have been proved, but up to the present only five of these have been worked. The coalfield has yet to be fully explored, and, outside the areas of the four working collieries, there is little reliable evidence regarding the development and character of the seams. Such evidence as is available, mainly relating to the working areas, shows the seams to resemble those of South Wales in coal type, except that anthracites are absent. They have volatile matter contents ranging from about 10 per cent. to 37 per cent.; as in South Wales, the coals of below about 14 per cent. of volatile matter are non-caking in character, but above this figure there is a steady increase in caking properties with increase in volatile matter up to a maximum in the 20–30 per cent. volatile range, which yields metallurgical coking coals. Above 30 per cent. of volatiles there is a slight fall in caking properties, and the coals are classed as gas coals. This type is present only in small amount, the majority of the seams having less than 30 per cent. of volatile matter.

The Kent seams are in general very friable, producing a high proportion of smalls on mining, and this is a factor that must be taken into account in considering the markets for the coal. One of the seams at present being worked is of a hard nature, however, and besides being used on railways it provides an admirable fuel for domestic use.

The output of saleable coal in 1945 was 1.2 million tons.

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    Northumberland and Cumberland, 1s. 3d. (post free 1s. 5d.).
    Durham, 1s. (1s. 2d.).
    Northeastern Coalfield (Yorkshire), 1s. 6d. (1s. 8d.).
    North Midland Coalfields (Nottinghamshire and Derbyshire, and Leicestershire and South Derbyshire), 1s. 6d. (1s. 8d.).
    Northwestern Coalfields (Lancashire and Cheshire, and North Wales), 2s. (2s. 3d.).
    Midland Region (Cannock Chase and South Staffordshire, Warwickshire, Shropshire, and North Staffordshire), 2s. (2s. 3d.).
    Forest of Dean, 1s. 3d.
    South Wales, 4s. (4s. 4d.).
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Chapter III

THE MINING OF COAL

by J. A. S. RITSON[*]

THERE are two industries which are fundamental to mankind, agriculture and mining. Without them human civilisation would never have progressed beyond the Stone Age. Agriculture provides food, clothes, timber, etc. Mining provides fuel and the metals which play such an intimate part in our daily life, such as pots and pans, weaving machinery, motor cars, etc. Nevertheless, they differ in one most important characteristic.

The products of agriculture are replaced season after season. Seed is sown and the crop harvested, animals reproduce themselves year by year, forest trees are cut down when ripe and the area replanted. On the other hand, once a ton of coal or other mineral has been mined and used by man the world's supply of that particular mineral has been decreased by one ton. It can never be replaced. Minerals, including coal, are a wasting asset and the world's reserves daily become less and less. This is not to suggest that the coal reserves of Britain are nearing exhaustion. This is not so because it has been estimated that there is still 400 years' supply of workable coal at the present rate of production.

Coal mining is a very ancient industry in Britain. It is probable that the Romans burned some coal in their house-warming appliances because coal ashes have been found in a few Roman camps, but they did not work it regularly. Some camps were built close to, and even over, coal outcrops without the mineral being worked. The working of coal as a regular industry apparently commenced in Britain about the 12th century and the earliest workings recorded were on or around the shores of the Firth of Forth, the River Tyne, and in Staffordshire. For several centuries the annual output remained small and in 1800 had reached only ten million tons. Coincident with the early days of the coal trade there grew up a race of seamen who carried the coal to London and South Coast ports. These men, adventuring further afield, became the backbone of the crews of the British overseas trading fleet and played an important part in naval and mercantile history.

In the early days all coal mines were small and worked coal close to the surface. As soon as trouble arose such as bad air, excess water, roof difficult

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to hold up or the distance coal had to be carried to the surface excessive, the mine was abandoned and another started in its place. The steam engine was not used at mines until late in the 18th century and wheeled haulage was almost unknown. Many of the mining districts were distant from the towns and travel facilities being very limited, the miners and their families lived in isolated communities. The strangeness of his trade, which differed so much from that of the ordinary man, his dirty face and clothes when returning from work, the rough, uncouth manners which were the outcome of his daily battle with Nature in the mine, all tended to cause him to be looked upon as of a race apart. Nevertheless, these very conditions bred a sturdy self-reliance with at times lack of consideration for others which caused him to take drastic steps to obtain what he considered to be his rights. In spite of these unfavourable traits, the result largely of his environment and segregation into small communities, the British miner is one of the finest types of Briton, ever ready to risk his life for a friend or his country, to help his neighbour when in trouble, and always a sportsman.

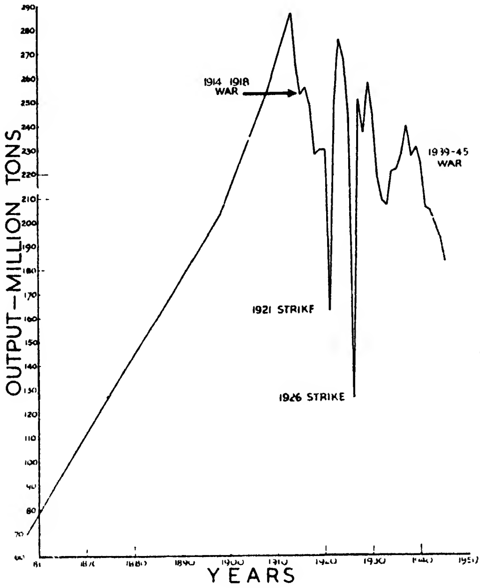

Figure 8.—Output of coal for last 100 years

The coming of the Industrial Revolution with its ever-increasing demand for power resulted in a great increase in coal production, which reached its zenith in 1913 with an output of 287 million tons.

Preliminaries to Opening a New Coal Mine

General. Today all the unwrought coal and the mines themselves are State property though the surface is still in private hands. It may well be, however, that the Ministry of Town and Country Planning may have some say about the actual site of any new mines.

The normal procedure is as follows:—The type of coal (i.e. gas, coking, steam, etc.) varies in the different coalfields and the first point to decide is what type of coal is wanted. The thickness of the different seams also varies. They lie at different depths below the surface, they may be flat or steeply inclined; undisturbed, heavily faulted or affected by igneous intrusions; the roof and floor are also very variable, some good, others indifferent to bad; the coal may be high in inherent ash, sulphur or salt, or may contain much extraneous dirt which will have to be removed on reaching the surface. All these factors have to be considered and may be described as the natural variations. Other considerations must also be examined, such as availability of suitable transport arrangements, in which the presence of the three R's is important: Road, Rail or River (canal). Possible markets for the products, the necessity for cleaning, sizing and grading, the presence of water for drinking and power purposes, adequate supply of local labour or alternatively a suitable site for building a colliery village and room for the colliery surface machinery, railway sidings, etc. Naturally also the actual presence of coal at a reasonable depth and in adequate quantities must be *proved*. This is usually done by means of boreholes.

Prior to 1938, when the State decided to acquire the mineral rights of coal, the prospective colliery proprietor had to negotiate with the surface owner for permission to open a colliery on his land. The surface owner might or might not own the mineral rights and in the latter contingency the mineral owner had to be approached as well as the surface owner. This dual ownership, and the fact that the areas in the respective private owner's hands were relatively small, meant negotiations with several owners and resulted sometimes in the shafts not being situated at the best place for working the coal economically. The many leases involving royalty payments, certain rents, way leaves, provisos, etc., were a definite handicap. Today such drawbacks ought to be non-existent.

Boreholes

A common method is to fix diamonds of the industrial type into a ring or crown which is attached to a tube called the core tube. The core tube and crown are fastened to hollow rods which extend to the surface, where they are rotated by mechanical means. This causes the diamond crown to bite into the rock and a specimen of the rock cut through enters into the core tube. Every six feet or so, the rods are raised to the surface, the specimen is withdrawn from the core tube, and the process begins again. In this way a complete sample of all the rocks passed through is obtained. Samples of coal are analysed for quality and the length of the core gives the thickness of the seam. Thus the quality and, knowing the area, the quantity, of the respective seams is obtained as well as a complete record of all rocks passed through. This is invaluable when the question of sinking the shaft has to be decided. Lastly, estimates of the cost of working, the capital cost in sinking and equipping the mine and the probable net profit per ton are made. If the result is satisfactory, plans are drawn up for developing the mine and sinking the shafts begun.

Method of Approach

Should the seams of coal be near to the surface, the simplest means of approach is by incline. Two or more roads, about 12 ft. wide and 6 ft. high clear of all supports, are driven downwards at any angle up to 30° until they reach the seam it is proposed to work. Suitable conditions for this method of approach, however, are rarely found nowadays and recourse has to be made to vertical shafts.* A preknowledge of the ground through which it is proposed to sink having been obtained from boreholes, a suitable method can be decided upon. Broadly there are three methods, each devised to suit certain conditions. If the ground is normal and contains neither excessive water nor running sand, then the ordinary method of sinking is used. If the ground is very heavily watered, usually from open fissures in limestones or porous red sandstone, then the cementation method is used. If, on the other hand, unstable sands saturated with water have been found by the boreholes, then the freezing method is adopted.

In ordinary sinking the sites of the shafts, which are usually circular in Britain though some in Scotland are rectangular, are marked out on the surface and the top soil and clay removed down to bedrock. While this is being done or before it is done, temporary or the permanent head-gear is erected over the site of each shaft and the winding engines are fixed in position. (Sinking is usually done with temporary engines and the main engines are erected later.)

The actual process of sinking under ordinary conditions is simple. A number up to 36 short boreholes between 4 ft. 6 in. and 6 ft. in length are drilled downwards at the bottom of the shaft, charged with explosives and fired, the broken rock is filled in large buckets (kibbles) holding between 1 and 4 tons, and then hoisted to the surface, where it is dumped. As the depth of the shaft increases, the circular sides are temporarily supported by steel or wooden rings, behind which are inserted wooden planks or steel sheets. When 30 yards or more of the shaft has been so lined, the permanent lining of brickwork or reinforced concrete is put in. This lining is built by men standing on a scaffold slung in the shaft by ropes from the surface. There is a hole in the centre of the scaffold through which the sinking bucket can pass so that the lining of the shaft as well as the sinking and boring can take place simultaneously. Slung also in the shaft are sheet metal tubes 24 to 30 in. in diameter for ventilation, electric pumps and delivery pipes for the water pumps, lighting cable, compressed air pipes for the pneumatic drills, etc.

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* *As a short term policy a number of new inclines are being driven to assist in overcoming the present fuel shortage. These will mine coal too deep to be worked by opencast methods.*

When excessive water is encountered, then the cementation process is used. This consists normally of drilling a series of holes inclined at from 15° to 30° outwards from the shaft bottom for a length of 100 ft. Then a mixture of cement and water is forced into the holes, commencing with the consistency of milk and gradually increasing to the thickness of treacle until no more can be pumped, even under pressure of 1,000 lb. per sq. in. In practice the whole 100 ft. is not bored at once. A plug of about 30 ft. is always left in the bottom of the shaft to anchor the drills and pipes. Then drilling is commenced and continues until water is struck. The drills are withdrawn and cement pumped in until the water ceases to flow. Then drilling is recommenced until the 100 ft. is attained. Next 70 ft. of the shaft is excavated leaving the 30 ft. plug and so on until the water bearing ground is passed through and ordinary methods are recommenced.

When porous ground is met with, chemicals are used in conjunction with cement. Solutions of sodium silicate (water glass) and ammonium sulphate are pumped in. These combine to form a jelly-like compound which acts first as a lubricant to facilitate the passage of the cement and in time hardens to a solid itself.

When running sand is found (as on the coast of Durham), resort is made to freezing. A ring of boreholes, carefully surveyed for verticality are drilled in a circle about 4 ft. outside the shaft diameter. Into these holes concentric pipes are fitted, the outer one closed at the bottom end and the inner one open. Cold brine at about minus 20° C. is forced down the inner pipes and rises up the outer. In time a circular wall or ring of ice is formed and within this protective ring sinking is carried on. After sinking, thick cast iron rings are inserted, the joints made water tight and the ground outside allowed to thaw. The cost of shaft sinking varies widely, depending on the nature of the ground, the depth and other factors. It may be as much as £100 a yard of depth.

General Layout of the Mine

The most important arteries in the mines are the shafts, and these must be protected from all risk of damage. Therefore, an area of unworked coal is left at the shaft bottom, known as the shaft pillar through which only the essential transport roads are driven. The pillar is large enough to protect the main surface buildings and in a deep mine may exceed 500 yds. in radius. Immediately at the shaft bottom is the cage or skip loading station so arranged that all full tubs approach the shaft from one side, one way traffic for all tubs being essential if 2,000 one ton tubs, the normal daily output of a medium to a large mine have to be handled in eight hours, which is at the rate of four a minute. All underground roads in the vicinity of the shaft bottom are graded so as to take full advantage of gravity. From the shaft bottom, main roads, usually in parallel sets of three, are driven towards the boundary of the colliery area or " take." There are three because one is used for the haulage of coal, another as a travelling road for the miners and the third to carry out the vitiated (return) air from the working faces. If the seam is level and no special proviso in the lease inhibits it, the main road or roads are so driven as to intersect the greatest quantity of coal and thus have the longest possible life. In a steeply dipping seam, the main roads are driven to the full dip or rise and auxiliary roads are driven on the level at right angles to them.

As far as possible every main haulage road should be straight and graded to an even inclination. Sometimes when the dip of the seam varies both in amount and direction, subsidiary roads follow the contours. It may well be that in some special instances the continental practice of " horizon " mining may be used in Britain. This means sinking the main shafts to a depth below the seam and driving level roads as haulage roads in stone, until they intersect the seam or enable short vertical shafts to be sunk upwards to intersect the seam. This system is practised most successfully in German and Dutch coal mines and has been for generations normal practice in British and American metal mines. By means of these main development roads the area is split up into convenient units and within these units extraction commences. It must be understood that these main roads are not made in one operation. Their advancing innermost ends are truly exploration roads and, though maintained absolutely straight, follow small variations in dip or rise. Subsequently these hills and hollows are evened out and the road made full size and fitted with its permanent lining.

Methods of Extraction

In the area of extraction, or working face as it is usually called, there are two main methods employed to work the coal. These are (a) extraction in one operation or " longwall "; (b) extraction in two operations or " bord and pillar." Each system has many variations but the principle is the same whether the actual getting is by hand or machinery or the direction of working is advancing or retreating.

Longwall

In this system a length of coal face 100 to several hundred yards in length is prepared. From this face a slice 4 ft. 6 in. to 5 ft. 6 in. in depth is cut every day and taken to the surface. As the face advances an empty space between roof and floor is left and into this space are built dry stone rubble walls or packs. The object of these packs is to control as far as is possible the rate and extent of the convergence of the roof and floor. When it is realised that the whole weight of the overlying rocks has ultimately to be carried, and that this amounts to 1 lb. per sq. in. per ft. of depth, it will be realised how impossible it is to prevent some subsidence. At the actual face itself, falls of roof are prevented by vertical props and bars set between the roof and floor.

The normal procedure every twenty-four hours on a longwall face is as follows: —

Morning Shift. Miners hew, blast and lever the coal down if coal cutting machines are not used. If coal cutters are used, the coal is blasted or hewn down with hand or pneumatic picks. It is then filled into tubs or on to conveyors and starts its journey to the shaft bottom. As coal is removed from the face, the miner sets props under the newly exposed roof and, in some districts, pulls out the row of props furthest back from the face. This allows the roof to fracture at a safe distance behind the face, thus reducing the risk of a fall at the face where the men are working. Props are always set in rows aligned parallel to the face. For each mine there is a fixed statutory distance between props in the same row and between rows of props. An average distance is about 3 ft.

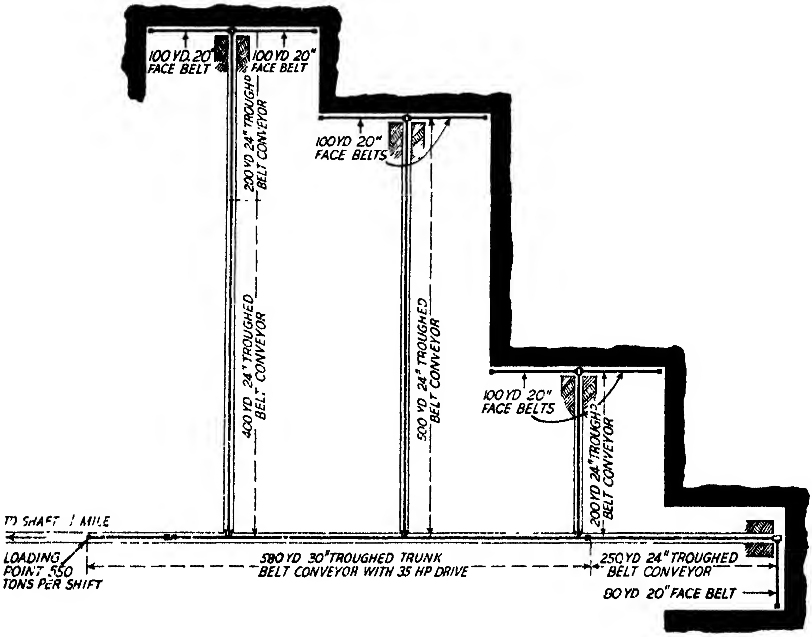


Figure 9.—Longwall System

Afternoon Shift. On the afternoon shift if mechanical coal cutters and conveyors are used one gang of men operate the coal cutter and another place the conveyor nearer to the face, which has moved forward during the morning shift.

Night Shift. Another gang of men go to the face, blast down the roof in the approach roads and use the stone to build the dry stone walls. Thick walls are built on either side of the approach roads and probably other walls between. The stone for these is recovered from the fallen goaf or waste from where the props have been withdrawn. Other gangs of men are employed during both afternoon and/or night shifts repairing roads and on general maintenance work. A longwall face usually advances away from the shaft, but in a few cases the development roads are driven in advance and a longwall face is opened up which retreats towards the shaft.

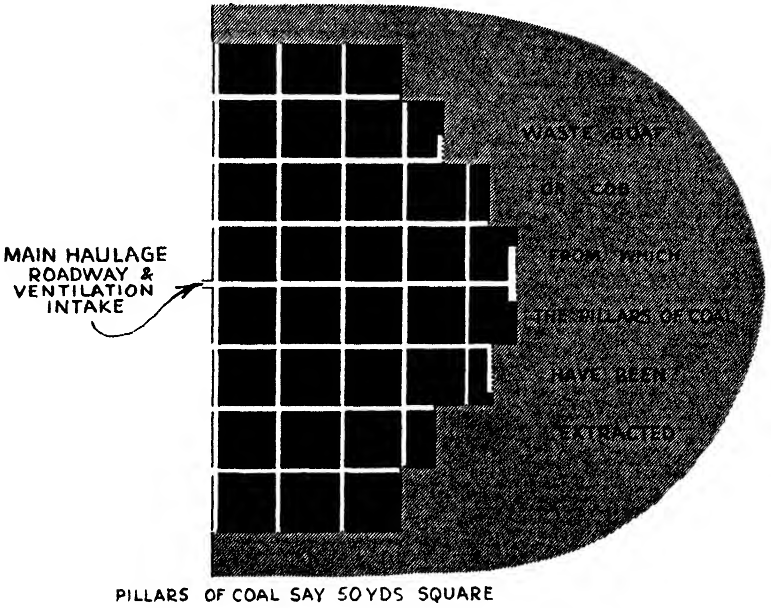


Figure 10.—Bord and Pillar System (British)

Bord and Pillar

This method which has many variations and local names is essentially extraction in two operations. The first operation is to divide the working area up in pillars, either square or rectangular, which is called the " whole " working, and then remove the pillar, which is called " broken " working. The pillars vary greatly in size according to the depth of the seam from the surface and the extent to which machinery is employed. Sizes vary from 22 yds. by 22 yds. to 66 yds. by 66 yds.; 20 yds. by 40 yds., 30 yds. by

60 yds., etc. A seam of coal is not a homogeneous block but has vertical planes of weakness, known as cleat, which are most pronounced in a N.E.-S.W. direction. Roads driven east and west cut across this cleat and are easier to work and, in hand mining, are usually six yards wide and called " Bords." Roads driven at right angles, i.e., parallel to the cleat, are harder to work. They are usually three to four yards wide and called " walls." When an area has been blocked out into pillars, the pillars are extracted by taking slices off them, known as " working the broken." It is considered bad practice to allow coal to stand in pillars a long time, so usually the broken workings follow close behind the " whole." Great care must be taken to see that the pillars are taken out in the right sequence, which means that the line of the pillars being extracted should be about 45° to the line of the bords and the walls. If this is not done, invariably great difficulty is experienced in controlling the breakdown of the roof over the void made when a pillar is removed.

Machine Mining

In the majority of mines today the laborious work of undercutting the coal by hand is done mechanically and the unnecessary lifting to fill a tub is substituted by filling on to a conveyor. A mechanical coal cutter consists of a chain into which small picks are inserted and which revolves rapidly round a rectangular frame or jib. The jib varies from 3 ft. 6 in. to 6 ft. in length. A sufficient space is cut under the coal to accommodate the jib and the jib put in position and set in motion. The whole machine is pulled under its own power slowly along the face and a groove or " cut " the depth of the jib and 4 in. to 6 in. high is made. The machines are driven by electricity or compressed air and are rated at forty to fifty horse power. The average length of face cut per machine per shift is 100 yds. The following day the machine is turned round and cuts in the opposite direction. After the undercutting is completed, men with hand held rotary drills, operated by compressed air or electricity, bore holes every three to six feet apart into which explosive is inserted and the coal broken down. On another shift men shovel this coal on to conveyors. A conveyor is a continuous rubber-canvas moving belt, placed parallel to the face and the same length as the face. The outer end delivers into a tub or, more frequently in a modern mine, on to another conveyor at right angles, the road conveyor. Instead of a moving belt, some engineers prefer a continuous shaking trough which propels the coal in jerks to the outer end; others like a continuous stationary trough in which there is a moving double chain or scraper which pushes or carries the coal along.

It will be noted that in spite of all this coal face machinery (and over 75 per cent. of all coal got is either mechanically cut or conveyed, usually both) there is the human link, namely the filler. To make the face fully mechanised a number of types of mechanical loaders are being tried with varying success. Under especially good conditions a combined cutter-loader is meeting with considerable success. Mechanisation is not confined to longwall and probably the most revolutionary change in British coal getting during the 1939-45 war has been the introduction of American methods of mechanical mining.

American natural conditions underground are vastly superior to those in Britain chiefly because the mines are of recent development, shallow and working in virgin areas, whereas most British mines have been working fifty years and more. The best seams here have been worked and the consequent subsidence following the first working has made the secondary seams even more difficult to work. American mining methods are based essentially on modified bord and pillar which is worked on the retreating system. Development roads divide the area up into large panels of twenty and more acres. The pillars, generally long and thin, are blocked out commencing at the innermost end of the panel. As soon as the pillars are formed they are extracted. The coal is undercut by a mobile coal cutter which moves from working place to place, blasted and mechanically loaded also by a mobile machine which gathers the broken coal on to an inclined conveyor, raises it up and delivers it into a tub, or on to an easily extensible conveyor, or to a mechanically propelled underground "lorry" with large pneumatic tyres known as a shuttle car. Under suitable conditions such as a horizontal or slightly inclined thick seam, i.e., over 4 ft. with a good roof, this system is said to be doing excellent work.

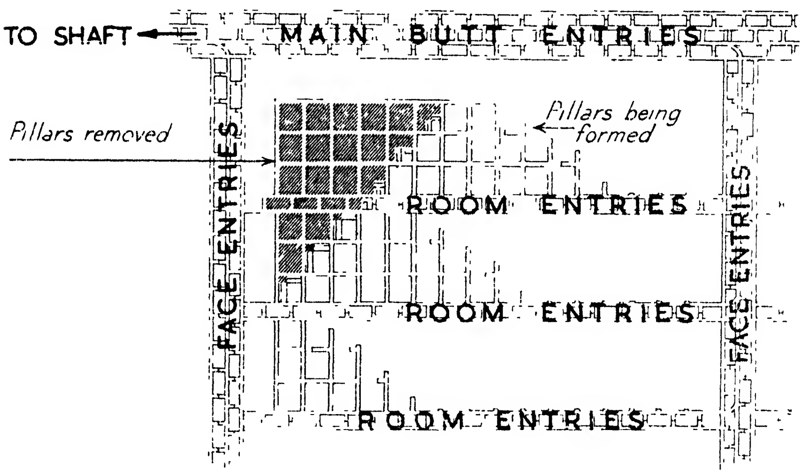


Figure 11.—American Pillar System

Underground Transport

The organisation of the underground transport is a very complicated operation. In a mine producing 2,000 tons of coal a day, between four and five tons of coal contained in four, six or eight tubs arrives at the shaft bottom every minute. These have to be collected from half a dozen different working areas probably at four different points of the compass and all brought to one side of the shaft. Not only have the full tubs to be handled, but empty ones sent into the workings to replace them. Transport can be divided into four groups for convenience, each one being complementary to the other. The groups are face, subsidiary, main and shaft haulage. At the face, which is the initial gathering point, human and animal haulage is dying out. Youths still push tubs to and from the innermost sidings in some mines, in others they are assisted by small ponies under twelve hands high. These are being replaced by main road conveyors, shuttle cars and small electric or compressed air driven rope haulages. The subsidiary haulage is used to collect tubs from the innermost sidings and take them to the main haulage road. It may be locomotive haulage using a battery locomotive, but this is not as yet common practice, it is either a belt or a rope as a rule. The belt is the same type as is used at the face but wider and faster running, thus having greater carrying capacity.

There are two common forms of rope haulage, " endless rope " and " main and tail." With the endless rope there are two sets of rails and a continuous band rope travelling slowly, one side going inwards and the other outwards in the middle of its respective set of rails. The rope at its outer end passes several times round a pulley which is driven by an electric or compressed air motor. To the outgoing rope single tubs or in groups of two, three or four are attached by chains or clips at regular intervals and the same with empties going inwards. The speed of travel varies from 1½ to 2½ miles per hour.

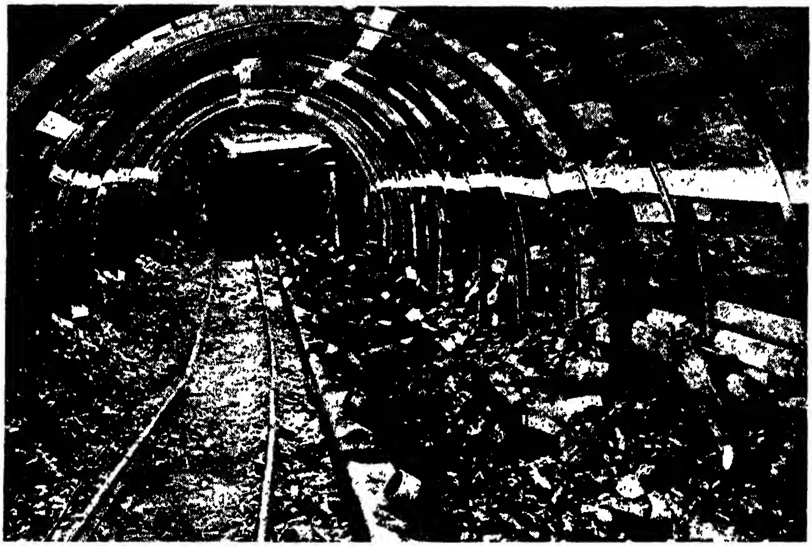
With the main and tail, there are two separate ropes each wrapped round its respective drum. The drums are so arranged that each in turn can be clutched on to the driving motor while the other must free wheel. Only a single road is required with a passing place, but one rope, the tail rope, is twice the length of the other. Tubs at the innermost siding are made up in groups or sets of anything from six to twenty-four. The main rope is attached to the front of the set and the tail rope, after passing round a pulley, is fastened to the rear. The main drum is put into gear and the set is hauled out, pulling the tail rope behind it. When it reaches the main haulage, the ropes are detached, the tail rope attached to the innermost end of the empty set and the main rope to the rear. The tail drum is put into gear and the main drum free wheels. The set travels inwards pulling the main rope behind it. The speed is five to ten miles per hour.

Main Haulage

This is usually one or other of the rope systems described above and with long, well laid, straight roads is reasonably satisfactory. In some modernised mines locomotive haulage is used; diesel or storage battery and other types may be introduced shortly. It is unquestionable that given straight, reasonably level well graded roads with heavy rails and sleepers, properly laid and ballasted, locomotive haulage is the most economical form for use on underground main roads.

Shaft Haulage

At most mines the shafts are fitted with cages (lifts), two to each shaft. Into the cage at the bottom are put the full tubs and an equal number of empties into the cage at the surface. The position of the cages is reversed through the medium of a powerful winding engine, and thus the coal reaches the surface. At an increasing number of mines skips are replacing cages. A skip is a long, narrow rectangular box into which coal is poured and then drawn to the surface where it is automatically dumped into a receiving hopper. At the pit bottom the tubs are tipped into a collecting hopper which feeds a loading hopper holding exactly one skip load. When the descending skip arrives at the bottom the loading hopper discharges its load into it. The skips are provided with anti-breakage devices both when loading and discharging and are a rapid and economical form of hoisting.



[PHOTO: CHAS. R. H. PICKARD, LEEDS

Figure 12.—Main roadway showing two methods of transport—by rail and by belt conveyor. Note steel supports to roof in place of timber (Newdigate Colliery)

Ventilation

All mines have to be ventilated primarily "to dilute and render harmless all noxious and inflammable gases." In addition large quantities of air are required to keep the working places cool and free from excessive humidity, especially in deep mines. If the air in one shaft is warmer than in the other a circulation is induced. The cool air descends the " downcast " shaft and is known as the " intake " air, while that ascending is the " return " air and travels the " upcast " shaft.

Ventilation due to temperature differences is usually called natural ventilation. Unfortunately, it produces insufficient quantity for large, modern mines and mechanical means have to be used to supplement it.

[PHOTO: CHAS. R. H. PICKARD, LEEDS

Figure 13.—Mechanical chain coal cutter undercutting seam on the left, with belt conveyor on the right (Newdigate Colliery)

Mechanical ventilators are usually fans arranged to suck air through the upcast shaft. They are of two kinds:—(a) Cylindrical with curved vanes round the periphery, the air entering the ends of the cylinder, turns through 90° and is flung out at the circumference, and (b) screw fans, shaped like an aeroplane propeller and acting in the same way, except that the air passes through the fan instead of the fan through the air as in a plane. The quantity of air required varies with each mine and may be as much as 400,000 cu. ft. a minute with an engine of 400 to 500 h.p. After descending the downcast shaft the intake air is divided or split into separate streams, one for each main district where again it may be sub-divided so that fresh, cool, dry, undiluted air shall reach each longwall face or set of bord and pillar workings.

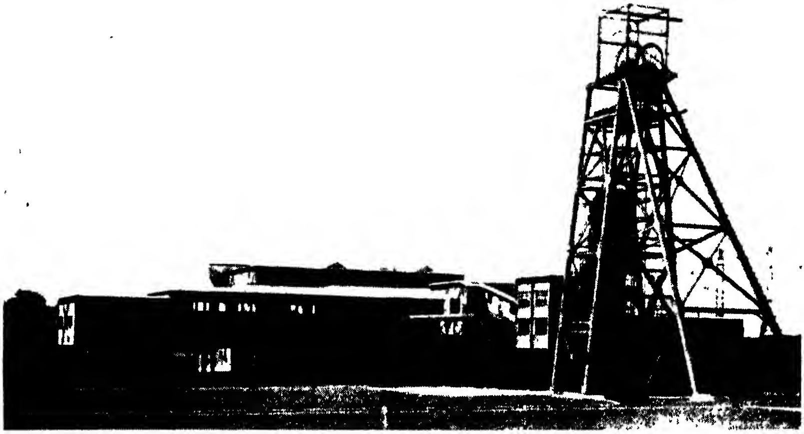


Figure 14.—General view of a modern colliery

Figure 15.—View at the top of the shaft showing tubs and cages

After traversing the face it travels by return airway, reuniting with other return air currents and finally reaches the upcast shaft and the fan, which is in Britain generally placed on the surface. Very great care is taken to conduct it round the mine and air tight walls, double doors and canvas curtains are used to prevent leakage from intake to return.

Sometimes small auxiliary fans are placed underground to boost up the quantity entering any particular district and steps are also taken to regulate the quantity in each section.

In most coal mines some inflammable gas, usually methane, is found in the workings. It comes from the coal seam itself and the rocks immediately above and below the seam. The quantity varies and may be as much as 2,000 cu. ft. per ton of coal. Sufficient air must be circulated to keep the percentage of methane in the air current less than 2½ per cent. Another function of the ventilating air is to keep the relative humidity of the air as low as possible. In a hot mine the chief cooling agent is the evaporation of sweat from the miners' bodies. The sweat will only evaporate if the air is dry. Drops of visible or unevaporated sweat have little or no cooling value.

Pumping

Shallow or steeply inclined seams usually make a good deal of water, in some cases more than 1,000 gallons a minute, and the weight of water removed is several times greater than that of the mineral. The water is collected to a central pumping station adjacent to the shaft bottom by subsidiary pumps in the working areas. The type of pump commonly used is the multistage centrifugal or turbine pump directly coupled to an electric motor.

Supports

In the preceding narrative mention has been made from time to time of supports. Two materials are commonly employed, steel and wood, though for special jobs brickwork and/or concrete is used. The use of steel is increasing, partly due to the difficulty of obtaining timber during the second world war, partly to mining engineers realising its superiority to wood, and partly to the lessening of the miners' prejudice. The miner used to say " wood talks," meaning it creaks when subject to excessive pressure, and this warned him of danger. It is true that steel gives less warning, but steel is so much stronger than wood it rarely breaks and the risk of accident is less. Steel as arches in the shape of an inverted U is used in many main underground roads and 5,000 miles of roads are so supported. (See Figure 12.) Near the face where the ground is still subsiding, steel arches mounted on wooden stilts are often used. The stilts are clamped to the legs of the arches, and as the roof descends the stilts slip through the clamps and the arch maintains its shape and its strength. On the face itself, either steel or wooden props are used, but no face should ever be carried on mixed wood and steel props.

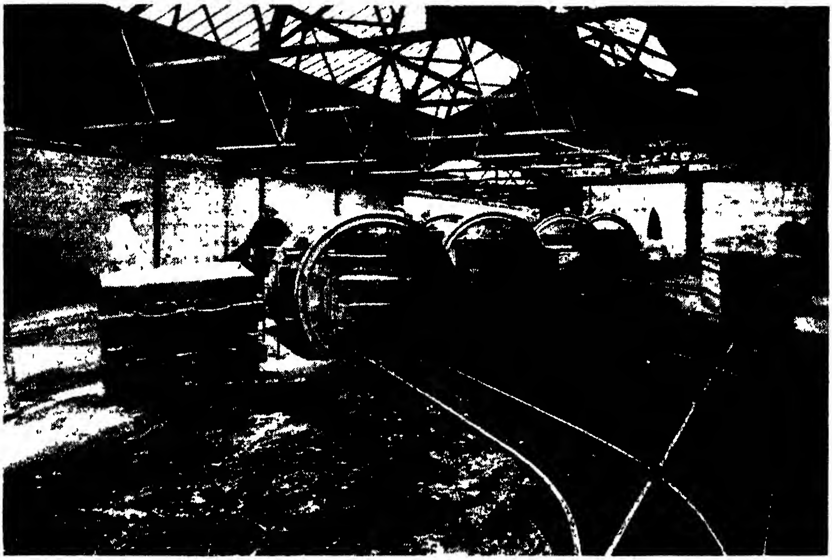


Figure 16.—Tipplers at the pit head

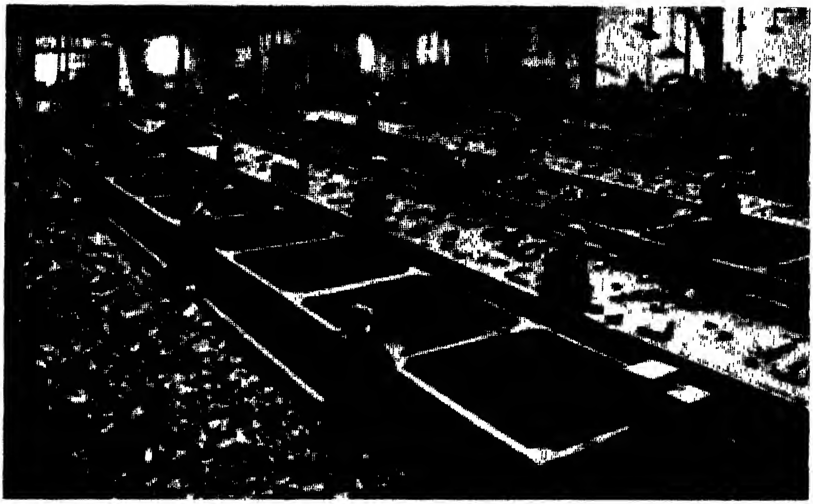


Figure 17.—Screens and picking belts

Lighting

Compared with a factory, lighting in a mine is poor, but great difficulties have to be overcome. Owing to the presence of inflammable gas, only lights incapable of igniting the gas can be used in most mines. The miner has to carry a portable lamp because lighting from the electric mains is not yet practicable except in a few cases. The two types of lamp used are either electric portable lamps with a battery, the lamp being carried either in the hand or on a strap fastened round the man's waist with a cable leading to a small fitting and bulb attached to his hat, or an oil flame safety lamp. Both types of lamp give from one to four candle power, depending upon their weight, which may be as much as ten pounds.

Explosions and Accidents

A colliery explosion is a horrible event and always appals the general public. When examined statistically, however, it is found that explosions cause a very small percentage of the total number of deaths from accidents over a period of ten years. It is the constant daily sniping of a life lost here and another there that make up the yearly total. During 1945 the total death rate per 1,000 men employed, both surface and underground, was 0.8, of which more than 50 per cent. were from falls of ground.

Colliery Power

Steam was the only medium available for mechanical power in coal mines until nearly the end of the 19th century, and it was used mainly for winding, pumping and underground haulage by means of wire-ropes passing down the shafts from engines placed on the surface. The unsuitability of wire ropes and steam for the transmission of power over long distances led first to the use of compressed air and later to electricity underground. At the present time steam, compressed air and electricity are widely used in and around the mines.

The maximum load during the winding cycle may be as much as 6,000 h.p. or more, therefore, the nature of the power supply system at any individual colliery is determined mainly by the type of winding equipment installed. Winding engines are still mostly driven by steam, and for this reason steam boilers are installed at the mapority of the pits in this country. The maximum demand of a winding engine may reach a rate of 120,000 lb. of steam per hour for a few seconds during the peak load, whilst the average demand may be only 30,000 lb. per hour. This great fluctuation in the demand for steam requires a high thermal storage capacity in the boiler plant, hence the popularity of the Lancashire Boiler in the past. The modern tendency, however, is to use water-tube boilers with mechanical stokers or pulverised-fuel burners. This type of boiler requires a steady load for efficient working, so that when steam winders are used it becomes necessary to provide additional thermal storage capacity in the form of high-pressure accumulators. A development which has hitherto enabled the steam winder to hold its own against the electric winder, is the utilisation of exhaust steam in mixed-pressure turbines for the generation of electricity and the production of compressed air for use underground and on the surface. The combined efficiency of this system, when low-grade fuel is used to generate steam, places the individual colliery power plant in a very favourable position from the standpoint of fuel economy, but the amalgamation of colliery undertakings into large groups has led, during recent years, to the establishment of large central power stations for supplying electricity and compressed air in bulk to the individual collieries in the group. This tendency favours the use of electricity for all purposes when it can be applied, including winding. The advantage of electric winding under these conditions is that the total winding load is more or less constant when a considerable number of winders are supplied from the same source, and for this reason it is possible to use a.c. motors for winding instead of the more expensive converter system with or without the balancing flywheel.

Although winding usually imposes the greater instantaneous load on the power supply systems of an individual colliery, it does not necessarily involve a total expenditure of energy greater than ventilation and pumping, since winding is intermittent and the ventilation and pumping loads are continuous. The average amount of air passing through the workings of a modern colliery for the purpose of ventilation is about five times the weight of coal producd. Thus, in a colliery having an output of 3,000 tons of coal a day, the rate of flow of air into the workings is of the order of 300,000 cu. ft. per minute and the power required to drive a fan to handle this amount of air may be of the order of 400 h.p. The amount of water to be pumped varies greatly in different coalfields and at different pits in the same coalfield. At some collieries, the pumping load is negligible whilst at other pits the annual consumption of energy by the pumps is greater than that of the winding engines and the fan combined.

Increased mechanisation at the coal-face has led during recent years to a greater demand for electricity and compressed air. Recent tests show that complete mechanisation of the processes of coal-cutting, loading and conveying at the coal-face, in a seam of normal thickness, requires an input of about 150 h.p. for an output of about 300 tons of coal during a working shift of 5.5 hours. This corresponds to a consumption of about 2 kw.h. per ton. The total average consumption of energy for winding, haulage, pumping, ventilation and coal preparation is about 20 kw.h. per ton, therefore complete mechanisation at the coalface is unlikely to increase the energy consumption by more than about 10 per cent. of the consumption at the present time. In fact future consumption will probably decrease when more efficient machinery becomes available for haulage and winding.

According to the fourth report on the Census of Production, which was last published in 1930, the total capacity of all the prime-movers installed at the collieries was 3,067,000 h.p., the aggregate capacity of the electric motors supplied with current generated at the pits was 1,376,000 h.p., and the capacity of motors supplied with electrical energy from external sources was 537,000 h.p. The total capacity of prime-movers and motors installed at all the coal mines in the country would thus be about five million h.p. With an average consumption of 20 kw.h. per ton and an annual output of 200 million tons, the total annual consumption of energy in the coal mining industry is thus about 4,000 million units a year, which is approximately one tenth of the output of the statutory electricity supply undertakings in the country. It is significant that the consumption of coal for the generation of all forms of power at the collieries at present is about 11 million tons per annum, whilst the statutory electricity supply undertakings consume only about 24 million tons per annum to generate ten times the amount of useful energy. This implies that colliery plants have a low thermal efficiency as compared with those of the large central stations, and this fact provides a strong argument in favour of the elimination of small power plants.

Surface Plant

At the surface are the headgears carrying the pulleys over which run the ropes raising and lowering the cages, and these form the characteristic feature of every colliery. In addition are large buildings housing winding engines, power generating machinery, boilers, repair and maintenance workshops, fan house, screening, sizing and grading plant, the coal washery, lamp rooms, etc. These form a very imposing series of buildings which, in modern colliery layouts, can have quite a pleasing appearance.

Conclusion

Throughout this description of coal mining, very few figures have been given. Some are given now. The cost of sinking and equipping a colliery averaged 10s. to 15s. per ton of yearly output prior to the 1914-18 war. Today it will probably be 40s. to 60s.

The figures in the following tables are abstracted from the Ministry of Fuel and Power Statistical Digest, 1945, published October, 1946.

	1913	1938	1945
No. of persons employed	1,107,000	782,000	709,000
Output in million tons	287	227	183
Export in million tons	94	46	8
Gas Industry in million tons	18	19	21
Electricity in million tons	5	15	24

Percentage of Total Output from Seams of Different Thickness

	Under 2	2–3	3–4	4–5	5–6	6 feet
1913	3.5	15.3	26.5	25.6	17.5	11.6
1924	4.6	17.6	26.9	23.9	17.0	10.0
1944	3.7	22.0	29.3	24.2	12.7	8.1

Tonnage Raised to Nearest Million

1913	10	44	76	73	50	33
1924	12	40	61	54	38	23
1944	7	40	54	44	23	15

Percentage of Coal Cut by Machine from Seams of Different Thickness

1913	24	17	10	4	3	2
1924	44	34	21	10	8	4
1944	85	89	88	77	67	54

Age of Collieries	Number	Output as a percentage
Unknown	113	9
10 years	46	1
20 ,,	57	5
30 ,,	94	12
40 ,,	135	17
50 ,,	122	15
60 ,,	94	13
70 ,,	101	12
80 ,,	83	10
Over 80 years	65	5

Mechanisation

	1938	1944
Percentage of total output cut by machines	59	72
Percentage of total output carried by conveyors	52	71

Chapter IV

THE PREPARATION OF COAL FOR THE MARKET

by E. T. WILKINS*

COAL in the form in which it comes from the pit is in general not suitable for use until it has been "prepared for the market." Almost universally the coal has to be separated into various sizes or grades by screening in order to fit it for use in the consumers' appliances. At some collieries it happens that large coal can with advantage be subjected to a breaking process in order to meet a demand for nut sizes. In these circumstances machines designed to produce the maximum yield of nut sizes with the minimum production of the less valuable "fines" are necessary. Associated with the problems of coal breaking are those of anti-breakage, for it is on the consumer's premises that the correct size of coal is required, and any degradation which occurs subsequent to the preparation of the coal is clearly undesirable.

In general the coal coming from the pit contains a significant amount of shale and other impurities of a stony nature, which contribute largely to the ash content of the coal. One of the most important branches of coal preparation is that concerned with the removal of this so-called "dirt" by various washing and dry cleaning processes; about 100 million tons of coal a year, or 50 per cent. of the total output, is mechanically treated in this way, and a further quantity is cleaned by hand picking.

Modern methods of mining produce large quantities of small and fine coal which make it necessary to employ auxiliary processes. By "de-dusting" and "de-sliming" processes the fines may be separated from the coarser sizes prior to washing; by "flocculation" and filtration fines may be separated from washery waters; by de-watering processes the moisture content of washed coal, etc., may be reduced. A possible future development is the "dustproofing" process for overcoming the dustiness of some classes of fuel. Some fines are more readily utilised after they have been reconstituted in lump form by briquetting. These are the main aspects of coal preparation which are discussed in this chapter.

It is sometimes said that we in Britain have been less progressive in our

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* *Principal Scientific Officer, Fuel Research Station, D S I R*

attitude towards coal preparation in general, and coal cleaning in particular, than have some Continental countries. This criticism may have been justified, but, owing to the inherent purity of most British coals, it was for a long time less necessary to resort to mechanical methods of improving coal in this country than in others where the coal was not of such high purity. However, with the advent of modern methods of machine mining it became more difficult to prevent the mined coal from becoming adulterated by dirt bands and stone from "roof" and "floor" of the seam; in consequence, the need for coal cleaning has increased and is likely to increase still more in the future.

In a few localities some of our best seams have been worked out or are nearing exhaustion, but it is known that there remain large reserves of coal of the types which helped Britain to establish her industrial supremacy. Until adequate coal preparation plant is available, it may be that some of this coal will appear on the market containing more ash than is desirable because of the contamination by dirt bands, etc., referred to above. It is, however, worth remembering that the inherent quality of the coal is not affected by such contamination, and that when the dirt is removed by efficient washing the original quality of the coal can be more than restored—a quality which, incidentally, is still the envy of most of the world.

SCREENING OR GRADING

The first operation in handling coal at the pit-head is usually a preliminary screening so as to separate the larger sizes of coal, which are frequently cleaned by hand-picking. The smaller sizes, e.g. below about 3 inches, which normally go to the cleaning plant for the removal of dirt, are subsequently rescreened into nut and other sizes as necessary.

Standardisation of Sizes

For a long time the coal industry has adjusted its screening plant to meet a large variety of consumer's demands for special sizes of coal. Many grades were prepared, often differing only slightly in their upper and lower size limits. One objection to the use of a large number of grades is that the same name is sometimes applied to different grades, which results in confusion. Another is that, in general, modern combustion appliances do not need a great variety of sizes. A large measure of rationalisation was recommended in 1946 in the Report of the Coal Grading Committee of the British Colliery Owners' Research Association, which was served by representatives of coal producing, marketing, consuming and other interests. These recommendations included a reduction in the number of grades produced and the standardisation of nomenclature as shown in Table 6.

The same Committee also proposed that coals passing through a screen and having no lower limit of size, should be called "smalls" and should be described by the size and shape of the screen aperture through which they have been made, and by their fines content expressed as a percentage

TABLE 6

Recommended Standard Size Groups for Graded Coals

Name of Group	Typical Screen Size (in. rd. hole)	Permitted Range of Screen Apertures (in. rd. hole)*		Criteria of Undersize—neither to exceed	
		Upper Limit	Lower Limit	A.†	B.†
Large Cobbles	6 × 3	6 to 8	3 to 5	—	—
Cobbles .. .	4 × 2	4 to 5	2 to 3	—	—
Trebles .. .	3 × 2	2½ to 3½	1½ to 2	15% thro' 1¼" sq	2% thro' ¼" sq.
Doubles	2 × 1	1¾ to 2¼	1 to 1½	25% thro' ⅞" sq.	3% thro' 3/16" sq.
Singles	1 × ½	1 to 1½	½ to 1	20% thro' ⅜" sq.	3% thro' ⅛" sq.
Peas	½ × ¼	½ to ¾	¼ to ½	15% thro' 3/16" sq	3% thro' 1/16" sq
Grains	¼ × ⅛	¼ to 7/16	¼ to ¼	25% thro' ⅛" sq.	3% thro' 1/32" sq.

* Appropriate equivalent square apertures which may be used.

In. rd. hole ..	8	6	5	4	3½	3	2½	2¼	2	1¾	1½	1	¾	½	7/16	¼	⅛
In. sq. hole ..	7	5¼	4¼	3½	3	2⅝	2⅛	1⅞	1¾	1½	1¼	⅞	⅝	⅜	⅜	¼	⅛

† These square meshes refer to those defined in B S. 410 and are to be used for the determination of sieve analyses as required by B.S. 1293.

passing ⅛ in. square mesh. It is along these lines that the size grading of coals is likely to become standardised in the reorganised coal industry.

Types of Screens

There are many designs of screens used for coal grading, most of which are of one or other of the following types:—

Gravity or Bar Screens. These consist of a parallel arrangement of metal bars, suitably spaced, and set at an angle such that the coal will slide down them, thus allowing the undersize material to pass between. This type of screen has the advantage of simplicity and low installation and operating cost, but the sizing is not accurate and breaking of the coal in passing down the screen is sometimes excessive. Many bar screens are still in use, but they are being gradually superseded by better types.

Revolving or Trommel Screens. These consist of punched plates or wire mesh, bent to form a cylinder, which is rotated about its axis. The axis is set at a slight inclination to the horizontal so that when coal is fed at the upper end, oversize material will traverse the screen longitudinally whilst undersize passes through the holes. Several such screens may be arranged one inside the other, but spaced apart in order of decreasing aperture size from the centre one outwards, or a single cylinder may have apertures which are smaller at the feed end than they are at the discharge end. In this way several products may be made from a single plant. The Trommel screen is efficient when used dry or wet, i.e. in a stream of water, but often causes appreciable breakage of nut sizes.

Shaking or Jigging Screens. These consist of a rectangular plate, perforated with holes of the required size and shape, fixed in a suitable frame. The screen is mounted on flexible supports and is connected to an eccentric, or other driving mechanism, which moves the screen backwards and forwards a distance of between 2 and 6 inches about 100 times a minute. Usually the supports are arranged so that during the forward stroke the motion carries the screening surface and the particles on it slightly upwards; on the return stroke the screen moves backwards and slightly downwards, thus withdrawing itself from under the particles. This motion, together with the slope of the screen, causes the particles to slide jerkily in contact with the screen. Screens may be superimposed or may be arranged end to end so as to prepare a number of different grades. Screens of this type are efficient for sizes down to about ¼ inch, are accessible, cheap to operate, and have a high capacity; in consequence, they are very widely used in modern colliery practice.

Vibrating Screens. The high-speed vibrating screen finds favour for separating fine sizes on account of its high throughput of difficult material. In one type of plant the screen resembles the shaker screen, except that the amount of movement is smaller (½ inch to ¾ inch), and the speed of vibration higher (up to 500 vibrations per minute). In another type, the screen surface consists of a sheet of woven wire mesh, the two opposite sides of which are held stationary in a frame, whilst along the centre line the tightly stretched " cloth " is made to vibrate by a mechanical or electrical device. The screen is set at a steep angle (e.g. 40° to the horizontal) and is vibrated through quite a small distance at a speed of about 1,000 – 2,000 vibrations per minute.

COAL CLEANING

For all purposes for which coal or coke are used it is advantageous that the ash content should be moderate or low. This means in most instances that the coal must be cleaned by washing, dry-cleaning or hand picking at the pit-head to remove some of the ash-forming constituents.

The advantages of using cleaned coal are many and various. Most people recognise the need for clean fuel in the home; in industry the need is as great or greater. To quote only a few examples, in the gas and coking industries the gas outputs of the carbonising plant and the quality and effective output of usable coke are improved by the use of clean coal. In the smelting of iron a reduction of the ash content decreases the fuel consumption, increases the ease and lowers the cost of operating the furnaces, at the same time improving the quality of the iron. The cash value of these advantages varies according to circumstances, but estimates made prior to 1939 indicated that, at some works, each 1 per cent. reduction in the ash content of the coke used for smelting resulted in a saving of about 9d. per ton of iron produced. In boiler firing, if the ash content is excessive it decreases the power output of the boiler, increases the losses of fuel in the ashes, and causes the formation of deposits on the water-tubes, thus necessitating more frequent shutting down for cleaning. In the case of pulverised fuel firing the cost due to grinding the harder stony material is increased. Superimposed on all coal usage is the added cost of transporting useless material, for, having hauled the more-than-useless dirt from the colliery to the consumer, the resulting ashes must be recovered and disposed of, often at an appreciable cost.

In general the advantages of cleaning can only be achieved if the cost of treatment is small. The costs in any particular instance naturally depend on a number of factors, but in 1944 it was estimated at between 10 and 15 pence per ton of coal treated, depending on the types of plant installed. This is a remarkably small cost when the complexity of the coal cleaning operation is considered, but it must not be assumed that this amount represents the total difference between the production costs of a ton of uncleaned and a ton of cleaned coal. Owing to the fact that weight is lost when dirt is discarded, the difference in the selling price of the raw and clean coals must take account of what is sometimes called the " loss of vend " when coal is sold by weight. Since, however, in a modern plant almost the whole of the coal substance is recovered by the washer, the loss of vend is generally small when expressed in terms of potential heating value of the coal.

The " Washability " of Coal

It will be evident that ordinary mechanical coal cleaning processes can only separate particles of higher ash content from those of lower ash content; they cannot extract ash from the coal lump. The degree of cleaning possible with any particular coal therefore depends upon the distribution of its ash-forming constituents which, for present purposes, may be classified thus: —

(a) " Free dirt," derived from dirt bands, roof and floor of seam, etc., which occurs separately from the coal and may thus be removed by processes capable of separating different kinds of particles one from the other. The ash content of " free dirt " may be up to about 80 per cent., the other 20 per cent. consisting mainly of combined water and carbon dioxide which are given off on heating.

(b) " Fixed ash " derived from the original plant ash and the clay, silt, etc., which became spread through the original coal-forming mass. In some of the cleanest coal seams in this country the fixed ash amounts to about 1 per cent. of the coal.

If coal cleaning consisted merely of separating coal from dirt, very simple machines could be used, because of the considerable differences between the physical properties of these substances. Cleaning is, however, made more difficult by the fact that raw coal as it comes from the mine contains middlings of a wide range of intermediate ash content. The middlings of low ash content may generally be included in the washed coal without serious effect on its ash content, while the dirtier middlings may not.

Broadly speaking, there are two types of middlings. In one type the ash is distributed throughout the lump as in (b) above. Little can be done to reduce the ash content of this material which, if too high to be included in the clean coal, may either be discarded or preferably used locally on a suitable appliance such as the colliery boiler. The other type of middlings consists of intergrown layers of dirt (or high-ash middlings) and coal (or low-ash middlings). In suitable coal washing plants it is possible to separate this middlings, to crush it so as to release the intergrown layers, and to recover usable coal therefrom by re-washing.

By means of X-rays it is possible to " see " the distribution of ash in coal; Figure 18 is an X-ray photograph in which the ash-forming constituents appear as dark markings.

" Float-and-Sink " Test. The separation of raw coal into components of different ash contents is conveniently carried out by making use of differences in specific gravity. The specific gravities of pure coal and some of its associated impurities are as follow: —

Bituminous coal		1.12 – 1.35
Light middlings		1.35 – 1.5
Heavy „		1.5 – 1.8
Dirt.	Carbonaceous shale	1.8 – 2.2
	Shale	2.2 – 2.6
	Pyrites	4.8 – 5.2

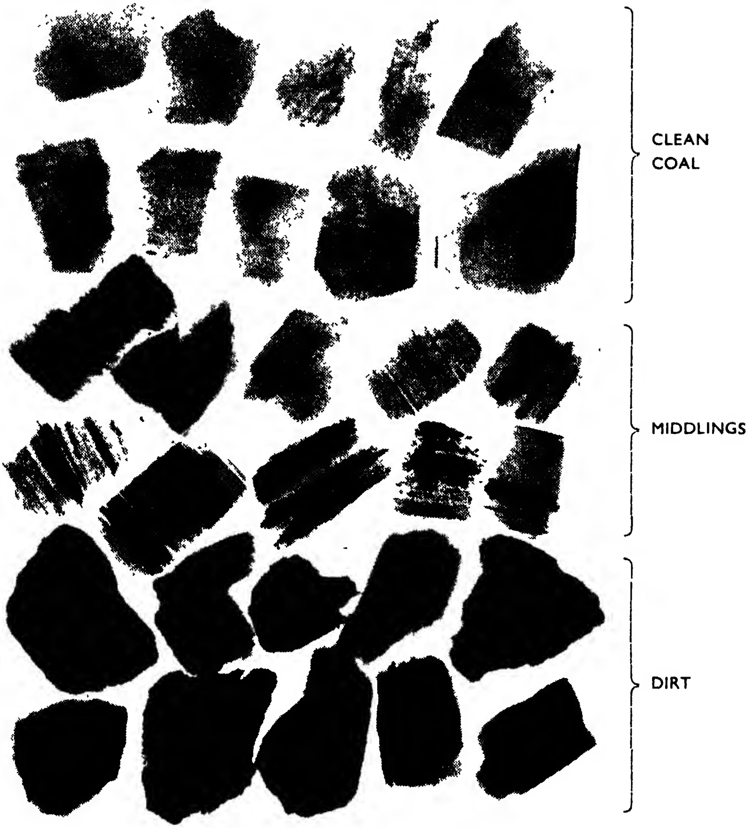

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Figure 18.—ASH IN COAL. X-ray photographs showing occurrence of ash in clean coal, middlings and dirt

For test purposes and to determine the " washability " of a coal, liquids of specific gravity between about 1.25 and 1.60 or higher are used as a separating medium. Suitable liquids for this purpose are made by mixing benzene and carbon tetrachloride in various proportions; alternatively, aqueous solutions of calcium or zinc chlorides are sometimes used.

To carry out this test, the coal sample is added, small quantities at a time, to a liquid bath of suitable specific gravity, e.g. 1.25; the " floats " and " sinks " are then removed separately. The " sinks " are then re-treated in a bath of slightly higher specific gravity, and so on until the coal has been divided into a number of fractions of different specific gravities. One set is of results obtained in this way, shown in Table 7.

The separation obtained in this test tells a great deal about the quality

TABLE 7

Results of Float-and-Sink Test

Specific gravity of coal fraction	Yield per cent.	Ash per cent.
Lower than 1.25	5.0	0.8
Between 1.25 and 1.30	60.0	2.5
„ 1.30 „ 1.35	10.0	8.0
„ 1.35 „ 1.40	4.0	16.0
„ 1.40 „ 1.50	3.0	25.0
„ 1.50 „ 1.60	3.0	35.0
Higher than 1.60	15.0	70.0

and yields of products from a commercial cleaning plant operating on the same coal. For this purpose it is necessary to calculate from the " float-and-sink " results the " cumulative " values, as has been done in Table 8, where the yield and ash contents of the " floats," at each specific gravity of separation, refers to all the coal in the sample which is of lower specific gravity, and similarly for the " sinks."

TABLE 8

Cumulative Float-and-Sink Results

Specific gravity of separation	Floats		Sinks	
	Yield per cent.	Ash per cent.	Yield per cent.	Ash per cent.
1.25	5	0.8	95	16.0
1.30	65	2.4	35	39.3
1.35	75	3.1	25	51.8
1.40	79	3.8	21	58.5
1.50	82	4.6	18	64.1
1.60	85	5.6	15	70.0

It will be seen that results of this kind, if plotted in the form of a graph, make it possible to predict what would be the " theoretical " yield of clean coal of any required ash content, what would be the ash content of the rejected dirt, and what would be the necessary specific gravity of the separation. In practice, the performance of the most efficient modern coal cleaning processes approaches very closely to that indicated by these laboratory " washability " tests.

General Principles

For many years it has been customary for coal above about 3 inches in size to be cleaned, where necessary, by hand picking, while the smaller sizes were largely mechanically cleaned.

The "picking belts" consist of slow-moving conveyors, down each side of which stand men who lift out the dirt and inferior material from the belt as it passes. In some instances "bright" and "dull" coals are separated in this way when these constituents, having different properties, are required by different consumers (Figure 17).

When the consumer pays special attention to the appearance of the coal, hand-picking may be essential, because thin layers of inferior material, which are insufficient to affect the properties of the lump as a whole, may detract considerably from its appearance. With the improvement of mechanical processes for cleaning the larger sizes of coal and the increasing tendency for coal to be bought and sold to a specification based on chemical and physical analyses rather than on its appearance, it is probable that mechanical cleaning will eventully supplant hand-picking.

Most coal cleaning machines now in use effect the separation of coal from dirt by making use of the above-mentioned differences in specific gravity, although not all use the principle of the "float-and-sink" test. Various principles are employed in machines which differ, not only in their constructional details, but also in the efficiency with which they operate—the main criteria of the efficiency of a cleaning plant being the proportions of "sinks" in the cleaned coal and of "floats" in the rejected dirt.

Coals containing a large proportion of middlings are generally considered difficult from the point of view of cleaning, and in such cases a highly efficient plant is required, otherwise the reduction in ash content and/or the coal recovery may be unsatisfactory. If the amount of middlings is small, i.e. if the coal has an easy washability, then a relatively simple process may be satisfactory, but, owing to the present high value of coal, no plants which depart seriously from the theoretical washability are likely to be installed in the future.

The most efficient processes involve the use of wet washers and, in consequence, the preponderant part of the output of clean coal is produced in a wet condition. For some purposes for which coal is used, including carbonisation in certain types of plant, efficient dry cleaning would be preferred to wet washing, it being argued that, by washing, one form of inert material (water) is substituted for another (dirt) and that heat must be expended to drive off the water. Hence for some purposes "dry-cleaners" are used, but the more extensive use of these machines has hitherto been hampered by their lower efficiency.

Although plants differ widely in their constructional details, the principles upon which they depend are few, and the more important processes may be grouped under one or other of the following headings:—

Jig Washers. This is the most common type of washer in use at the present time. Its origin is to be found in the small hand-operated devices used for the concentration of metalliferous ores in the middle ages, and later in the first mechanically operated coal washing jigs installed in the middle of the last century. Except in principle, however, the modern jig, generally washing 100 tons or more of coal per hour, bears little resemblance to its ancestors. The essential features of a coal jig are as follows:—

(a) A deep bed of coal is put on to a perforated grid submerged in water.

(b) The water is caused to pulsate, or jig, up and down through the coal bed. On the up-stroke the bed lifts and expands so that the particles have some freedom of movement; when the bed is in this condition the particles of lower specific gravity move upwards and those of higher specific gravity move downwards relative to the bed. On the down-stroke the bed re-packs.

(c) When the coal has been jigged a sufficient number of times the bed becomes stratified with particles arranged with increasing specific gravity from top to bottom of the bed. From such a stratified bed the clean coal may be removed from the upper part and dirt from the lower part.

A typical machine for carrying out these basic principles is described later. Various explanations have been put forward to explain stratification by jigging, but since there is disagreement among experts on this subject, no explanation need be attempted here. The fact that jigs can separate particles according to specific gravity, even when their sizes are very different, is made use of in this country, where it is customary to wash " through coal," i.e. coal which has been separated from the " run-of-mine " coal by screening through a single sieve. Several well-known engineering firms manufacture jig washers which are fundamentally similar. The principle of the jig washer has been applied on an experimental scale to dry cleaning, but it has not so far been proved very successful.

Trough Washers. The principle of these washers is akin to that by which stones are sorted in the bed of a fast-flowing river; the particles which are largest, flattest, and of highest specific gravity gather in the lower part of the bed and those of opposite properties come to the top.

In the plants used for coal washing, the lower layers of the descending bed of coal are removed through a series of slots in the bottom of the trough. Some of these slots may discharge pure dirt for rejection, others an imperfectly separated mixture for re-treatment. The main plants of this type are the Rheolaveur and Hoyois washers. Different in construction, but similar in principle, is the Blackett washer, in which the trough is a spiral on the inside of a horizontal rotating drum. The principle of the trough washer has been applied in certain dry cleaners, but is not widely used.

" Dense-medium " Washers. This system of washing employs the principle of the float-and-sink test although it is customary to float the coal, not on a true liquid, but on a " dense-medium " consisting of a suspension of fine dense particles in water. Such dense-media have the advantage that they are readily removed from the coal by spraying with water, and the dilute suspension thus obtained may be concentrated for re-use merely by allowing it to settle in a tank.

Suspensions of various substances have been used as dense-media, including sand (Chance process), barytes and clay (Barvoys process), iron oxide (Tromp, Ridley Scholes and other processes), " loess " and flotation tailings (Dutch State Mines process). With a medium suitably chosen as regards its density, viscosity and concentration, extremely efficient separations at any desired specific gravities may be carried out with all sizes of coal except fines, which must be separated from the larger coal before it enters the washer. For separating middlings as a separate product three systems have been employed:—(a) to use two washers in series, the first for separating the raw coal into clean coal and a mixture of middlings and dirt, the second for re-washing the latter mixture, (b) to use a single washer, incorporating a device for separating the sinking material in a slowly rising current of the heavy-liquid, so that the lighter middlings particles are carried upwards and the heavier dirt particles are able to make their way downwards against the current, (c) to use a single washer, employing a medium of specific gravity which increases with depth in the separating bath, so that middlings take up an intermediate equilibrium position from which they may be collected separately. The Tromp washer is of this latter type.

Concentrator Tables. These machines, which have been developed from ore dressing practice, are used occasionally for washing small coal. The same principle is employed in the most widely used types of dry cleaning processes. The simplest form of plant consists of a " table," slightly tilted to one side and mounted on flexible supports, so that it can be oscillated in a lengthwise direction like a shaking screen. Attached to the surface of the table are several low " riffles " or laths running more or less paralled and lengthwise of the table. A shallow bed of coal flows across the table and, in the wet process, becomes stratified by the combined action of the oscillating motion and a stream of water which flows with the coal. In the dry process a similar stratification is obtained by blowing air through perforations in the table. The lower stratified layers of dirt are moved lengthwise of the table by the combined effects of the oscillation and the riffles, while the upper layers of coal can pass over the riffles and off the side of the table. Although dry-cleaning tables have met with some success, all dry cleaners operate under two handicaps. Firstly, the efficiency of the separation which they achieve, normally falls appreciably below the " theoretical " as indicated by the float-and-sink analysis. Consequently they produce a cleaned coal containing more dirt, or a dirt containing more good coal, or both, than does a well-designed wet washer. Secondly, when there is natural dampness in the mine or when dust-suppressing methods are used underground, the coal often comes from the pit sufficiently damp to interfere with the free movement of the particles and hence with their separation.

Froth Flotation. None of the processes described above is satisfactory for the finest sizes of coal, because the forces tending to separate the coal and dirt particles are too small. Coal below about 0.1 inch may, however, be cleaned by froth flotation processes in which, although the coal is made to float and the dirt to sink, separation does not depend on the specific gravity of the particles. This may be shown by the fact that when the process is applied to a gold-bearing sand it is the gold which floats and the lighter sand which sinks.

The property of coal which is utilised in froth flotation processes is the " wettability " by water and by oil. The shale is preferentially water-wetted and may be likened to a piece of paper or fabric which, if first wetted by water, does not absorb oil placed upon it. The coal, on the other hand, behaves as though it had a greasy surface which is readily wetted by oil and this oil may actually displace water already on the surface—an example of the principle that " like wets like." Thus if oil is added to a suspension of coal, dirt and water, the oil is absorbed as a thin film over every coal particle but is not absorbed by the dirt. The amount of oil required to do this is small owing to the thinness of the film, and in most instances only 1 pint or so of oil is required for the treatment of each ton of coal. When the pulp has been oiled, the next stage is to bring it into contact with large numbers of small air bubbles. These air bubbles attach themselves exclusively to the oiled coal particles (again because in this way the oil can repel the water) and thus float them as a froth while the dirt either remains suspended or sinks. The various froth flotation plants which are in operation differ mainly in the method by which they generate the air bubbles.

Details of Plants

There are altogether some 700 coal cleaning plants of more than 30 types in use in this country. The following list shows the numbers of plants of the more important types:—

Wet Processes

Jigs	Baum type	347	
	Others	101	448
Troughs	Rheolaveur	29	
	Blackett	22	
	Hoyois	15	
	Others	3	69
Dense-medium	Chance	13	
	Barvoys	12	
	Tromp	3	
	Others	2	30
Concentrator tables	H.H.	5	
	Notanos	3	
	Others	2	10
Froth flotation			40
Miscellaneous			14
		Total	611

Dry Processes

Air tables	Birtley	36	
	Raw Static	15	
	Others	8	59
Friction and Resilience devices	Berrisford	22	
	Spirals	9	
	Others	2	33
Miscellaneous			1
		Total	93

Some of these machines are obsolescent and the future trend will be towards the more extensive use of only the most efficient types. It is not possible in this brief article to describe more than a few of the more important types of plant. Details of others will be found in the books mentioned at the end of this chapter and in articles in various technical journals.

The Baum Jig. Most modern jigs in this country are of the Baum type, which have the following two characteristics: (a) the machines are designed for washing unsized coal (instead of the sized coal which is characteristic of the so-called " Continental " system of jigging); (b) the jigging of the coal bed is derived indirectly from a pulsating air pressure.

A typical Baum-type jig is shown in Figures 19 and 20. This washer consists of a tank (A) filled with water and divided longitudinally by the partition (B) so that in cross-section it is U-shaped (Figure 19). In one limb of the U are grids (C) supporting a bed of coal about 1 ft. thick. The other limb is fitted with air-valves (D) which are connected to a compressed air supply, by means of which the water is made to pulsate up and down through the coal bed at a rate of about 30–60 times a minute. In the washer shown in Figure 20, the coal enters on the right hand side and proceeds across the two perforated grids to the left hand side, where the clean coal passes over a weir. The heavy dirt, which is separated near the inlet, passes out by way of a slot (E), a rotating dirt extractor (F) and elevator (G). The lighter refuse or middlings separates nearer the washer outlet, where there is similar gear for removing it. The fine dirt which passes through the grids is moved by the worm (H) to the elevators.

The extraction of dirt must be regulated to correspond exactly with the rate at which it separates, otherwise the dirt will either accumulate in the washer (if the extraction rate is too slow) or coal will pass out with the dirt (if the extraction rate is too fast). Originally the regulation was by hand, but in modern machines it is effected by an automatic device. In Figure 20 this consists of a " float " (J) which is weighted so that it takes up a level intermediate between that of the dirt and the coal in the stratified bed. If the dirt layer increases in thickness the float is raised and this sets machinery in motion to accelerate the rate of extraction of the dirt and vice versa.

A general view of the operating platform of a Baum-type washery is shown in Figure 21. In this picture the water level in the wash box has been lowered to expose the coal bed and the " floats " of the automatic dirt extractor. The raw coal supply chute (bottom right hand corner), the clean coal off-take (behind the " float "), and the five air-supply pipes to this washer are also visible. In the background is a smaller washer (with four air-supply pipes) for re-washing and thus further improving the smaller sizes of coal. The water used in jig washeries is normally stored, and partially clarified, in large tanks, which are often conical in shape and situated at a height such that the water will flow by gravity to the washer. Such tanks surmounting a small tower are a characteristic feature of many washeries.

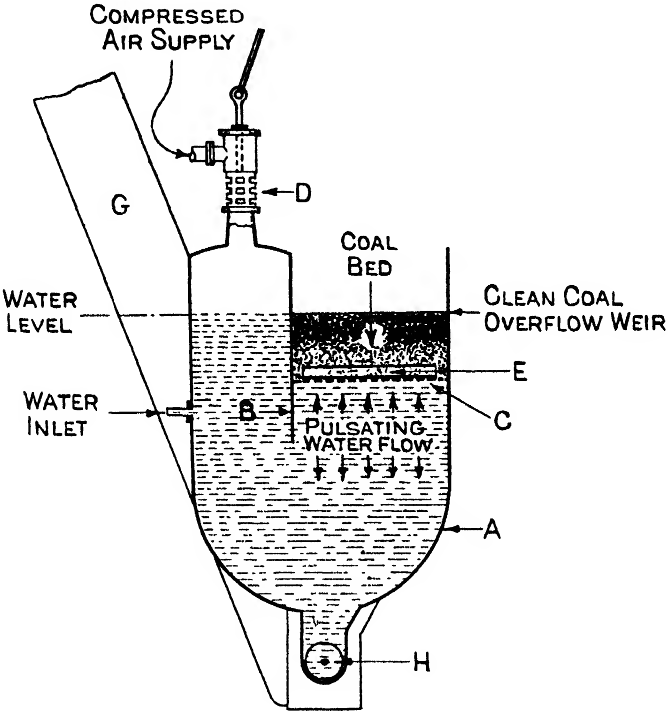

Figure 19.—BAUM WASHER. Diagrammatic cross-section

The Chance Washer. A diagram of this washer, sectioned to show its internal arrangement, is shown in Figure 22. It consists of a conical vessel, containing a stirred mixture of sand and water of the appropriate specific gravity, to which the raw coal is fed unsized except for the removal of material finer than about $\frac{1}{16}$ inch. The clean coal floats on the sand suspension, and is carried by the rotation of the stirrer to the point where it can pass over a weir to a screen where any adherent sand may be removed by water sprays. The dirt collects at the bottom of the cone and, periodically, a gate-valve opens to allow the accumulation to fall into a collecting chamber. A second gate-valve, which is only opened when the upper one is shut, allows the dirt to be discharged from the collecting chamber on to a de-sanding and de-watering screen. Normally this plant makes two products, i.e. clean coal and refuse, but in the design shown in Figure 22 there is provision for middlings to be withdrawn separately from an intermediate level in the cone. A characteristic of this washer is that the sand-water suspension is unstable and requires vigorous stirring with water passing upwards through the sand to maintain it as a dense medium.

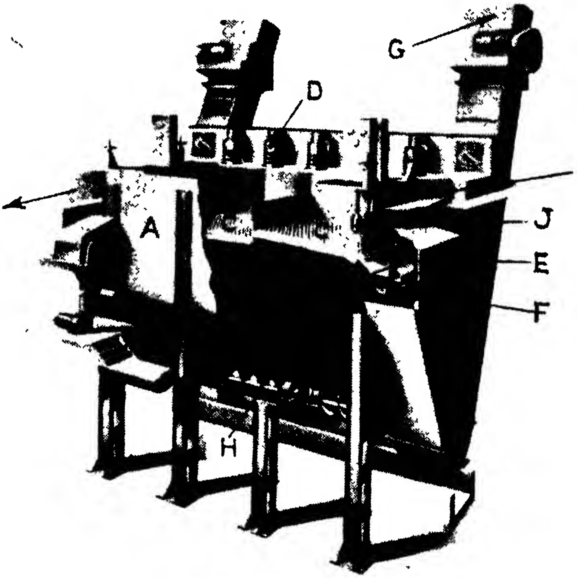

Figure 20.—BAUM WASHER. General view. Part of front plate removed to show construction (Simon Carves Ltd.)

The Barvoys Washer. This is a dense-medium washer which differs from that described above both in the construction of the plant and in the properties of the medium, which in this instance is relatively stable so that it behaves more like a true dense liquid.

The plant consists of a rectangular separating vessel with a tapering lower portion, the whole being filled with a medium of the required specific gravity. This medium consists of a suspension of finely ground barytes (barium sulphate) and clay in water. The raw coal is fed to one side of this vessel and the floating product is moved towards the offtake by means of mechanical rakes. The specific gravity of the medium is such that both middlings and dirt sink in the separation vessel and pass thence into a small separate vessel in which there is a slowly rising current of the medium. The speed of this rising current is such that the heavy dirt can sink against it but the middlings are carried upwards and collected separately. The three products, i.e. clean coal, middlings and dirt, are sprayed with water to remove the adherent medium and the dilute medium thus formed is re-concentrated by allowing it to settle in a large tank or " thickener."

Figure 21.—A MODERN WASHERY. Operating platform of jig washer (Coppée Co. (Gt. Britain) Ltd.)

As with other dense-medium processes, fine coal must as far as possible be separated from the feed coal, and Barvoys washers are frequently used in conjunction with Hoyois (trough) washers for cleaning the smaller sizes. Any very fine coal which appears in the bath, as a result of either imperfect screening or abrasion of larger lumps, is recovered continuously by passing a portion of the medium through a froth flotation cell.

Froth Flotation Plants. Two types of process are in use in this country and although outwardly the plants for operating them bear little resemblance to one another, their only fundamental difference is in the manner of forming the air bubbles which are required to float the coal. In both processes it is necessary to use a flotation agent or agents which most commonly consist of tar oils or petroleum fractions. These reagents generally contain (i) a " collector " which is absorbed on the coal surface, and (ii) a " frother," such as cresol, which helps to form large numbers of small bubbles which attach themselves to the coal particles and buoy them to the surface. The amount of reagent required for each of the two processes is usually of the order of 1 to 5 lb. per ton of raw coal.

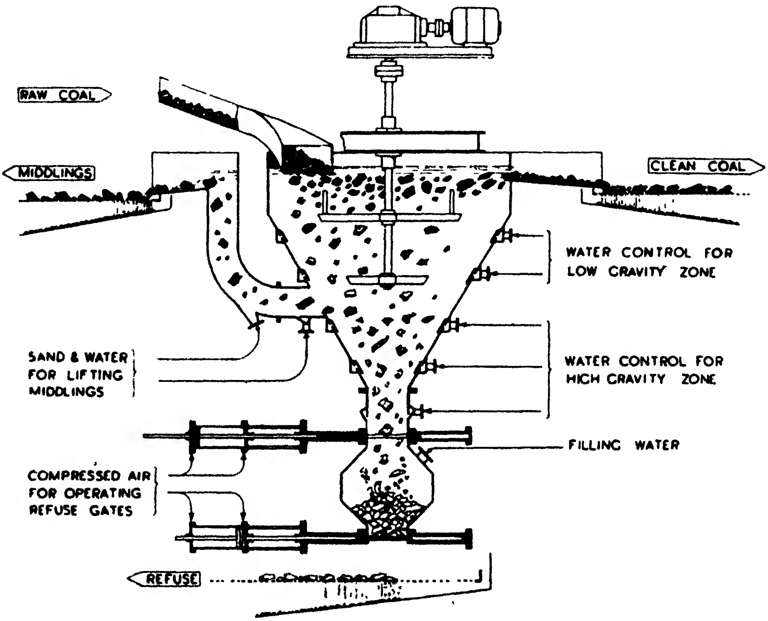

Figure 22.—" CHANCE " WASHER. Diagrammatic cross-section (Fraser and Chalmers Ltd.)

In one type of process the plant consists of a battery of open flotation cells each comprising a mixing chamber and a froth chamber. In the mixing chamber water and coal of less than about 0.1 inch are mixed by a rotating impeller or screw and the requisite amount of flotation agent added. The rapid rate of rotation of the impeller causes air to be beaten into the coal-oil-water mixture and the aerated pulp flows into the adjacent froth chamber, where there is sufficient quiescence to allow the froth to rise to the surface. The residue which sinks in this chamber passes to the second mixing chamber, where it is further aerated (more reagent being added if necessary) and more froth separated as before. By the time the pulp has flowed through the whole battery of cells, all the recoverable coal has collected in the froth chambers, from which it is removed by slowly revolving blades. In the vacuum flotation process, the coal, water and oil are first mixed together in a slow paddle mixer which ensures the proper distribution of the reagents but does not produce any froth. The prepared pulp is then allowed to flow continuously into a single overhead flotation chamber which is maintained at a reduced pressure by means of a vacuum pump. The pressure in this chamber is so low (about one-eighth that of the atmosphere) that expanded air bubbles appear in the pulp from three sources, viz. (i) out of solution in the water, (ii) out of the porous structure of the coal, (iii) by expansion of minute bubbles which had attached themselves to the coal during the mixing stage. The clean coal which collects at the top of the flotation chamber and the non-aerated tailings which sink to the bottom, return to ground level by separate pipes.

In most installations the clean coal is de-watered by filtering on a drum filter of the type shown in Figure 23.

PROCESSES AUXILIARY TO COAL CLEANING

Frequently the actual cleaning of a coal presents fewer technical difficulties than do the auxiliary processes which become necessary when cleaning is adopted. Among the most important of these auxiliary processes are several connected with fine coal.

De-dusting. For some types of washer it is convenient, and for others essential, that fines should as far as possible be removed from the feed coal prior to washing. If this is not done the washery water (or medium) becomes loaded with fine coal and dirt particles, and this not only alters its specific gravity and other characteristics so that washery performance is affected, but also adds to the difficulty of reconditioning the water or medium for re-use.

For separating fines from coarser coals, several de-dusting processes are available. These normally involve fine screening or alternatively winnowing the coal in an enclosed plant using a current of air from which the fines are subsequently recovered. If the fines separated in this way are not of excessive ash content they may be mixed for disposal with the washed coal, or they may be used separately, for example as pulverised fuel. As with dry cleaning, however, de-dusting cannot be satisfactorily operated with damp coal.

Flocculation. Fines which pass into suspension in the circuit water of a jig or similar washer are generally removed by allowing them to become deposited in a settling tank or pond. If settlement proceeds unaided it may be a slow process, but chemical " flocculating agents " have been developed which, added in very small quantities to the " slurry " (as the coal in water suspension is generally called), cause the fine solids to gather together into aggregates which settle rapidly and so leave clean water. The flocculating agents most commonly used are lime and/or concoctions of starch.

Filtration. For recovering the flocculated and settled slurry solids, or the clean coal from a froth flotation plant, in the form of a cake, it is generally found convenient to use a drum filter. This apparatus consists of a slowly rotating cylindrical drum supported on trunnions as shown in Figure 23, with its lower part dipping into a tank containing the material to be filtered. The drum is internally divided into a number of segments, each connected by a pipe to a valve placed at the centre of the cylinder to which a suction can be applied. The curved surface of the drum is composed of supported woven wire "cloth," and as each segment passes through the pulp in the tank, a suction is applied so that a cake collects on the cloth. When the cake emerges from the tank the suction is maintained so that de-watering takes place until a hard compact cake is formed. When the drum has made about ¾ of a complete revolution the cake is removed by the application of compressed air to its underside, the change-over from suction to pressure being made automatically by the central valve.

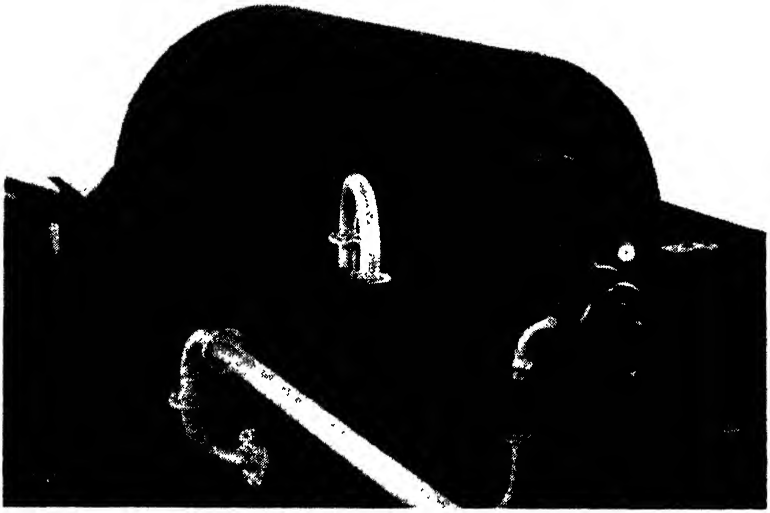

Figure 23.—DRUM FILTER. One method of de-watering fine wet coal (Coppée Co. (Gt. Britain) Ltd.)

De-watering. All washed coal is partially de-watered as it leaves the washery. In the case of sized coal the excess moisture is rapidly drained away by passing the coal over de-watering screens, but fine and slack coals do not drain so readily and thus may require other methods of de-watering.

One method of dealing with wet coal is to put it into drainage bunkers where it is allowed to remain for a sufficient time for the excess water to drain away. This involves having a battery of such bunkers which are filled in turn. A more recent development is to extract the water by means of a centrifuge which consists of a drum or " basket " rotating at high speed, into which the coal is fed and from which it is extracted continuously, the excess water being ejected by centrifugal force through holes in the basket.

" *Dustproofing.*" In America the need has arisen for the surface treatment of certain classes of coal to render them more permanently free from dust, or " dustproof "; the object being not only to fix any dust which may be present in the coal as it leaves the colliery, but also that which is made during subsequent transport and handling. The method of treatment is to spray the coal with small quantities of a suitable petroleum fraction or calcium chloride solution. The process is not equally effective with all types of coal because some are porous, and in consequence the fluid tends to penetrate into the centre of the lumps, where it cannot be effective. With a wide range of coals, however, the addition of between one pint and one gallon of a suitable oil per ton of coal is effective and under favourable conditions this effect will last for many months.

Similar treatments have also been used in America to prevent the freezing of wet coal, which causes dislocation of arrangements for unloading trucks in very cold weather. The value in this country of such " freeze-proofing " methods, and also the " dustproofing " referred to above, have not yet been established.

COAL BREAKING

Large coal must often be turned into more readily usable sizes by crushing or breaking. In general the term " crushing " is applied to an indiscriminate reduction in size, as for example in the crushing of coal prior to carbonisation, whilst " breaking " generally implies treatment in a machine designed to give the maximum possible yield of the desired nut sizes. Anthracite is a good example of a fuel which finds its maximum use as graded sizes, and the need for large sizes of all types of coal is tending to disappear as more modern and mechanically operated combustion appliances, requiring smaller graded fuels, are brought into use. The crux of the problem of coal breaking is to produce the minimum of the less valuable fines. Even under the most favourable conditions the proportion of the finer sizes may be considerable; for example, in breaking large coal to produce nut sizes 20 per cent. or more of the coal may be reduced to sizes less than about ½ inch.

Two types of breaker are in common use:

Pick Breakers. In these machines the coal is impaled as it passes under a nest of reciprocating steel spikes or picks which are spaced one from the other according to the degree of breaking desired. Frequently the coal undergoes a preliminary breaking as it passes under a nest of widely spaced picks, followed by a final breaking by a more close arrangement. Figure 24 is a photograph of the breaking platform of a pick breaker showing both the primary and the secondary picks.

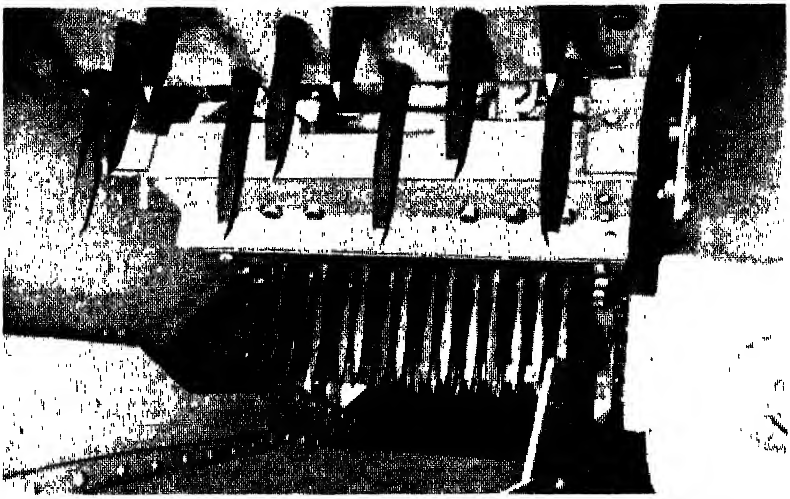

Figure 24.—COAL BREAKING. Breaking platform of Pick Breaker (Norton Tividale Ltd.)

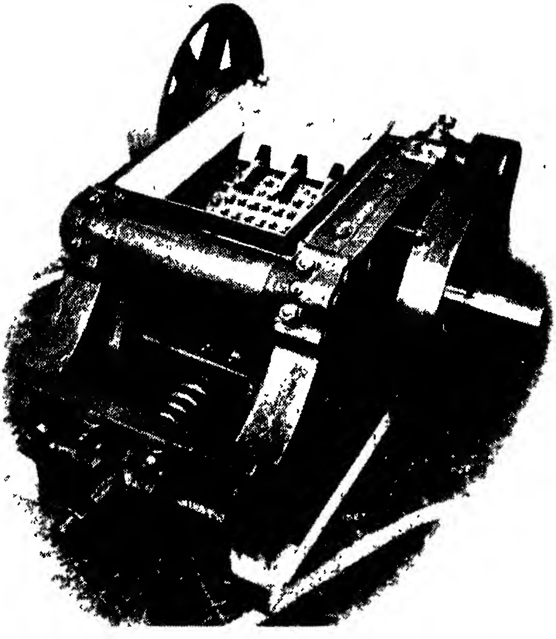

Figure 25.—COAL BREAKING. Single roll breaker (British Jeffrey Diamond Ltd.)

Roll Breakers. Various arrangements of toothed rolls have long been used for coal breaking. These include (i) single rolls in which the teeth on the roll press the coal against a sprung breaker plate, (ii) double rolls in which the coal passes between two rolls arranged side by side, and (iii) multiple rolls in which a progressive breaking is obtained.

These rolls are generally contained in a casing which is fed with the large coal at the upper end, the broken material being discharged from the bottom. A typical single roll breaker is shown in Figure 25.

Anti-breakage

Complementary to the techniques of breaking are those which aim at minimising the breakage which may occur before the coal reaches the consumer. Two examples may be given.

Spiral Chutes. Considerable breakage may occur if coal is allowed to fall freely into deep storage bunkers. To prevent such free fall the coal is made to slide more slowly down a fixed spiral chute, resembling a " helter-skelter," which is fitted permanently into the bunker.

Loading Booms. For loading railway wagons from colliery screens and washeries, the coal is carried into the wagon on an inclined belt conveyor which is raised or lowered as necessary to minimise the distance through which the coal has to fall.

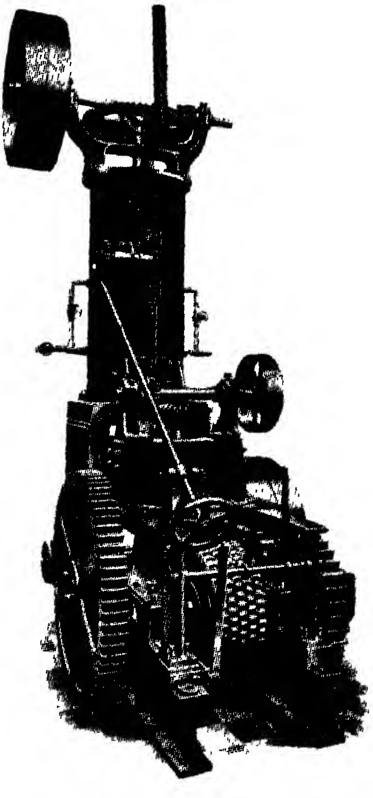

Figure 26.—COAL BRIQUETTING. Roll-type press for ovoids (Yeadon, Son and Co.)

BRIQUETTING

Although briquetting is not very extensively used in this country, it provides a valuable method of upgrading certain fine coals which might otherwise be wasted. Briquettes are best made from coal of low ash content because otherwise a " blanket " of fine ash tends to form around the burning briquette, retarding combustion and giving a dull appearance when burnt on an open fire. Coal of high ash content also requires increased amounts of binder, which adds to the cost and makes the briquettes smoky.

A commonly used system of briquetting is the "dry pitch process." In this process the small coal is mixed with about 8 per cent. of coal-tar pitch and, after a further crushing if necessary, is fed to a "pug heater." This heater consists of a vertical cylinder with internal stirring arms and means of steam-heating the contents to a temperature of about 95° C. Under these conditions the pitch melts and becomes smeared over the coal surfaces until the whole is a thick tacky paste. This paste is then pressed into shape in suitable moulds. Two types of press are used for this purpose.

Plunger Press. This machine is used for manufacturing fairly large block briquettes and consists of a large cast iron table, containing the moulds, which is rotated intermittently by a ratchet action. In position 1 a mould comes under the feed pan and is thus filled with paste. It then moves into position 2, where the charge is compressed by a plunger with a force of 1 ton or more per sq. inch. In position 3 the formed briquette is pushed out of the mould.

Roll Press (Figure 26). This machine for proiducing egg-shaped briquettes consists of two large rollers, in the faces of which are suitable indentations. The rollers are pressed together and geared so that where they are in contact the corresponding indentations in the two rollers come together to form a complete mould of the required shape. As the rollers rotate, a stream of hot paste is fed between them and the shaped briquettes drop out as the half-moulds separate.

Briquetting has hitherto been somewhat handicapped by the varying availability of pitch, for which there is no really satisfactory substitute. It is a disadvantage of briquettes containing pitch that they are not smokeless, but "eggs" prepared from clean coal and then carbonised to render them smokeless are also produced, and are excellent.

CONCLUSION

This survey is far from complete, but it indicates some of the many different types of process which go to make up modern coal preparation practice. These processes fit together into a pattern, or rather several patterns, because it will be evident that the chain of plants or processes most suitable at one colliery is not necessarily the best at another where the properties of the coal and the marketing conditions may be very different.

The selection and operation of the most suitable processes in any particular instance have now become the sphere of the coal preparation specialist. With the increased knowledge and improved plants now available, it is possible to produce better qualities of coal with greater consistency and less wastage of the nation's fuel reserves than was possible when many of the older plants still in operation were installed. Further research and development will undoubtedly result in still further improvements in coal preparation technique.

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Chapter V

SEABORNE DISTRIBUTION OF COAL

by SIR HENRY COOPER[*] *and* F. C. ASGILL[†]

THE transport and distribution of coal by sea dates back much further than that of any other means of long distance transport, records being available showing that coal was seaborne from the North-East Coast to the River Thames well over 200 years ago.

Since that time there have been many developments from the sailing ships or collier brigs of those early days to the modern steam ships and motor vessels now in use carrying up to 4,500 tons in the coastwise coal trade of this country.

By far the greatest quantity of the coastwise cargoes are destined for London and the great industrial areas on the banks of the River Thames, but the total quantity of coal carried coastwise to the other ports around our seaboard is quite considerable.

Before considering the practical side of the subject it will be of interest to glance at the tonnages involved, and the following brief tables give a graphic picture of the changes which have taken place in recent years.

TABLE 9

Tonnages Shipped Coastwise: As Bunkers: And for Export
('000 Tons)

Year	Total Shipped	Coastwise Cargoes	Bunkers Coastwise and Foreign	Export
1913 . . .	117,285	20,451	23,434	73,400
1938 . . .	70,935	23,319	11,760	35,856
1946 . .	32,203	22,070	5,679	4,454

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[*] *Chairman, Chamber of Coal Traders*
[†] *Chairman, Seaborne Coal Traders' Association*

TABLE 10

Quantities Shipped at Principal Coal Shipping Ports
('000 Tons)

Year	Scotland		N.-E. Coast	Humber	Bristol Channel	N.-W. Coast	Other	Total
	West	East						
1913 ..	16,846		34,936	14,696	38,852	8,680	3,275	117,285
1938 .	3,689	7,127	28,130	7,045	20,147	3,792	1,005	70,935
1946 .	1,878	1,526	15,816	3,434	5,488	3,472	589	32,203

TABLE 11

Principal Foreign Countries Importing British Coals
('000 Tons)

	1913	1938	1946
France	12,776	6,155	749
Germany	8,952	3,687	—
Denmark	3,034	2,997	560
Sweden	4,563	2,655	46
Eire	—	2,477	1,284
Italy	9,647	2,260	114
Argentina	3,694	2,030	3
Egypt	3,162	1,577	23
Norway	2,298	1,366	23
Spain	2,534	1,004	79
Netherlands	2,018	889	26
Algeria	1,282	887	253
Portugal	1,202	714	88
Belgium	2,031	658	89
Brazil	1,887	531	12
Gibraltar	355	410	212
Channel Islands	168	260	148
French West and Equatorial Africa	149	131	68
Canary Islands	1,115	61	*
Russia	5,998	1,860	—
Other Countries	6,535	3,247	677
TOTAL	73,400	35,856	4,454

* *Imports if any included in "other countries"*

To quote more figures here is unnecessary, and those interested in further details are referred to the various Board of Trade Returns or the Coal Trade Year Books where such particulars are readily obtainable.

The most important items to be considered when dealing with the delivery of coal by sea are as follows: —

(a) The stemming of the coal for shipment.
(b) The chartering of a suitable vessel.

(c) The actual provision of the coal by the collieries and the loading methods.

(d) The arrangements for the discharge of the cargo at the receiving end.

Stemming

The first step is to arrange a " stem "—that is to say, the shipper proposes to the colliery or collieries a vessel of a given size ready on a certain date to load a specified quantity of coal. Prior to the 1939/1945 war it was the practice to stipulate that the coal should be loaded by the colliery within a certain number of hours, but war conditions made it impossible to enforce these arrangements and the practice has not yet been revived. In spite of this, however, shipowners still insist that their ships shall be loaded within a given period and reference will be made in the section dealing with chartering to the necessity of speedy loading and its bearing upon the ultimate cost to the receiver.

When the colliery has agreed to load the vessel nominated, the vessel is said to be " on stem " or " stemmed " and the shipowner immediately makes the necessary arrangements to charter the ship he has in view.

Chartering

The distributor wishing to transport coal by sea and having decided upon the type and size of vessel most suitable for the purpose, obtains an offer of such a ship either through the medium of a shipbroker or direct from a shipowner. Having stemmed the cargo, he then accepts the ship and signs a contract of affreightment or " charter party," as it is commonly known, which embodies all the terms and conditions agreed as between the shipowners and the charterer. There is no cost to the distributor for utilising the services of a shipbroker as he obtains his remuneration from the shipowner. A distributor who may not be experienced in the transport of coal by sea is well advised always to utilise the services of a shipbroker in the chartering of a vessel, as the pitfalls which may beset the inexperienced in the chartering of tonnage are many.

There are standard forms of charter party covering different classes of business; the best known in the coastwise trade of Great Britain being " East Coast to London," " Coastcon " and " Welcon."

In the early days of the 1939/45 war the Ministry of War Transport, in collaboration with the Chamber of Shipping of the United Kingdom, fixed rates of freight applicable to certain sizes of ships operating between the different ports of the country and standard schedule rates of freight, as they are called, remain operative at the time of writing (June, 1947). These eliminated the ordinary element of negotiation as between shipowner and charterer. Prior to this arrangement, and presumably at some time in the future, it will be necessary for shipowners and charterers to negotiate again for the best terms obtainable under a " free market " and the potential distributor of seaborne coal will have to secure from the shipowner the longest possible hours for loading and discharging, bearing in mind the rate of freight which he is able to pay for the business in view, and the effect on the transaction of the incidence of despatch money and demurrage. If the time occupied in loading and discharging the cargo is longer than the hours allowed under the Charter Party, then demurrage is payable to the shipowner. Unless this is recoverable from the collieries or from those responsible for discharging, or from them both, then it adds to the cost of the coal to the receiver, or alternatively involves the distributor in a reduction in his profit, or perhaps even in a loss. If on the other hand the loading and discharging is accomplished in less than a specified time, despatch money accrues and benefits either the distributor or his customer.

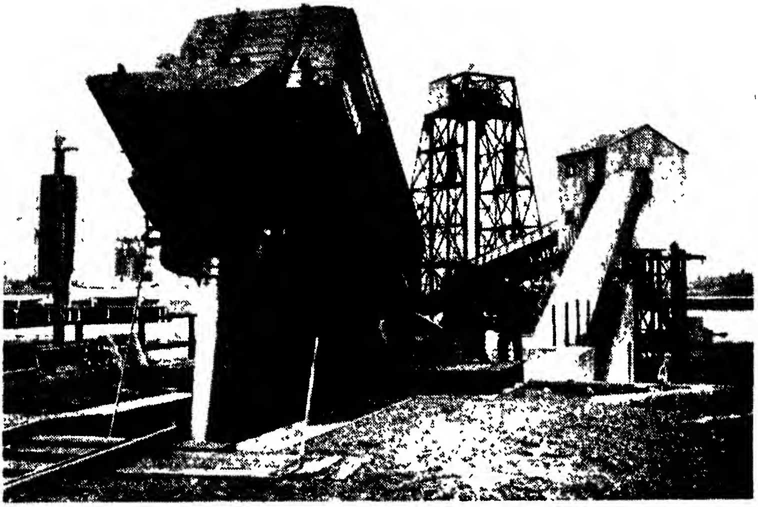
BY COURTESY OF GREAT WESTERN RAILWAY

Figure 27.—Coal handling plant at Newport docks

Provision of Coal by the Colliery

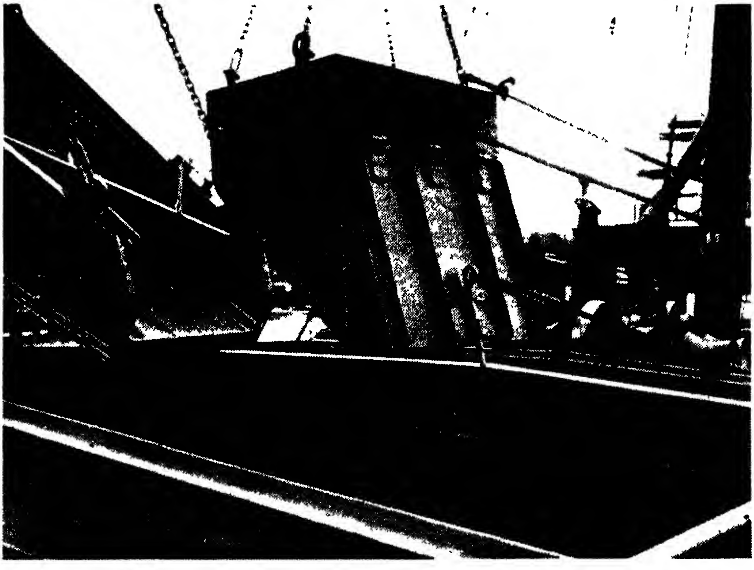
In most districts the shipper takes delivery of the coal either free on board (f.o.b.) or free alongside (f.a.s.) at the shipping port, the colliery making all traffic arrangements and paying all charges to these points; another practice which, however, is gradually becoming less, but which still occurs in the Humber to some extent, is for the colliery to deliver the coal to the shipper at the pit, the shipper making his own arrangements for delivery to the docks.

The most usual method of getting coal from the collieries to the port of shipment, and one common to all districts, is for the coal to be loaded into railway wagons and conveyed by the railway company to the docks. There are variations of this, some collieries having their own railway lines and loading staiths. There is, however, one quite different method of transport practised in Yorkshire where the Aire and Calder Navigation connects a number of collieries in the West Yorkshire Coalfield to the port



[BY COURTESY OF GREAT WESTERN RAILWAY

Figure 28.—Loading on to belt conveyor at Port Talbot



[BY COURTESY OF GREAT WESTERN RAILWAY

Figure 29.—Anti-breaking hopper

of Goole by canal. A unique system of transport is in operation on this waterway. The coal is loaded into small steel box-like barges called "compartments," a "train load" of which is coupled together and towed by a small tug to the port. There the compartments are uncoupled, each compartment being floated on to an under-water cradle, which is raised by hydraulic power and tipped in the same manner as a railway wagon.

Provision of proper shipping wagons is a most important aspect and one which, although primarily the responsibility of the colliery, must always be borne in mind by the shipper. The standard type of shipping wagon is one having end doors, although many shipping appliances are adapted for bottom door or hopper wagons; this is particularly the case on the North-East Coast.

The usual method of loading is by hoist. The wagon is placed, with the end door facing the dock, on a platform which is elevated to the requisite height and angle, the end door released, and the coal tipped over a chute into the vessel's hold. A variation of this to suit bottom door wagons is for the coal to be emptied into a container which is elevated and tipped. On the Tyne, where some of the loading places have been in existence for well over a hundred years, the staith method of loading is still general. In this case the wagons are hauled up an inclined ramp with chutes at the end or side at intervals; when opposite the chute corresponding to the height required for tipping, the bottom doors are released and the coal drops through the rails on to the chute into the vessel's hold.

A third method, employed where the accommodation on the dockside is restricted, is by means of conveyor. The coal is emptied either through bottom or end doors into a hopper feeding a travelling belt, generally steel, but in some cases rubber or fabric, which is elevated clear of obstruction and ends in a loading tower equipped with a chute in the usual manner. This method is useful in the bunkering of large liners, with bunker hatches at a higher level than can be reached with the ordinary coal hoist.

At some of the smaller ports, and as auxiliaries at the large docks, the crane method is in use. The wagon is lifted bodily on a cradle swung over the ship's hold, the end or bottom doors are released, and the coal dropped direct into the hold.

In addition, at out of the way loading ports other methods are employed, such as grabbing the coal from the wagons into the vessel (i.e., the employment of discharging gear for loading) and loading by hand ex railway wagons by means of barrow or baskets. This is usually employed in bunkering small steamers to avoid shifting berth.

Anti-breakage devices are in use at certain British ports, the underlying idea being to deposit the coal as gently as possible into the holds of the ships. Attention has to be paid to the speed of loading, as any method which reduces this is not popular with the shipowner or the charterer. These devices are often similar in principle to the "down" side of an escalator, working almost vertically, and capable of being lowered or raised as desired.

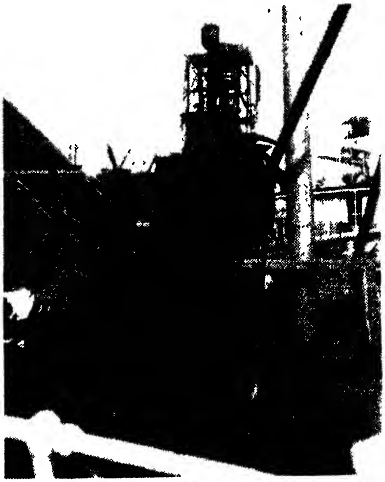
Each " step " carries a certain quantity of coal to the bottom, where it can be dispersed as required in the ship's hold.

Much attention has been paid to conveyor design with a view to eliminating breakage without interfering with the speed of loading.

Weighing

One of the causes of greatest concern to the distributor is that of weight. Coal is not generally weighed at the point of shipment, though there are exceptions. In South Wales in particular, and at one or two places on the River Tyne, weighing machines are installed at the points of loading enabling wagons to be weighed immediately before and after tipping, thus getting a true weight of the contents put into the vessel. Even so, if the coal is washed and contains an undue amount of moisture, the weight so recorded is that of the coal and the moisture. This moisture drains from the coal to some extent on the voyage, and the weight recorded by the receiver may be much less than that advised as shipped. It is the custom for all colliery weighing machines to be tested regularly, and they are generally considered to be reliable. Facilities exist at some pits for taring of wagons before loading, and colliery weights in such instances are regarded with more confidence than those where the painted tares of the wagons have to be taken. Here, again, unless a reasonable allowance for moisture is made at the time of loading, there is bound to be some discrepancy in the weighings.

Figure 30.—Coal chute anti-breaking



[BY COURTESY OF GREAT WESTERN RAILWAY

Figure 31.—Anti-breaking escalator

Trimming

In the course of loading a vessel there is a tendency for the coal to form a cone, the top of which extends above deck level while the hold is only partially filled. This is particularly evident in the case of vessels with double decks " 'tween decks " or even in single-deck vessels with small hatchways and large irregularly shaped holds. To overcome this a gang of men is employed during loading who shovel the coal into the sides and corners of the hold and generally level out the cone. This operation is called trimming. The trimmers are paid by the ship on a tonnage basis, with extras for length of carry and for special structural features.

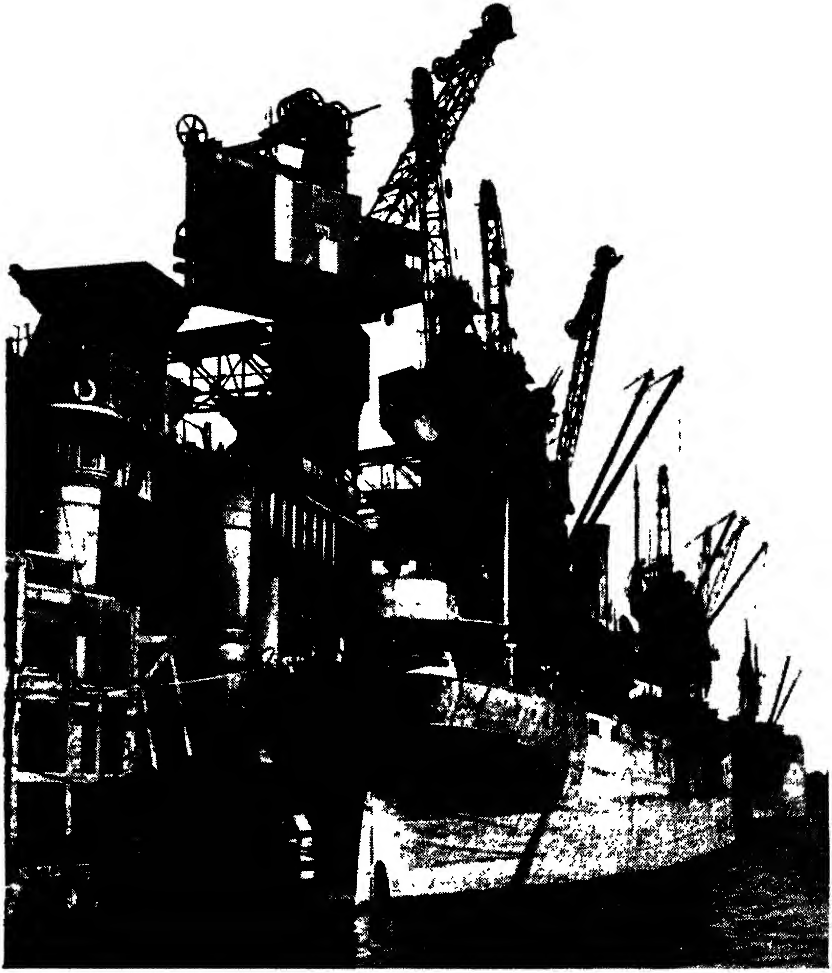
Types of Vessels

In the export trade the type of vessel to be employed will depend largely on the destination to which the coal has to be sent, as due regard must be given to the homeward cargo. The type of vessel proceeding to South America might be different to that which would be sent to a Mediterranean port, and ships proceeding to the Baltic should be suitable for bringing back timber to this country.

The coasting trade has evolved its own type—vessels built specially for coal carrying and, in some cases, for special ports and rarely carrying anything but coal. Such vessels are generally of the self-trimming type—that is to say, their hatchways extend practically the full length and breadth of the holds, which are rectangular and free from obstruction. The only trimming these vessels require is levelling off the tops of the holds. They come under the lowest scale of trimming rates as they can be loaded and discharged in minimum time, and invariably return to the loading port in ballast. Regularity of service such as is possible in the supply of coal to large utility undertakings has enabled a type of steamer to be evolved which can carry coal direct from colliery loading staiths to works as far up the Thames as Fulham and Wandsworth. These steamers have lowering masts and funnels to enable them to negotiate the bridges on the Thames. Most modern colliers have their engines placed aft. This expedites discharging and reduces the possibility of damage by grab.

Insurance

It is vitally important to insure the cargo against loss and/or damage. This subject is one upon which many books have been written, and the short space at our disposal makes it impossible to describe the many risks against which the distributor should cover. Suffice it to say that even if the ship carrying the cargo touches a quay wall or perhaps " smells " the ground whilst the cargo is on board without even damaging the cargo or in any way affecting it, a claim may be made against the owner of the cargo in general average. It is, therefore, advisable for the distributor to see that the cargo is adequately covered against perils of the sea and war



[BY COURTESY OF THE GAS LIGHT AND COKE CO.

Figure 32.—Unloading wharf at Beckton

risks before shipment takes place. It is customary to employ a marine insurance broker, who will give to his client whatever guidance he may require.

Arrangements for the Reception of the Cargo at the Discharging Port

Having stemmed the coal, chartered a suitable vessel, and insured the cargo, the distributor must make arrangements for its discharge and forwarding onwards from the point of discharge.

The owners of the berth the distributor has chosen to use will be advised of the sailing of the ship and instructions passed to them of the quantities and qualities of fuel contained in each of the holds and the destinations to which it is to be forwarded. If delivery is to be effected by barge, the distributor will be responsible for seeing that a sufficient amount of craft is available on the berthing of the ship. He is also responsible for the provision of sufficient empty wagons by the railway company when the coal must be moved by rail ex the ship.

In cases where the distributor has sold the coal on a delivered basis he must see that any dues which may be levied on the cargo at the port of discharge are paid. Finally, he must see that his customer receives his fuel in a manner which gives him cause for satisfaction.

Discharging

The forms of discharging are even more varied than the methods of loading. There are still places where vessels are beached at high tide and the cargo discharged by the ship's gear into carts by manual labour whilst the vessel is aground in the harbour. At many ports at home and abroad, where there is adequate quay accommodation, discharging is only possible by ship's gear, and most charter parties stipulate that the steamer is required to give free use of ship's steam winches, gear, and winchmen; but the number of mechanical discharging plants on shore is increasing yearly, both at home and abroad. The most common type is by crane and grabs or crane and tubs. In the former case the grabs are mechanically filled and emptied, but in the latter the tubs are loaded and discharged by manual labour. The crane method is that employed on wharfs doing a general trade, as the cranes can be used for discharging various articles other than coal or similar bulk cargoes. The radius of discharge is limited by the swing of the jib of the crane, although this is increased in the case of cranes with luffing jibs. The transporter type of discharging plant finds favour where the coal has to be discharged into a coal store as well as into truck or barge. The type of plant depends on the local conditions, e.g., a plant primarily intended to discharge house coal would be designed to avoid breakage as far as possible and with speed of discharge a secondary consideration, while apparatus solely used for the discharge of unscreened or small coal would make rapidity of discharge its first consideration.

There are on the River Thames and elsewhere along our coast discharging plants comparing favourably as regards efficiency of management and rapidity of discharge with those in any part of the world.

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Chapter VI

COAL TRANSPORT BY RAIL

by F. W. COOPER* *and* J. N. V. DUNCAN†

FOR many years past there were some 5,000 owners of mineral wagons which worked over the main line railways of Great Britain; now there is only one. This brief sentence summarises the revolution which occurred in the railway transport of coal on 1st January, 1948, the date on which the railway companies passed into the ownership of the State under its chosen instrument, the British Transport Commission.

The Transport Act of 1947 created this Commission with powers to take over and administer all the internal transport resources of the country formerly belonging to the major railway, road, canal and port undertakings. The Act provided, in Section 33, that as from the date of its operation " no privately-owned railway wagon shall be used on any of the railways in Great Britain owned or operated by the Commission." Certain types of wagon are exempted from this prohibition, but they are wagons designed for certain specified traffics and unsuitable for the conveyance of general merchandise or minerals. From the point of view of the coal industry, the general effect of this Section of the Act has been to settle once and for all the Private Wagon controversy which was almost as old as the railways themselves.

Before glancing back at the history of this cardinal question, some knowledge of which is necessary to an appreciation of the present problems of coal transport by railway, it will be as well to describe briefly the method by which the coal is carried from colliery to the port of shipment or to the works or depot of the inland purchaser. First, a word about the various types of coal wagon which are designed for different methods of discharge. Some have two side-doors only for unloading domestic coal at depots; some have two side- and one end-door so that they can be used also for shipment traffic, many ports being fitted for the discharge of wagons from end-doors at coal hoists; others have bottom-doors for discharge at shipping staithes or large works adapted for this method—this type of wagon is particularly common in Northumberland and Durham; the standard wagon has five doors (two side-, two bottom- and one end-door besides other improvements). Lastly, many industrial and public utility concerns have installed " rotary

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† *Assistant Director of Marketing, National Coal Board.*

tipplers," which lift the loaded wagons bodily and discharge them in a few seconds without the use of doors at all.

After screening, preparation, and weighing of the coal at the colliery, the wagons are consigned and labelled away; they are then worked from the colliery sidings by the main line railway service. In the case of coal for shipment, which has always been the primary outlet for many collieries (some having their own private railways connecting with private shipping installations), it is normal practice to make up full train-loads, which then go direct from the colliery to the ship. Inland traffic, too, has of recent years been increasingly despatched in " through " train-loads when intended for public utility undertakings and other large consumers, or when smaller users are concerned in trains made up of " blocks " of traffic for different destinations along the same line of route. In the difficult conditions of the recent war and after, a good deal of such preliminary concentration has been undertaken at collieries to assist the railways, but by far the greatest proportion of coal traffic passes in consignments smaller than train or " block " loads and is worked by the railway service from collieries to " gathering " sidings where thousands of wagons from groups of adjacent collieries accumulate for formation into train-loads to various destinations. Such wagons may have to be re-sorted several times in the course of their journey; first at the yard where they are gathered with others from adjacent collieries and " staged " to another main centre along the same line of route; secondly when they are concentrated again there for a main trunk haul to the neighbourhood of their destination; and finally at this distribution point, where they are re-marshalled for the last stage of their transit to the ultimate destination. In recent years the British railways, in common with others all over the world, have embarked on large-scale experiments designed to increase the speed and reduce the expense of shunting at their large concentration yards. The first development was the construction of " hump " yards which, in brief, employed the force of gravity to run the wagons into various groups according to destination. Gravitation yards of this kind speeded up the sorting of traffic but increased the damage to wagons from rough shunting, and the next development was the use of mechanical " retarders " to regulate the speed of wagons after passing over the humps. These were introduced in 1928 in the L.N.E.R. yard at Whitemoor, which is the main distributing point for coal traffic into East Anglia; but experience proved that the action of the mechanical retarder, which grips the wagon wheels, set up violent stresses which often caused extensive damage to wagon frames and bodies. Hence the next development was the " eddy current " rail brake in which the retarding force is applied electrically, and this system has since been introduced in a number of new or re-modelled yards. At the present time a further important development on these lines is projected at Toton Up Sidings, one of the main concentration points for the traffic from the Notts and Derby coalfields *en route* to London and the South of England.

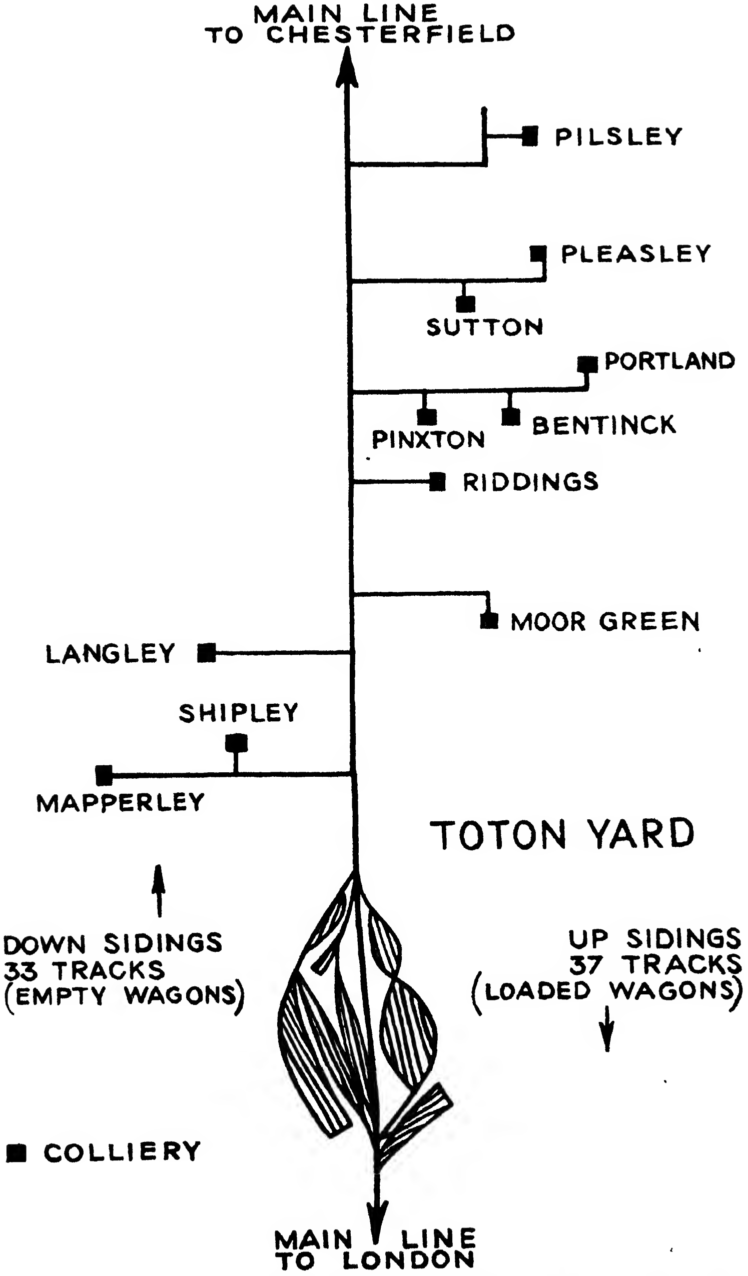

Figure 33.—Diagram illustrating flow of coal traffic in less than train loads from collieries to large concentration yards

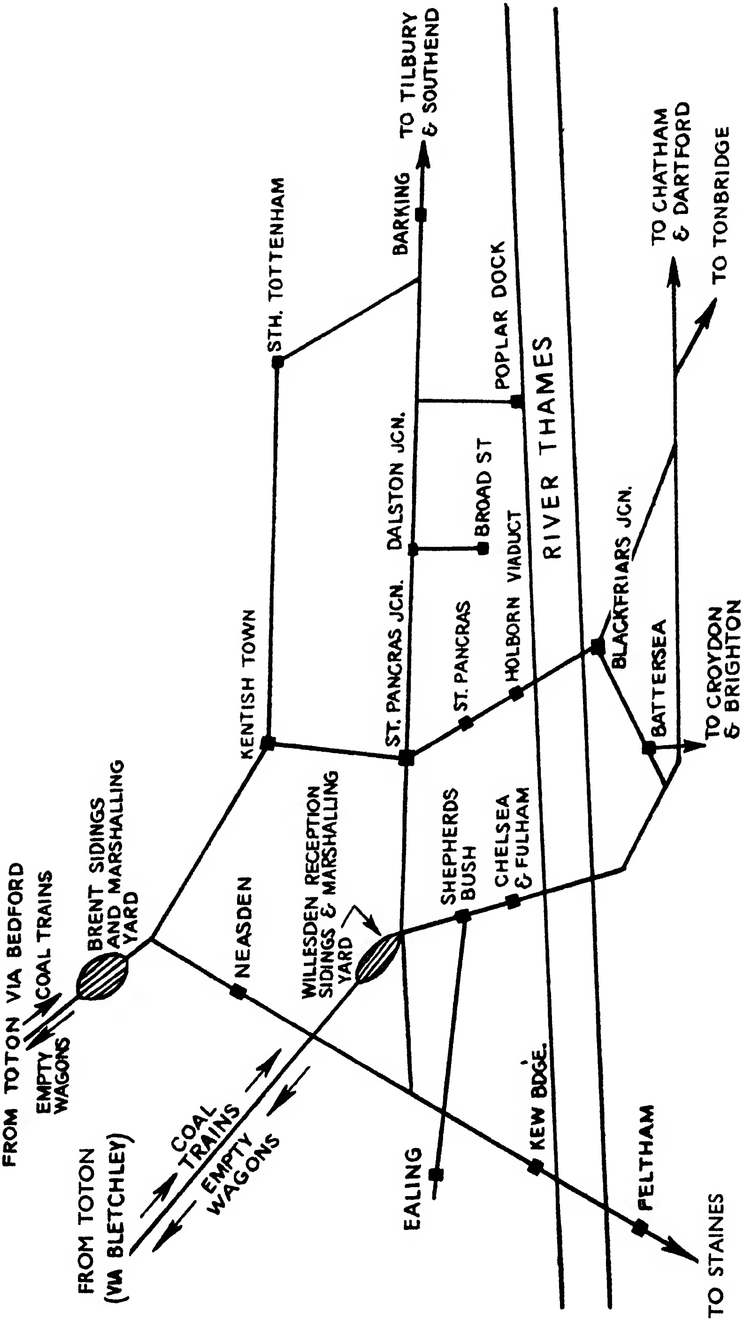

Figure 34.—'Diagram illustrating distribution of coal traffic from main reception yards to main terminal centres in London area

The London area naturally constitutes a special problem in the ultimate distribution of railborne coal to a host of consumers, particularly in the house-coal market; from the central terminals at which the full train-loads arrive the wagons are despatched to local depots under a special system of regulation set up between the railways and the coal trade to ensure that merchants receive their coal as they require it without causing congestion of wagons at their terminals.

A paramount consideration at every stage in the transit of coal is promptitude in the loading, sorting, transit and release of wagons; it is such a bulky commodity that, if not moved by expeditious and efficient methods, it can cause a vast wastage of capital due to the proportion of wagons constantly detained under load and to the siding space habitually congested by loaded wagons. The optimum to be aimed at is to maintain the rotation of loaded wagons from collieries, their transit, discharge, and return to the pits empty for re-loading in an unbroken rhythm which demands the smallest overall permanent stock of wagons. This brings us back to the importance of the recent concentration of ownership of all main line wagons in the hands of the British Transport Commission.

The earliest public railway in Great Britain, the Stockton and Darlington, was primarily a specialised kind of roadway for the carriage of coal, and set the precedent of levying tolls for the right of passage over the line, the wagons and even the locomotives being owned and operated by the railway's customers. As the railway system of the country expanded it became manifestly impossible for such a system of operation to continue and the railway companies became common carriers of all kinds of merchandise, providing track, terminals, wagons and locomotives, and undertaking the whole operation of carriage at inclusive rates based on mileage (as distinct from tolls), covering all the services performed. The general trade and industry of the country could not have expanded under any other system, but the coal industry always remained an outstanding exception. So many operations within colliery precincts entailed the use of wagons—among them the important function of temporary storage pending despatch—that colliery owners felt it essential to retain the full ownership and control of their own vehicles. In time many large distributors did the same and ultimately some 580,000 mineral wagons, or nearly one-half the total main-line wagon fleet of the country, were built by private firms, financed by private capital, and maintained in running order by private repairing companies. This private coal-carrying fleet was supplemented by railway-owned mineral wagons, and the railway companies quoted different carriage rates according to whether the coal was conveyed in " owners' wagons " or " company's wagons."

Railway working problems have grown progressively more complex in proportion as the growth of technical efficiency—and of outside competition—has encouraged not only the trading but also the travelling public to demand improved standards of speed and service. Restrictions of gauge and lay-out enforce the application, in increasing measure, of scientific methods to railway operation of which the distribution of rolling stock is a dominant feature.

The railway companies and others urged the private wagon-owners to form " pools " if not on a national, at least on a district basis, which would afford some greater elasticity in the work of distribution, but there were so many conflicting interests that it was impossible to obtain any measure of common agreement. The Standing Committee on Mineral Transport in their report issued in 1929 recommended that all privately-owned wagons should be grouped into pools of a minimum size of 3,000, leading to the ultimate substitution of some 200 pooling units for the existing 5,000 independent owners. This figure, which shows that there were several times as many wagon owners as there were colliery owners, illustrates the complexity of the problem and the difficulty of reaching comprehensive agreement.

In the end it required a major war to enforce a solution of the problem. One of the first acts of the Minister of War Transport, on taking over control of the railways in September, 1939, was to requisition all privately-owned main line wagons, since the exigencies of war demanded that they should be worked in a national pool along with the railway-owned wagons without respect of ownership. The owners were paid hire compensation, but the availability of such a large fleet for purposes of the national war effort represented an important contribution by the wagon owners to the country's needs in a critical emergency.

Under the Coal Industry (Nationalisation) Act of 1946 a large proportion of those requisitioned wagons became, like other assets of the colliery companies, the property of the National Coal Board as from 1st January, 1947, undergoing still another change of ownership when they were vested in the Transport Commission in January, 1948.

The mineral wagon fleet, which will henceforth be operated by the Railway Executive on behalf of the Transport Commission, is made up of wagons of a great variety of ages and types reflecting progressive changes in design and construction over many years. The modern wagon has been evolved by stages from the six-, eight-, and ten-tonners of the nineteenth century. In 1923, at the time when the railways were amalgamated into four groups, an effort was made to reduce the number of different sizes of wagon in traffic; further building of the smaller ones was prohibited, and at the same time a 12-ton design, produced by the Railway Clearing House, was adopted as the future standard for mineral traffic. This specification, which included such improvements as oil axle boxes, became obligatory for both private and railway-owned wagons built after 1st July, 1924. Standardisation remained, however, a distant goal for many more years. On the one hand many of the smaller and older wagons had a considerable period of life to work out; on the other, the size of wagons continued to increase. The railways had already begun to use 20-ton and even 40-ton steel wagons for conveyance of their own locomotive coal; they were now attracting traders, by the offer of a 5 per cent. rebate in charges, to follow their lead in the use of 20-ton wagons, and some of the larger coal distributors did so. On this subject, again, the 1929 report of the Standing Committee on Mineral Transport is a valuable work of reference and indicates the number of factors which govern the design of wagons. At the time of its publication 20-ton wagons could be handled at fewer than 40 per cent. of the collieries and at only slightly more than 50 per cent. of ports and private sidings serving large works. " Under existing conditions at the terminals, we agree that the 12-ton wagon is the most suitable for overall use, and there is no doubt that drastic reconstruction at terminals is essential before any large extension of the use of 20-ton wagons can be regarded as a practicable and economical proposition." Subject to the adaptation of the terminals, this Committee was prepared to recommend the adoption of the 20-ton wagon, but further research has since then induced the Ministry of Transport to adopt a standard 16-ton all-steel wagon of which some 30,000 were in traffic by the end of 1947. For many years to come, therefore, wagons of several different sizes and specifications will still be running in this country, though those built before 1900 will shortly have disappeared from the main lines. De-requisitioning and the subsequent removal from main line of wagons of this age and older began in 1946, and later the railways scrapped wagons built in 1910 and earlier, when repairs were considered uneconomical. These are being replaced by 16-ton all-steel wagons with five doors.

Colliery wagon repair shops and wagon repairing depots are usually situated at places within easy reach of large marshalling yards, and in addition the repairers have depots with small staffs and stocks of material at many " out " stations, where minor running repairs can be attended to with a minimum of delay, as all repairs have to be executed in conformity with the repairing and re-building regulations issued by the Railway Clearing House. Wagon examiners are employed by the railways at yards and junctions to keep a constant check on the wagons passing through, and to mark any in need of repair with distinctive labels. These are of two classes, green which directs the wagon home for repairs, and red which prohibits the wagon running in traffic at all until the necessary repairs have been done.

Intensive study is now being devoted to the best method of utilising the many fine wagon-building and repair facilities belonging to British Railways, private firms and the National Coal Board. They can all assist directly or indirectly in the important dual task of recovering and improving on the pre-war standard of rolling stock construction and maintenance in the United Kingdom in addition to supplying an expanding export market.

Chapter VII

ROAD DISTRIBUTION AND DEPOT WORK

by JOHN CHARRINGTON*

APART from the relatively few large consumers of industrial fuel who can accept delivery by truck loads into their works, or by ship or barge alongside a wharf, coal has to be transferred from the truck, barge or ship into which it is loaded by the colliery on to a road vehicle for delivery to a consumer. The operations of unloading the truck or ship received from the colliery, reloading on to a lorry or horsedrawn vehicle and delivering to a consumer comprise the main items in a distributors' costs, and on the efficiency with which they are carried out his ultimate profits depend to a very large extent. Whilst by far the greater part of the coal which is sold by distributors is handled in one of these ways, there is, in addition, a considerable tonnage which is loaded into distributors' vehicles at the Landsale Wharves at collieries.

Unloading of Trucks and Ships

To deal first with the problem of the transfer of the coal from the truck or vessel in which it is received, it will be realised that the methods employed will depend on two main factors—the type of " container " in which it is received and the type of " container " in which it can most economically be delivered to the consumer. There is, apart from a few out-of-date exceptions, only one recognised method of unloading a shipload of coal, and that is by crane and grab. Attempts have been made to clear coal from vessels by suction, and although this method is satisfactory with grain, it has not so far been successfully operated in this country. It is understood, however, that a process embodying both suction and pressure is in use in America and it may well be that this method of clearance may yet be employed satisfactorily here. The cost of detaining a ship longer than is absolutely necessary is a considerable item, from £60 to £90 a day according to size, and the most efficient—and consequently expensive—plant is therefore justified to ensure the quickest possible turn-round of the vessel. With modern grabs, the largest colliers can be discharged well within one day. At most seaborne wharves the grab discharges the coal into large

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overhead bunkers from which it can easily be loaded by gravity into road vehicles in bulk or in sacks. This process is very satisfactory with small coal, but when handling large coal a good deal of breakage results, with a corresponding loss of money when the small coal has to be sold at a much lower price than the large. There are a few premises in the South of England where seaborne coal is not only screened to remove coal dust, but is re-sized into Large Nuts, Small Nuts, Doubles and Singles, and the operation is performed in as thorough a manner as it is at the collieries. The handicap placed on the receivers of coal when breakage results from handling is largely fictitious today, and there is no doubt that the pricing of coals at so much higher figures for large coal than for small is out of date and artificial. The popular belief many years ago was that large coal was clean coal, and in any event there was little or no demand for smalls. Nowadays, with the enormously increased demand for small coal, the price structure in the industry is quite out of date and is in urgent need of revision by the National Coal Board. When this reform has been dealt with, the problems of financial loss on smalls when handling coal at destination should be largely disposed of.

The unloading of trucks presents a different problem. Mineral trucks in this country vary considerably in detail, and while some have bottom doors which can be opened to allow a proportion, but by no means all, of the coal to empty by gravity, some have end doors, but the majority have only a door in the side from which the coal has to be removed by shovel. Truck tipplers can, of course, discharge the contents of a truck quickly, but they are an extremely expensive item of equipment and their use has so far been confined to power stations and large consumers where the tonnage to be handled justifies the high capital expenditure.

At the great majority of railway depots the rails are at ground level and therefore merchants are compelled to empty the wagons by shovel into sacks for immediate sale or on to the ground for stocking.

Storage of Coal by Merchants

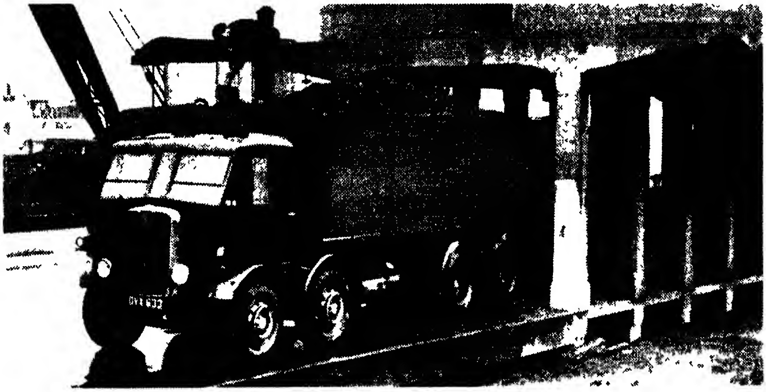
It has always been a major responsibility of the merchant to store coal in the summer months for sale in the winter. In normal times this service benefits both the collieries and the consumer, by enabling the colliery to dispose of more tonnage during their slack summer period and ensuring the consumer supplies in the winter when demand is at its maximum. In addition, the Railway Companies are unable to carry to the large centres, such as London, the tonnages of fuel which are required to meet the demands of the public at the peak times in the winter, when fogs and snow often interrupt the regular flow of coal from the pits. The larger merchants have always kept stocks of special fuels that are only required intermittently by a few owners of specialised types of equipment. With the advent of new appliances sometimes demanding for their most efficient utilisation a fuel with certain narrowly defined characteristics, the number of grades that a merchant will have to stock is on the increase and is no inconsiderable item in a merchant's expenses. Prior to 1939 it was not uncommon for a merchant in London to store 20 or 30 different grades of fuel, many of them particular sizes and grades of anthracite of which his annual sales would be small. It is probable that in the future the merchant will be called upon to stock more, rather than less, coal in the summer, if for no other reason than the overriding necessity of keeping the miner in regular employment throughout the year. It may even be necessary for the merchant to take his supplies in equal monthly quantities throughout the year, in which case the tonnage he would have to stock in the summer would be much more than he stocked prior to 1939 and would involve him in considerable additional cost in rent of stocking ground and provision of extra capital—not to mention the wages to be paid for putting coal on the ground and picking it up again, and the extra degradation that stocking causes.

Wherever possible, a merchant's stock is kept at the railway station or wharf where his coal is received, but in some cases the ground required is not available and then he has to cart his coal for stocking from the point of receipt to his own yard, and bear the extra cost of cartage.

At a waterside wharf the coal would normally be stored in large bunkers or bins within reach of the crane which discharges the ships. Similarly, at a railway siding the coal is stacked on ground alongside the railway line, for which the merchant pays rent to the Railway Company, the various classes of fuel being separated by partitions made of sleepers, galvanised iron sheets, or in a few recent cases, reinforced concrete. The floor of the stacking ground is traditionally made up with a hard core foundation on which a good thickness of chalk is laid and well rolled in, the chalk being subsequently covered with a layer of coal dust and again rolled. This provides a good surface for the loaders' shovels to slide along when they come to pick up the stock, and soaks up a high proportion of the surface water, but has the disadvantage that in frosty weather, which is the time when stocks are normally being lifted, the chalk is lifted by the frost and any vehicle that is driven on to the ground cuts up the surface badly. There would appear to be a strong case for investigations into the more extended use of bitumastic slag or concrete for surfacing stocking grounds.

Loading of Coal at Depots

Wherever coal has to be delivered in quantities of a lorryload or more at a time it is clearly more economical to load it loose in a lorry than to bag it. Unfortunately, few domestic consumers in this country have the facilities in their houses to accept delivery into their storage bunkers in this way. In certain parts of the country house coal is still delivered loose and tipped into the roadway outside the consumer's premises, being subsequently barrowed in by the merchant's men or by the consumer himself—or herself. This method of delivery is, however, on the decline, and there is an increasing demand from the consumer for the coal to be bagged and delivered direct into his bunker by the merchant. Much industrial coal, however, is delivered in bulk and where the trucks can be unloaded and the lorries loaded by gravity and the coal delivered in a tipping lorry, or one with a movable floor, the cost of distribution can be reduced to a minimum. The majority of house coal, however, has to be delivered in bags and considerably more expense is involved. Most grades of house coals should, moreover, be screened and have pieces of slate and pyrites picked out before being delivered to the consumer. In view of the small number of depots with overhead rails, the great majority of the house coal has to be screened by hand in the old way, the sieves used ranging from ⅜″ to ¾″ mesh, according to the type of fuel being screened (e.g. anthracites would normally be screened over the smaller size, house coals over the larger size). The bags used are made either of hemp or jute, and in some parts of the country are tarred to make them waterproof and give them a longer life. They are normally made to contain either 1 cwt. or 1¼ cwt., but 2 cwt. sacks are still used in London in considerable numbers, and ½ cwt. bags for particularly difficult deliveries. There are many different shapes of bags used, some parts of the country demanding long narrow bags, others squat and wide bags; some prefer handles, some not, the preference appearing to be one of custom and tradition rather than variation in the methods of handling.



[BY COURTESY OF JOHN HUDSON AND CO., LTD

Figure 35.—Petrol-driven lorry used for bulk delivery of coal being loaded from overhead storage bunker

There is much in this system of shovelling coal from trucks into sacks by hand; of screening the coal by hand operation, and of wheeling coal in barrows to the stocking ground, whence it has to be eventually shovelled by hand into bags, which must seem old-fashioned, slow and wasteful of man power. A growing number of coal merchants would share that point of view, but the difficulties inherent in any scheme of modernisation are formidable. For example, the provision of mechanical plant is expensive;

neither is it easy to employ in a depot which was never laid out for the purpose; the diversity of design of coal trucks, and the inevitable loss when coal is broken, represent some of the difficulties. Nevertheless, these and similar problems are under continual review by Trade Associations, and there is a growing desire to make the introduction of modern methods possible at railway sidings.

The fact should not be overlooked that when a ship or a barge has to be cleared, the provision of machines for the purpose is essential and the wharf must be designed accordingly. Railway depots, which were constructed many years ago, have, on the other hand, been laid out with a different object in view, and short of building entirely new railway depots, it is extremely difficult to adapt most of them to the introduction of other methods.

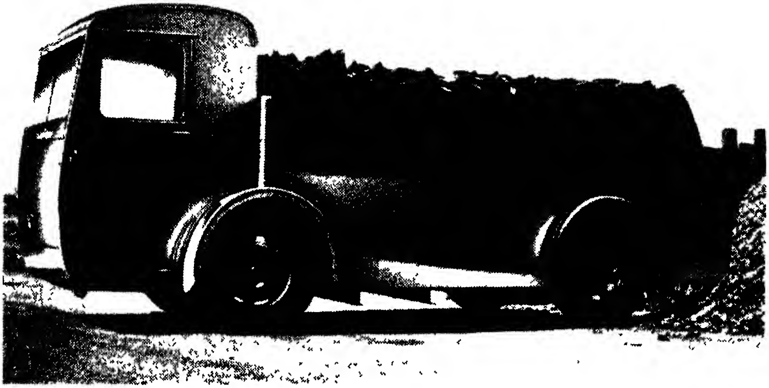


Figure 36.—Electric lorry with load of sacks

Delivery of Coal by Road

Until the introduction of the petrol-driven lorry, all coal was delivered by horse-drawn vehicle or steam wagon. The steam-driven vehicle had certain attractions for the coal merchant, depending as it does on solid fuel, and it might be thought should have been encouraged by successive Governments owing to its use of a home-produced fuel instead of imported oil. Many of its disadvantages of high initial cost, lighting up, relatively slow speed and great weight, were offset by long life, low maintenance costs and extreme reliability, but the steam wagon has virtually been driven off the road partly by the taxation structure but mainly owing to the greater flexibility of the petrol-engined lorry with its much improved performance of recent years, also by the great advances made in the adaptation of diesel engines for vehicular use. Many horses still remain in the trade, although their numbers dwindle year by year, and it is probable that they will become obsolete within a comparatively short time, except in certain country districts. For delivery in restricted areas, particularly where many individual deliveries have to be made from one load, they are still cheaper than mechanical transport; but in this highly mechanised age it is becoming increasingly difficult, particularly in the towns, to find men who are prepared to drive such a slow-moving vehicle as a horse van, or to devote the time in caring for their horse that the best type of old carman used to spend. In spite of their many drawbacks, horses have certain advantages besides cost over the lorry. Horsedrawn vehicles being by their very nature articulated, loads can be got ready for them whilst they are on the road, and, without decrying the reliability of the modern lorry, a horse if properly looked after should seldom " break down " or cause trouble. Against this, they sometimes cannot be used when the demand for their services is most urgent, i.e. when the roads are treacherous owing to frost or snow. The type of horse van or trolley in use has not varied much in the last fifty years, except that in recent times the wooden wheel with an iron tyre on the trolley has given place in some districts to a lorry type of wheel with a pneumatic tyre and run on ball bearings. By this means at least 25 per cent. more weight can be pulled by the horse without additional strain.

Types and sizes of petrol lorry vary as between merchant and merchant according to the type of trade he has to handle and the nature of the district. The carrying capacity is usually between 3½ and 5 tons, and whilst some merchants prefer a vehicle with drop sides for use when carting coal in bulk and for the extra advertising space it affords, the majority prefer a platform body for its low weight, economy of upkeep, and the ease with which the sacks can be drawn from it. When considering the size of lorry to be employed the satisfaction of the consumer must be fully considered. A large vehicle carrying perhaps 6 tons may be suitable where individual deliveries are large and the whole load could be delivered to a few houses—but where the average size of order is perhaps only 6 cwt. or even less, a smaller vehicle is more suitable as affording less risk of the consumer having the wrong coal delivered to him owing to the driver mixing the bags. The electric vehicle makes small progress, but if the weight of the batteries could be reduced and its radius of operation increased it should prove an ideal vehicle for use in congested areas, for not only does it depend upon home-produced fuel, but it is silent and does not emit fumes.

The sale of coal is still covered by the Weights and Measures Act of 1889 and by Bye-Laws passed by local authorities. Some of these regulations are out of date and impose useless and sometimes costly restrictions on merchants. An example of this is the clause in the Act of 1889 which permits local Councils to make Bye-Laws compelling a merchant carrying coal on a vehicle for sale to carry a weighing machine on that vehicle; and Bye-Laws to this effect have been passed by most Councils. The object was to enable a customer or Weights and Measures Inspector to checkweigh a delivery. The right, however, is seldom if ever exercised by a consumer, and the Weights and Measures Inspectors in these days usually carry their own weighing machines with them. Until this particular clause can be repealed, merchants are compelled to carry round these machines on their lorries, with the consequent waste of space, petrol, etc. Other points which are covered by statutory rules include the type of delivery ticket that must be used, the display of price tickets on vehicles when coal is sold from the vehicle, and the affixing of metal tabs on bags to show what quantity is contained in the bag.

So much for the present, but what of the future ? Since 1939 the coal distributor has, like other traders, had little time to consider improvement of methods, either of distribution or coal handling. He has had to contend with labour shortages, mechanical deterioration of irreplaceable transport, a constantly reducing overall tonnage, and in the case of house coal deliveries, a complete metamorphosis of his old methods. Where he had planned his transport and labour for deliveries in ton lots or more, he has been restricted in the main to innumerable deliveries of a few hundredweights. These disadvantages are not materially less at the present time, and one of them—labour shortage—must of necessity continue to become more and more acute in view of the recently announced birth rate statistics, together with the incidence of the raising of the school leaving age, and the period of compulsory military service.

It would therefore seem to be important to introduce mechanical methods to counteract this inevitable man power shortage and to eliminate the shovel as far as possible. Our mineral wagons with their flat bottoms and small doors, requiring slow and laborious man labour to unload, are one of the chief deterrents to quick handling at the depots. If self-clearing hopper-bottomed wagons were made available, all other adjuncts of mechanisation, such as truck unloaders, coal conveyors and loaders, would follow with a consequent decrease in distribution costs, a smaller labour force and a cleaner, more popular job for all employed in a coal yard.

Chapter VIII

SOME CONSIDERATIONS ON THE STORAGE OF COAL

by A. E. MINNS*

THE following notes give briefly some of the considerations involved but it is not possible in the space available to deal with all aspects of the storage of coal.

Reasons for Stocking

The storage of coal is a relatively costly process, but it is an essential contribution to our national economy in that it ensures against failure in continuity of supplies, which may be due to any of the following reasons:—

(1) Seasonal variations in the rate of consumption.
(2) Production breakdowns owing to holidays, mechanical failures or trade disputes.
(3) Failure of transport arrangements between pit and point of consumption.

Of these three reasons, the first is by far the most important, as the winter consumption of coal is about 30 per cent. more than during the summer. Before the 1939/45 war the output from the pits could be regulated to some extent to take care of seasonal fluctuation in demand, but now both pits and transport facilities have to be worked at full pressure in order to produce and carry our national requirements. To ensure continuity of supply during the winter, it is necessary to establish reserve stocks of coal as near the points of consumption as possible.

Size of Stocks

The size of the stock so created at any one point varies between the capacity of the domestic coal cellar and stocks of up to 250,000 tons or more laid down by the larger Public Utility Groups or on Government Account.

Deterioration

The question is often asked as to whether coal deteriorates whilst in stock

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* *Consulting Engineer to the Ministry of Fuel and Power on Coal Stocking*

Fortunately, reduction in the calorific value of coal when stocked in the open is slow. This loss has been assessed at from 3–5 per cent. per annum, but it seems certain that this figure is a maximum only found with coals having a comparatively high volatile content. The annual rate of deterioration is reduced as the coal remains in stock.

Spontaneous Combustion

By far the most serious risk of damage to which coal in stock is subjected is that of spontaneous combustion. A great deal has been written on the cause and methods of dealing with spontaneous combustion in coal heaps, and much experimental work has been carried out to find effective methods of prevention and of control when combustion has in fact started. It is not possible, however, to put forward any definite rules whereby complete immunity can be achieved.

Certain varieties of coal, particularly " Opencast," have shown themselves more liable to firing when in stock; those coals with a relatively high volatile content being most dangerous. Firing is more frequent in heaps consisting of mixed sizes of coal than heaps of graded or washed coal.

Whilst the causes of spontaneous combustion are not by any means certain, it seems clear that it is due to heat produced by a slow oxidising process. Coal as stocked is a good heat insulator which prevents the dissipation of the heat generated in the initial stages of oxidation. The temperature therefore rises, accelerating the rate at which oxidation takes place until a point is reached when active combustion or firing occurs.

Methods of Fire Fighting

Methods of treatment vary with the size of the stock. Often the fire is situated in comparatively small local patches, and the method generally adopted is to dig the coal out and spread it around to allow cooling. Where the fire is more general, large scale watering may be employed, but a permanent cure is not always obtained by this method. The water is useful as a vehicle to convey the heat away from the source of trouble, but, on the other hand, there is no doubt that the tendency to fire in certain coals is increased by the presence of moisture. A condition often arises, especially with bituminous coals, where a layer or crust of tarry products forms above the seat of the fire, which prevents the access of water, with the result that further digging operations have to be undertaken.

Precautions Against Firing

If coals liable to spontaneous combustion have to be stored, the following precautions should be observed: —

(1) The height or depth of stacking must be limited.

(2) Stacking by a method which ensures some consolidation of the heap is desirable. Artificial consolidation by rolling is sometimes employed.

(3) Heaps may be subdivided into units of five to twenty thousand tons to minimise the risk of fire spreading throughout the stack and to provide access for any mechanical plant which may be required to deal with outbreaks of fire.

(4) Heaps may be sealed by covering with a layer of finely-divided inert substance such as anthracite duff, flue dust or a bitumen coating. The duff being rolled in, forms a layer which prevents sufficient air entering the heap to cause combustion. A bitumen coating can be sprayed on as is done in road making.

(5) Regular temperature readings should be taken throughout the heap, either by thermometers lowered down tubes driven at approximately 40 feet intervals in each direction, or by direct reading pyrometer.

Methods of Handling

Coal is handled into and out of stock by methods which depend on two main factors:—

(1) The size of the stock to be created.

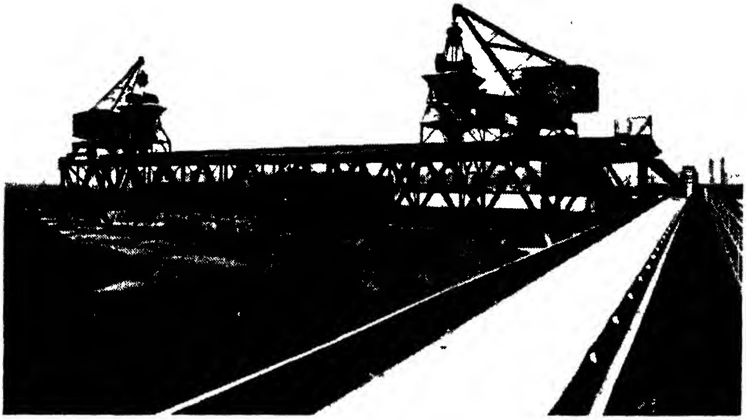
(2) The number of times per year the stock has to be emptied or filled.

Unfortunately, the ordinary railside depot stocks held by Coal Merchants throughout the country to feed their day-to-day demand are too small in both total and annual tonnage to justify any considerable mechanisation in the handling of coal from wagon to store or lorry. These stocks generally consist of a relatively large number of varieties of coal, each being handled at the rate of a wagon-load or two at a time. For this reason, any mechanical plant used must be portable, frequent movement being necessary. In practice, no considerable capital expenditure on plant is justified, as even with its use the amount of labour required at the depot is not materially lessened nor is the cost per ton reduced. Considerable work is, however, now being done by the distributive trade in order to provide for the mechanisation of larger depots.

Coal stocks created to provide increased consumption in winter for any particular class of user vary in size from a few hundred tons to heaps covering some fifty acres or more. In this case also justification for full mechanisation is open to some doubt, because the stocking ground is filled and emptied once only in that time.

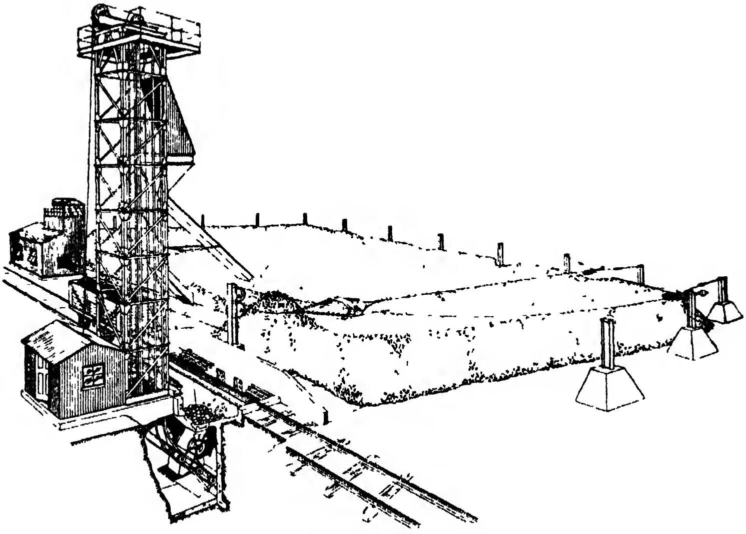
As we have seen above, the coal has to be stored at limited depths as a precaution against spontaneous combustion, the area covered being, therefore, relatively large. The capital cost of any mechanical handling scheme to serve such an area is, therefore, correspondingly high, and such stocks are usually put down or recovered by means of railway wagons or lorries with grabbing cranes, bulldozers, or other portable plant.

The third main category of stock is that used in conjunction with a large consuming unit, such as a Power Station, Gas Works, or other Public Utility Undertaking. In this case, coal is continually being put into stock and withdrawn for use, the stock acting as a day-to-day accumulator and often being



[BY COURTESY OF LONDON POWER CO

Figure 37.—Coal stocking plant, Scheme A



[BY COURTESY OF INTERNATIONAL COMBUSTION LTD

Figure 38.—Coal stocking plant, Scheme B turned over many times a year in accordance with the exigencies of transport and other factors.

In such installations reliability is of prime importance, whereas capital cost is, to some extent, a secondary consideration. The stocks are usually fed either from a railway wagon tippler or from ship by belt conveyors, the coal being distributed over the stocking area by two main methods, (a) distribution by conveyor belts, some of them movable, serving the whole site, or (b) by a system involving conveyors, and, in addition, a rope drag scraper equipment.

Figure 37 illustrates a typical layout of Scheme (a) above. When stocking, coal is brought by conveyor (not shown) running beside the installation, being transferred thence to a transverse belt operating across the stock in the base of the moving gantry. The coal is then distributed by means of a movable "take-off," visible in the centre of the gantry.

[BY COURTESY OF INTERNATIONAL COMBUSTION, LTD

Figure 39.—Rope drag scraper equipment

When reclaiming, the coal is grabbed by the movable cranes into hoppers running on the top of the gantry, weighing apparatus sometimes being incorporated. The coal then passes along a second transverse belt housed in the top of the gantry, thence down the chute and away to the boilers on the main conveyor shown on the right of the picture.

Figure 38 illustrates diagrammatically the arrangement of rope drap scraper equipment, in this case working from truck. Coal is distributed over the site by means of a bucket, hauled by a system of winches and wire ropes from a central point of discharge. A series of tail anchorages are arranged around the periphery of the site, or a moving tail car is employed, the position of these governing the direction taken by the bucket. Reclaiming is carried out by reversing the bucket so that it pulls coal towards the central point instead of away from it, a pit being installed into which the coal is scraped; thence it travels to the boilers by belt conveyor, either installed underground or fed by elevator from the pit.

Figure 39 shows a portion of such a coal stock, together with the bucket used with this system.

Layout of Stock

When considering the layout of a coal stock a good basis for capacity calculations is that 1,000 tons of coal spread over an acre of land would be 1 ft. thick.

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* _The reader will find much additional information in these two publications_

Chapter IX

ANALYSIS OF COAL

by H. E. CROSSLEY*

THE efficient utilisation of coal necessitates careful analysis, to provide information which will help in the selection of coal suitable for a given use. The development of plant design and operation has increased the number of critical factors to be considered. Analysis of coal, therefore, is concerned with many tests of different character. A brief description of these tests will be given, but for working details the appropriate authorities should be consulted.

The current authoritative publications in Britain are British Standard Specifications, particularly B.S.S. 1016 (1942), on the analysis of coal and coke, and B.S.S. 1017 (1942), on the sampling of coal and coke. Additional details, and in some cases alternative methods, are given in Fuel Research Survey Paper No. 44, 1940, " Methods of Analysis of Coal and Coke," published by H.M. Stationery Office.

SAMPLING

The first step in the analysis of coal is the provision of a sample of suitable bulk, particle size, and condition. This sample must be representative of the main bulk of coal from which it was taken, otherwise the analysis which follows is relatively valueless.

All consignments of coal are heterogeneous, consisting of pieces which are often very different in both size and composition. A little of the inorganic matter is intimately dispersed through the coal, and may be considered to be homogeneous with it. With most coals, however, the mineral matter is mainly separate from the coal, occurring as lumps or fragments of shale, etc. The sampling of coal, therefore, must be carried out by standard methods, which take full account of the above difficulties.

The specified British Standard methods of sampling are based on the following principles. The minimum number of increments of coal to be taken is not affected by the weight of coal to be sampled, provided the increments are uniformly distributed, but the number does depend on the " average error " of the coal, and the best indication of the " average error "

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is the ash content. The weight of each increment necessary increases with coals of larger particle size. Finally, a specified weight of sample is better obtained by taking many increments of relatively small weight than by taking few heavy increments. The procedures are arranged as follows. First a gross sample is collected, and from this two other samples are prepared, the "moisture" sample and the "analysis" sample.

Gross Sample

British Standards Specification No. 1017 details the minimum number of increments, the minimum weight of each increment, and the minimum weight of "gross" sample for different types of coal, according to the maximum particle size of the coal and its ash content, and the accuracy required. In each case the accuracy stated is assumed to be obtainable 99 times out of 100. The standards of accuracy are ±0.25 to ±1.0 per cent. (of ash), with maximum sizes of coal of 0.5 in. to 3 in., and ash contents up to 20 per cent.

Advice is given on the collection of samples from chutes, conveyors, wagons, heaps, etc. The weight of the gross sample ranges from 11 lb. with fine coal of low ash content to over 6,000 lb. with lumpy coal of high ash content. The larger amounts cannot be taken with small deliveries of coal, and in such cases greater inaccuracy is unavoidable.

"Moisture" Sample and Determination of Total Moisture

The moisture content of coal is an important characteristic, used for the calculation of results to a common basis of dry coal, and indicating incombustible matter. For general analysis a relatively small sample of coal is required, of fine particle size, so that representative portions of about one gramme each can be used for various determinations. Some coals are visibly wet when received, however, and cannot be passed through sieves, or crushed to a powder, and, in fact, all coals tend to lose moisture during fine grinding. A special sample is prepared from the "gross" sample, therefore, by a method which minimises the loss of moisture.

Alternative methods are given by British Standards Specification No. 1017 for the preparation of a "moisture" sample weighing 2 lb., crushing if necessary so that the sample passes through a $\frac{1}{2}$ in. B.S. Test sieve. Moisture is determined on the whole 2 lb. sample, either by weighing before and after drying in an oven, or by distilling the moisture into a measuring tube with petroleum spirits. If the 2 lb. sample is crushed to pass a 6-mesh B.S. sieve, and sub-sampled to give 8 oz., moisture may be determined by drying only ten grammes in an oven, or by using the same weight in a distillation apparatus.

Analysis Sample

The "gross" sample is crushed to pass a $\frac{3}{16}$ in. B.S. Test sieve. If the sample is damp or wet it is air-dried, that is, spread out in a thin layer for

6 to 10 hours, weighing before and after. The loss in weight is used for the calculation of analytical results to a basis of the sample " as received."

After crushing, the " gross " sample is sub-sampled, to give a quantity which is dependent on the ash content and the accuracy required. The sub-sample is then further crushed and sampled, to give about 2 lb. of coal which is sufficiently fine to pass through a 72-mesh B.S. Test sieve. This is the " analysis " sample, used for general analysis in the laboratory.

PROXIMATE ANALYSIS

The proximate analysis of coal consists of the determination of the percentages of moisture, volatile matter, and ash. The sum of these three is deducted from 100, and the difference is termed " fixed carbon." The analysis is of considerable importance, giving a preliminary indication of quality and suitability for various uses. The moisture and ash together may be regarded as an approximate measure of the total amount of incombustible matter present, whereas the amount of volatile matter gives valuable information of the type of coal, particularly with reference to the suitability of the coal for gas manufacture, or the ease with which the coal may be burned for steam-raising.

It must be emphasised that the determinations of volatile matter and ash are not absolute, but arbitrary. For example, the higher the temperature and the longer the time of heating, the greater would be the amount of volatile matter released from the coal. Also, ash prepared from a given weight of coal would be heavier if prepared at 500° C. than if prepared at 800° C., as carbonates and some sulphates stable at 500° C. are decomposed at 800° C. Further, the composition of coal ash is influenced by the availability of air during the combustion, so that with a restricted supply of air sulphides may be formed instead of sulphates. To some extent the determination of moisture also is arbitrary. It is carried out at a temperature which should remove free moisture, but at higher temperatures more moisture is volatilised from coal. This moisture is partly due to the decomposition of the coal, but some of it comes from the shaly matter, and some may have been uncombined, but intimately associated with the coal.

As proximate analysis is arbitrary, determinations carried out on a sample of coal will only agree if a carefully specified method is closely followed in each determination. The British Standard methods were evolved with the main object of ensuring that the results of analyses could be repeated with good agreement by different operators in different laboratories, provided that in each determination there is conformity with every specified detail of operation and laboratory equipment.

Moisture

The result of the determination of moisture is used to obtain the total moisture in the coal " as received," by taking into account any moisture previously lost by air-drying during sampling. It is also used for the calculation of other analytical results to a basis of dry coal, and in the volatile matter test it is deducted from the total amount of volatile matter. The order of the amount of moisture in the coal after being allowed to dry in air at ordinary temperatures depends mainly on the rank of the coal, ranging from as much as 10 per cent. with non-caking bituminous coals to only 1 or 2 per cent. with anthracites. To a lesser extent the amount depends on the humidity of the air in which the sample was air-dried.

The main difficulty to be avoided in this determination is the tendency for some coals to oxidise, and thus change in weight, when heated in air. A portion of one or two grammes of coal is heated to constant weight at 105° C. to 110° C. in a special oven. The oven should either be of the vacuum type, or it should be designed so that there is a minimum amount of free space, that is, a minimum amount of air. The air can then be removed rapidly by passing a reasonably small amount of nitrogen through the oven. Using a nitrogen-filled oven, the time taken for the coal to attain constant weight varies from about one hour with coals which have a low moisture content, to several hours with moisture contents of 7 per cent. and over. With a good vacuum oven, however, drying should be complete with most coals in one hour.

The loss in weight of the coal on drying is taken as the amount of moisture.

Volatile Matter

The determination of volatile matter assesses the amount of organic matter which will be driven off from the coal when it is heated under prescribed conditions. The order of the amount depends on the rank of the coal, as was the case with moisture, ranging from less than about 8 per cent. with anthracite to over 40 per cent. with non-caking bituminous coals. A preliminary selection of coals for various uses may be made on the amount of volatile matter, as in the following examples. Anthracites with about 8 to 15 per cent. of volatile matter are selected for small central-heating boilers and for malting kilns. Coals with about 12 to 20 per cent. of volatile matter are usually suitable for use in small boilers, minimising loss of efficiency in smoke but burning freely. Many coals with about 20 to 30 per cent. of volatile matter do not burn freely and thus render the coal unsuitable for steam-raising, but give coke which is often sufficiently strong to favour the use of the coal for the manufacture of metallurgical coke. Coals of about 30 to 35 per cent. of volatile matter are used for gas-making, and in the lower part of this range, for steam-raising in large boilers.

The conditions now standardised for the determination of volatile matter were specified after careful trial of various methods, and the reasons for the selection have been published (Fuel, 1942, **21**, 102).

The test is carried out by weighing one gramme of coal into a special silica crucible, fitting the lid, and heating in a muffle furnace at 925° C. for 7 minutes. The temperature is measured by means of a thermocouple, as described in the specification. Anthracites tend to decrepitate on heating, with the ejection of particles from the crucible. To minimise this effect alternative modifications are specified. In one modification asbestos pads are placed below the crucible to retard the rate of heating, in the other the anthracite is mixed with a caking coal of known volatile matter content.

After the deduction of the amount of moisture in the coal, the loss in weight is taken as the amount of volatile matter.

Ash

The ash resulting from the incineration of coal differs from the mineral matter originally present, as the minerals undergo changes during the heating. Shaly matter loses combined moisture, sulphides of iron (pyrites and marcassite) oxidise eventually to ferric oxide (Fe_2O_3) or ferroso-ferric oxide (magnetite, Fe_3O_4), and carbonates lose carbon dioxide, becoming sulphates if there is sufficient sulphur present. The determined amount of ash is often used, with the amount of moisture, for calculating other analytical results to a basis of dry ash-free coal. The true amount of mineral matter is used instead of the determined ash, however, if results are to be calculated to a basis of dry pure coal. The amount of mineral matter is obtained by calculation from the amount of ash, and formulae for this calculation were given by King, Maries, and Crossley (J. Soc. Chem. Ind., 1936, **55,** 277T). These formulae require further analysis of the coal, to determine the amounts of pyritic sulphur, sulphate sulphur, sulphate in ash, carbon dioxide, and chlorine. Further details of the changes during incineration are given in the same paper, and a later paper by the present author (Inst. of Fuel Bulletin, December, 1946) deals more fully with the nature of the mineral matter in coal.

In the specified method for the determination of ash, an amount of one to two grammes of coal is weighed in a suitable dish, and heated in a muffle furnace with adequate ventilation. The temperature is raised to $400 \pm 50°$ C. in 30 minutes and maintained at this temperature for a further 30 minutes. This slow preliminary heating minimises loss by decrepitation, and also prevents excessive fixation of sulphur compounds by alkaline substances in the ash. As the amount of this fixation varies considerably with experimental conditions, procedures which limit the fixation favour the reproducibility of results. Since the specification was published the present author has found that 490° C. is still more effective in depressing the sulphur fixation.

After the preliminary heating the temperature is raised to $775 \pm 25°$ C., and heating is continued until the ash attains constant weight, usually about 1 hour. This weight is taken as the amount of ash from the coal. The amount ranges from 1 or 2 per cent. with very clean coals to over 20 per cent.

The temperature of $775 \pm 25°$ C. was selected as suitable for the decomposition of the less stable compounds in coal ash. It is easily attained in the laboratory, and from 750° C. to 900° C. the ash suffers little further decomposition. Above 900° C. calcium sulphate begins to decompose and ferric oxide changes to magnetite (Fe_3O_4). Both reactions are slow, and at temperatures of 900° C. to 1,050° C. some ashes would attain constant weight only after several hours.

Special furnaces have been designed at the Fuel Research Station for the determination of ash (C. W. G. Ockelford, Fuel, 1945, **24**, 151) with the object of preventing contact between combustion gases and ash, thus still further limiting the fixation of sulphur in the ash. With these furnaces determinations can be reproduced closely, regardless of whether one determination is done on each occasion or several simultaneous determinations are carried out.

ULTIMATE ANALYSIS

Ultimate analysis refers to the determination of those elements which are the main constituents of coal. These are carbon, hydrogen, sulphur, nitrogen, and oxygen. The first four elements are determined directly, but as there is no satisfactory method for the direct determination of oxygen in coal, the amount of oxygen is found by difference, subtracting the total percentage of the other four elements, expressed on a dry, mineral-matter-free basis, from 100. By contrast with proximate analysis, the determinations of carbon, hydrogen, sulphur, and nitrogen are all of an absolute and finite nature. Analytical accuracy only is to be attained to ensure the reproducibility of results.

The ultimate analysis of coal is used for the checking of combustion conditions during boiler trials, to give indications of the nature of products of coal carbonisation, and to help in the classification of different kinds of coal. Sulphur is an undesirable constituent of coal, being concerned with corrosion troubles, atmospheric pollution, and the weakening of metals made with high-sulphur cokes. Nitrogen in coal appears mainly in the useful form of ammonium salts in gas-works liquor, but only part of the nitrogen is recovered. The amounts of carbon and oxygen in coal are characteristic of the rank of the coal, ranging from about 90 per cent. of carbon and about 3 per cent. of oxygen with anthracites, to about 65 per cent. of carbon and about 30 per cent. of oxygen with brown coals.

Carbon and Hydrogen

Carbon and hydrogen are determined simultaneously by the combustion tube method. An amount of 0.2 grammes of coal is weighed in a small combustion " boat," and the boat is transferred to a silica or glass combustion tube. The tube is heated and purified air or oxygen is passed over the coal. The gaseous products of combustion are fully oxidised in the tube by copper oxide to carbon dioxide and water, and a further section of the tube containing lead chromate removes oxides of sulphur. The gases leaving the tube are passed through two weighed vessels containing respectively a dehydrating agent such as calcium chloride, and a caustic alkali. The former vessel absorbs the moisture in the gases, and the latter absorbs the carbon dioxide.

The amounts absorbed are determined by re-weighing the vessels, and these amounts are calculated to the equivalent amounts of hydrogen and carbon. In this calculation the moisture content of the coal is deducted from the moisture caught by the dehydrating agent.

Sulphur

Methods for the determination of sulphur in coal depend upon the removal of the organic matter by oxidation in such a way that the sulphur is retained as a soluble sulphate. The sulphate is then precipitated as barium sulphate, and weighed as such, after drying or igniting.

Either of two methods can be used for the oxidation of the organic matter. In the first method one gramme of coal is burnt in oxygen in a calorimetric bomb. The bomb contains a little water, which absorbs the oxides of sulphur in the combustion gases. This method gives accurate results, particularly if certain precautions are followed (J. G. King and H. E. Crossley, Fuel, 1929, **8**, 544). Only one determination can be carried out at a time, however, and the method is not suitable for routine use unless advantage can be taken of determinations of calorific value. The alternative, known as the Eschka method, consists in heating one gramme of coal mixed with, and covered by, Eschka mixture, which consists of two parts by weight of magnesium oxide and one part of anhydrous sodium carbonate. The oxides of sulphur formed during the combustion are quantitatively retained by the Eschka mixture When all the organic matter has been burnt, the residue is dissolved in dilute hydrochloric acid, full oxidation being ensured by the addition of bromine water. This method is suitable for routine use, as several determinations can be carried out simultaneously.

As stated earlier, the final stage in the determination is the weighing of barium sulphate. The amount found is then calculated to the equivalent amount of sulphur.

Most British coals contain from 0.8 to 3.0 per cent. of sulphur.

Nitrogen

The nitrogen in coal is determined by the Kjeldahl method, in which about one gramme of coal is decomposed by boiling sulphuric acid, and the nitrogen is converted to ammonia. The ammonia forms ammonium sulphate with the acid, and is subsequently set free by distilling the residue with an excess of sodium hydroxide. The ammonia distils with the steam, being trapped by a known amount of standard sulphuric acid in a scrubber. This neutralises part of the acid; the remaining acid is determined by titration with standard alkali solution, and thus the amount of acid neutralised can be obtained. The equivalent amount of ammonia is obtained by calculation, and hence the amount of nitrogen.

The decomposition by boiling sulphuric acid is accelerated by adding selenium as a catalyst, and further acceleration can be obtained by adding also vanadium pentoxide (H. E. Crossley, Fuel, 1941, **20**, 144).

There is little variation in the nitrogen content of British coals, the normal range being about 1.4 to 1.8 per cent.

ADDITIONAL ANALYSES

Phosphorus

Phosphorus occurs in British coals in small quantities, normally from 0.005 to 0.1 per cent., but the higher amounts in this range are undesirably significant in some industries. When coal is carbonised the phosphorus remains in the coke, and if the amount present is relatively large, and the coke is used for metallurgical purposes, the phosphorus can have a bad effect on the quality of the metal. Further, recent work by the present author has shown that in some circumstances phosphorus compounds are volatilised from coal which is burnt in boilers, resulting in the formation of hard deposits on the heating surfaces of the boiler plant, and prematurely enforcing the shut-down of the plant for cleaning.

The method now specified (B.S.S. No. 1016) for the determination of phosphorus in coal begins with the preparation of ash from a known amount of coal. From 0.1 to 1.0 grammes of the ash is then decomposed by mixed nitric and hydrofluoric acids. The phosphorus is extracted from the residue by dilute nitric acid, and subsequently precipitated as ammonium phosphomolybdate. The precipitate is dissolved in a known amount of sodium hydroxide solution, neutralising part of the alkali. The amount of alkali remaining is determined by titration, and from this the amount of alkali which had been previously neutralised, and hence the amount of phosphomolybdate, and the equivalent amount of phosphorus, can be obtained by calculation.

Arsenic

Arsenic occurs in very small quantities in British coals, usually from less than 1 up to 10 parts per million parts of coal. A few coals contain up to 100 parts per million, and these might be unsatisfactory for the preparation of metallurgical coke, for a similar reason to that mentioned in the section dealing with phosphorus. The industry mostly concerned with the arsenic content of coal, however, is malting. For this purpose, anthracites with less than about 4 parts of arsenic (expressed as arsenic trioxide) per million parts of coal are selected, to obviate any risk of the contamination of the malt.

The first step in the determination of arsenic in coal is the removal of the organic matter without losing arsenic. This is done by mixing the coal with an excess of base, such as lime or magnesia, and incinerating it. The residue is transferred to a special apparatus, and treated with dilute sulphuric acid, stannous chloride solution, iron alum solution, and zinc. By this means the arsenic is converted to the gas arsine. The gas passes on to a tube across which there is a disc of paper impregnated with mercuric chloride. The arsenic reacts with the mercuric chloride, giving a stain which is pale yellow with the smallest amounts of arsenic, and blackish brown with relatively large amounts. This stain is compared with a set of stains made similarly from known amounts of arsenic, to obtain the amount of arsenic in the coal. This method is satisfactory for relatively small amounts of arsenic, but for larger amounts, say over 10 parts per million, it is preferable to form the stain on a thin strip of paper, and compare the length, not the colour, of the stained portion with standard stains. (H. E. Crossley, J. Soc. Chem. Ind., 1936. **55**, 272T.)

Chlorine

Chlorine occurs in coal as inorganic chlorides, mainly the chlorides of the alkali metals, sodium and potassium, but occasionally as the chlorides of calcium and magnesium. British coals contain from 0.01 to 1.0 per cent. of chlorine.

Although all the chlorides in coal are water-soluble in character, they are partly dispersed through the coal, and not accessible to water. The determination of water-soluble chlorine in coal, therefore, is of little value, as the more finely the coal is ground, the greater is the amount of chloride dissolved. The alkali chlorides are relatively volatile compounds, and this probably results in the distillation of alkalis from fuel beds in boilers, with subsequent condensation on the heating surfaces. In extreme cases this condensation of alkali salts leads to the rapid growth of deposits on the heating surfaces, and ultimately enforces the shutting-down of the boiler.

During the carbonisation of coal the chlorides are partly decomposed, yielding gaseous hydrogen chloride, which combines with ammonia in the gas. In this way ammonium chloride is formed, and this compound condenses in, and sometimes blocks, the gas mains. Greater trouble, however, is caused by the chemical action of the alkali chlorides on heated refractory linings and brickwork.

The amount of chlorine in coal is determined by incinerating a mixture of 5 grammes of coal with 9 grammes of Eschka mixture (see determination of sulphur) or 9 grammes of sodium carbonate, using part of the base as a covering layer. The mixture is heated in air at 450 to 500° C., until the coal is completely burnt. The residue is dissolved in dilute nitric acid, and a measured excess of standard silver nitrate solution is added. The chlorides precipitate an equivalent amount of the silver, and the silver remaining in solution is then determined by titrating with a standard thiocyanate solution. The amount of silver precipitated by the chlorides is obtained by difference, and from this the amount of chlorine is calculated.

Carbon Dioxide

The carbon dioxide in coal is mainly present as the carbonates of calcium, magnesium, iron and manganese. The determination of carbon dioxide is carried out to provide information necessary for the calculation of the amount of mineral matter in coal (see determination of ash). For this determination, a portion of the sample of coal is ground more finely, to pass a 120-mesh B.S. sieve.

Two methods are available. In the first method, an amount of 0.5 to 5 grammes of coal is boiled with dilute hydrochloric acid or dilute phosphoric acid. This sets free carbon dioxide, which, after purification, is collected in an evacuated flask. A measured amount of standard barium hydroxide solution is added to the gas, resulting in the precipitation of barium carbonate. The excess of barium hydroxide is then titrated with standard hydrochloric acid, and the amount of barium precipitated is obtained by difference. From this amount the equivalent amount of carbon dioxide is calculated.

The second method is similar, but differs in that the carbon dioxide is absorbed in a weighed vessel containing soda lime. The vessel is then re-weighed, giving the amount of carbon dioxide directly.

Forms of Sulphur

Sulphur occurs in coal in three forms, mainly as iron pyrites and organic sulphur. There is also a small quantity of sulphate in the coal. These forms are determined to provide information for the calculation of the amount of mineral matter in coal (see determination of ash), and also in laboratory experiments to assess the results which can be expected from the cleaning of coal. The organic sulphur, being part of the coal substance, cannot be removed by cleaning. The pyritic sulphur is removable, however, if the pyrites occurs in particles which are separate from the coal.

The analyses are carried out on coal ground to pass a 120-mesh B.S. sieve, the fine size facilitating extractions. " Sulphate " sulphur is determined by extracting 5 grammes of coal with dilute hydrochloric acid for 40 hours at 60° C. The sulphate in the extract is precipitated by adding barium chloride, and the determination is then completed as in the determination of sulphur. " Pyritic " sulphur is determined on the residue from the former extraction, by a further extraction, with dilute nitric acid for 24 hours at room temperature. The extracted sulphur may be determined by adding barium chloride, as before, or by determining the iron in the extract. The iron is equivalent to the pyritic sulphur, according to the formula of pyrites, FeS_2. The " organic " sulphur is determined by adding the amounts of " pyritic " and " sulphate " sulphur, and deducting the sum from the total sulphur in the coal.

CALORIFIC VALUE

The calorific value is the most important characteristic of coal which is to be used for heating, as in steam-raising, giving the amount of heat which would be released with perfect combustion.

There is only one accurate method of determining calorific value, and that is the bomb method. In this method one gramme of coal is weighed in a small crucible, which is transferred to a calorimetric bomb. The bomb is a strong cylindrical vessel, usually made of steel, and able to stand high pressures. The crucible is suspended between two electrodes, and the lid of the bomb is screwed down. Oxygen is then admitted until there is a pressure of 25 atmospheres. The bomb is immersed in a weighed amount of water in a calorimeter, the water is stirred, and the temperature of the water is noted at regular intervals. The coal in the bomb is then fired electrically, and the rise in the temperature is noted. The apparatus is calibrated by carrying out a similar determination with a weighed amount of a substance of known calorific value. The calorific value of the coal can then be calculated.

CAKING OR COKING QUALITY

There is a difference of opinion as to the meaning of the words " caking " and " coking " when applied to coal. The one thing that is agreed is that both apply to those qualities which are important in the production of coke for special purposes, such as for metallurgical use. Several qualities or properties are involved, such as the amount of liquefaction which takes place during carbonisation, the strength of the coke, and the extent of swelling when the coke forms. It is clear that no single test could give sufficient information on all these properties at the same time, and in consequence the various tests which are carried out are all limited in usefulness.

One of these tests is called the determination of agglutinating value. Mixtures of coal and sand are heated together, to find the critical ratio of sand to coal above which the carbonised mass either fails to support a 500 gramme weight, or gives more than 5 per cent. of the weight of the mixture as dust. To some extent this test gives an indication of the strength of the coke, but this is in many cases vitiated as the critical factor proves to be the excessive formation of dust. A further weakness of the test is that the critical value is affected by the presence in coal samples of relatively large amounts of very fine powder.

The determination of swelling index is more useful than the above test, probably because it is limited to the relative measurement of only one property, and there can be no confusion in the interpretation of results. An amount of one gramme of coal is heated in a special crucible in a specified manner over a burner, until the flame of burning volatile matter goes out. The coke button is removed from the crucible, and viewed through a tube to compare the shape with a set of shapes given in the specification. These shapes are numbered, from 1, which is a non-swollen button, to 9, a coke which has swelled to fill the crucible, and the number of the shape which matches the test coke is then taken as the " swelling index. '

Probably the most useful test, to give information regarding the behaviour of coal during carbonisation, is the Gray-King assay. The assay is a method of carbonising coal in the laboratory so that the amount of the various products, coke, tar, liquor and gas, can be determined. The appearance of the coke also indicates the swelling power of the coal.

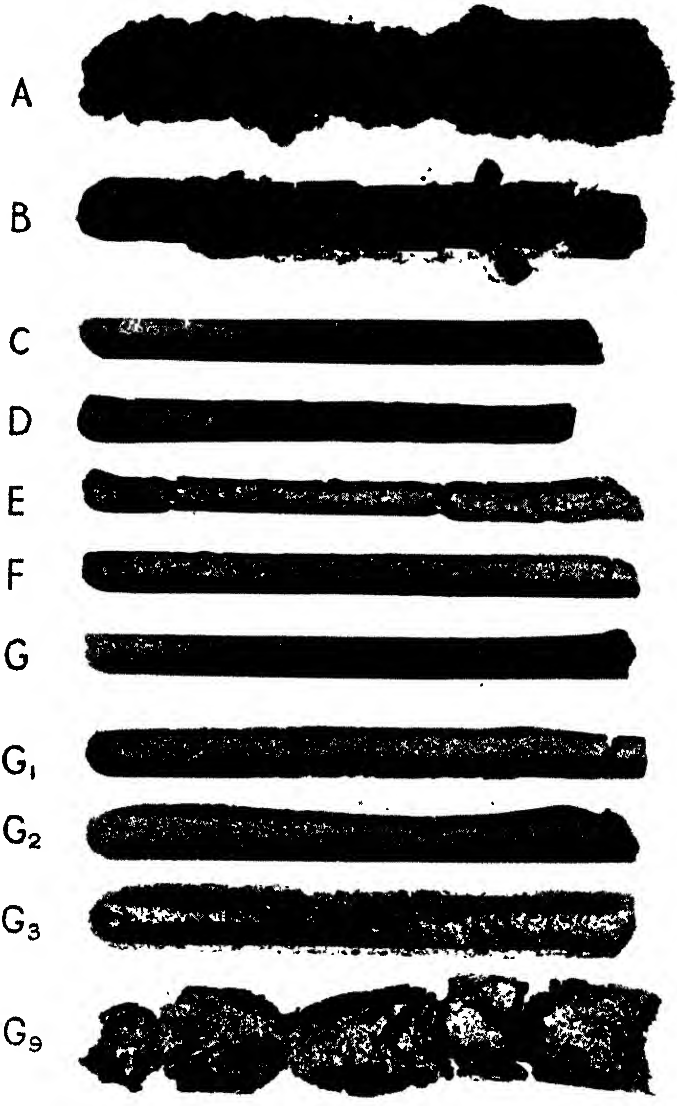

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Figure 40.—Cokes produced from different classes of coal in the Gray-King Assay Apparatus

The apparatus used for the Gray-King assay at 600° C. is shown in Figure 41. It consists of a retort tube B, which is inserted in the electrically wound furnace A. The tube C acts as a condenser for tar and liquor, a second tube (D) being used to absorb ammonia in dilute acid. The gas is collected in the holder E, which is connected to a levelling device (G, K, J) to maintain a constant pressure in the holder. The test is carried out on 20 grammes of coal, which is spread in an even layer along 6 inches of tube B, and heating begins at 300° C. The temperature is raised at a uniform rate to 600° C. in one hour, and this temperature is maintained for a further hour. Subsequently the weights of the various fractions are determined.

If the Gray-King assay apparatus is used with strongly swelling coals, part of the coal is pushed out of the uniformly heated zone in the furnace thus affecting the results of the assay. In such cases this trouble is avoided by mixing a weighed amount of electrode carbon with the coal, so that the mixture gives a hard, strong, non-swollen coke. The types of coke obtained are shown in Figure 40. The letters A to G have been used to designate cokes from coals that are non-coking (A) up to those that give a hard, strong coke of the same volume as the coal (G, " standard coke "). For coals of greater swelling power than G, the terms G_1, G_2, G_3 are used, the numeral indicating the number of parts of electrode carbon in 20 parts of the mixture giving a " standard coke " (G).

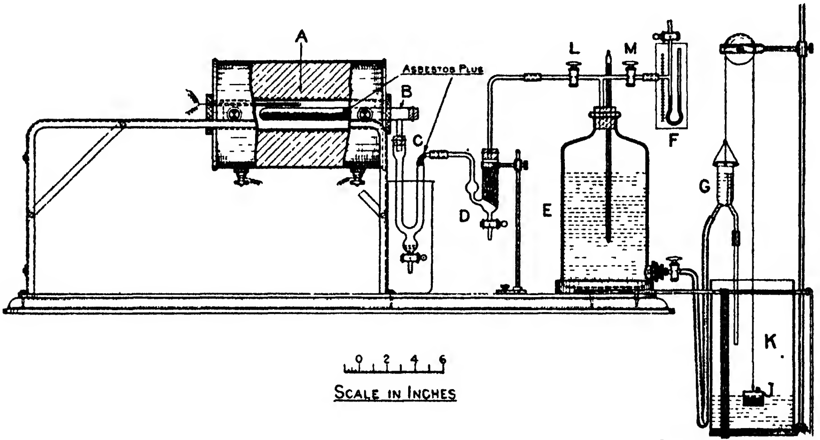

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Figure 41.—Gray-King Assay Apparatus

There is a modified apparatus, in which the coal is heated to 900° C. This differs from the low-temperature assay apparatus mainly in that the retort tube has a packing of crushed silica brick near the outlet, to bring about the cracking of tar vapours, as would occur in large-scale practice, and the tube used for the condensation of tarry matter is cooled in ice. The yields of coke, tar, liquor and gas can be related to industrial practice by calculation factors. Different kinds of carbonisation plant require different factors.

Chapter X

STEAM RAISING

by E. G. RITCHIE*

THIS chapter deals primarily with industrial steam raising equipment, but the appliances discussed are, of course, applicable in many cases to central heating installations. So far as the matter concerns methods of firing, fuels, etc., the subject is of interest in connection with industrial furnaces generally.

Of the total amount of coal consumed in this country, well over 50 per cent. is used for steam raising and in solid fuel-fired industrial furnaces where mechanical stokers are or might be employed. This figure includes the coal used for the generation of power in central stations, the coal consumed in locomotive boilers and that burned in marine boilers.

So far as industrial fuel usage is concerned (excluding power generating stations), probably 50 to 55 million tons per annum is consumed for steam raising and central heating, about 90 per cent. of this in shell boilers mainly of the Lancashire type. The coal consumption in solid fuel-fired industrial furnaces is of the order of 15 million tons per annum. We are, therefore, here concerned with a field of fuel usage aggregating about 70 million tons of coal per annum or about 35 per cent. of the total output.

The choice of steam raising equipment in this country is very wide, not only as regards boiler types, but also in relation to firing appliances and auxiliaries. It is, of course, impossible in a brief chapter to cover the ground adequately, but it is hoped that the references to modern developments in the industrial steam raising and fuel burning fields will be of general interest. The subject is not treated technically due to lack of space, but, in this connection, it may be stated that recent research on shell boilers and their firing appliances has shown that this type of steam raising equipment, so popular with British engineers and so adaptable and adequate to British industry, is capable of an efficiency approaching that of any other type of steam raising plant. It is true that the efficiency with which coal is consumed in industry is extraordinarily low, but this is not due to anything fundamentally wrong with the small cylindrical boiler or its equipment.

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* *British Coal Utilisation Research Association*

It is due often to lack of care or interest on the part of the user and failure to make full use of modern equipment. In many cases Lancashire boilers are being operated without economisers; brickwork settings are in faulty condition and very few boiler installations indeed are properly instrumented. The situation is one which calls for hard thinking and immediate action on the part of industrialists, particularly having regard to the acute shortage and higher cost of coal.

TYPES OF BOILERS

Boilers used for industrial steam raising can be broadly classified as follows:—

(i) Vertical boilers.
(ii) Locomotive type boilers.
(iii) Internal flue horizontal shell-type boilers.
(iv) Multitubular horizontal shell-type boilers.
(v) Water tube boilers.

TABLE 12

Sizes and Capacities of Vertical Boilers with Cross Tube.
Coal of 12,500 B.Th.U.

Height		Diameter		No. of Cross Tubes	Evaporation. Lb. per hour from and at 212° F.
Ft.	In.	Ft.	In.		
4	0	2	0	1	117
5	0	2	6	1	175
6	0	2	6	2	245
6	6	2	9	2	305
7	0	3	0	2	410
7	6	3	3	3	490
8	6	3	6	3	680
9	0	4	0	3	780
10	3	4	3	4	1,000
11	6	4	3	4	1,170
12	0	4	6	4	1,345
12	6	4	9	4	1,580
13	0	5	0	5	1,640
14	0	5	0	7	1,920

(i) Vertical Boilers

The readiest means of raising steam in small quantities is probably by means of the vertical cross-tube boiler. Details of the type are shown in Figure 42, while Table 12 gives a list of commercial sizes and ratings. The thermal efficiency of the vertical cross-tube boiler is about 50 to 60 per cent. In certain improved designs, however, the cross-tubes shown in Figure 42 have been replaced by a bank of smoke tubes to increase the convective heating surface, and in this way the thermal efficiency of the type has been raised to about 70 per cent. A well-known design embodying this modification is shown in Figure 43, while details as to dimensions and ratings, etc., are given in Table 13. Vertical boilers are suitable for loads up to about 7,500 lb. of steam per hour and for pressures not exceeding 100 to 150 lb./sq. in. For light loads they are economical in first cost as they are self-contained and do not require expensive foundations; they have the further merit of taking up very little floor space. Boilers of this type are usually hand-fired and do not require highly skilled labour in their operation.

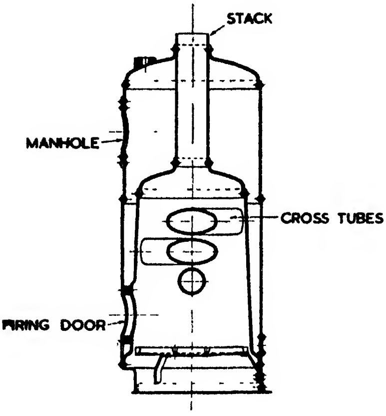


Figure 42.—Vertical cross-tube boiler

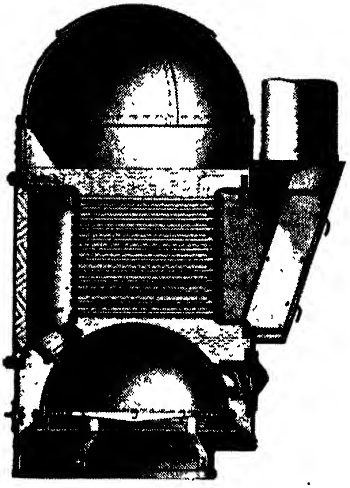


Figure 43. — Vertical boiler with smoke tubes

(ii) Locomotive Type Boilers

Where the head room in the boiler house is limited, and where the local conditions are not suitable to the use of a vertical boiler, the locomotive type may be employed as an alternative. This is, of course a development of the normal locomotive boiler adapted for stationary use. Like the vertical boiler it does not require elaborate foundations and is practically self-contained. It has the important advantage that it can be designed for a working pressure up to 250 lb./sq. in. The locomotive boiler has a very large heating surface for a given steaming capacity and therefore rapid changes in steam demand can be readily met. A typical design is shown in Figure 44. The boiler is fitted with a firebox in which the fuel is burned, the hot gases passing through a horizontal tube-bank into a smokebox at the opposite end. A chimney of considerable height or some form of assisted draught is often necessary, owing to the high gas resistance through the smoke tubes. Typical sizes and ratings are given in Table 14. The locomotive boiler can be made

TABLE 13

Sizes and Capacities of Vertical Boilers with Smoke Tubes. Coal of 12,500 B.Th.U.

Diameter		Height		Grate Area	Heating surface	Evaporation per hour	
						Cold feed	F. & A. 212° F.
Ft.	In.	Ft.	In.	Sq. ft.	Sq. ft.		
3	0	6	9	4.75	50	250	300
3	3	7	6	5.75	60	340	410
3	9	8	6	7.50	100	540	650
4	0	9	0	8.50	110	630	760
4	3	9	6	9.25	140	750	900
4	6	10	0	9.75	160	820	990
4	9	10	3	11.75	190	1,030	1,220
5	0	11	3	12.50	220	1,150	1,380
5	3	11	9	14.00	250	1,320	1,580
5	6	12	3	16.75	300	1,620	1,940
5	9	13	0	18.75	350	1,880	2,250
6	0	12	6	18.75	350	1,880	2,250
6	0	13	6	18.75	350	1,880	2,250
6	0	14	0	18.75	400	2,000	2,400
6	6	13	6	22.50	450	2,360	2,840
6	6	14	0	22.50	450	2,360	2,840
6	6	14	6	22.50	500	2,480	2,980
7	0	14	0	26.75	500	2,750	3,300
7	0	15	0	26.75	600	3,020	3,640
7	6	16	3	31.50	750	3,650	4,380
8	0	16	6	37.00	850	4,320	5,200
8	6	18	0	41.00	1,000	4,960	5,950
9	0	19	0	48.00	1,250	6,030	7,250

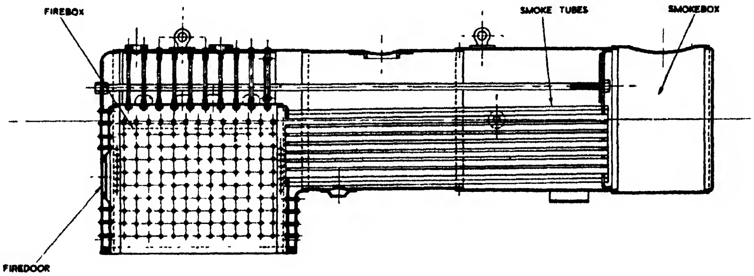


Figure 44.—Vertical section of locomotive boiler portable, it is therefore particularly suitable for building sites, etc., where steam is required for temporary operations. For stationary work it is losing favour and is being gradually displaced by one or other of the many types of Economic boiler.

TABLE 14

Sizes and Capacities of Locomotive Boilers.
Coal of 12,500 B.Th.U.

Heating surface	Grate area	Length overall		Diam. of barrel		Tubes		Evaporation per hour in lb from and at 212° F.
						No.	Diam.	
Sq. ft.	Sq. ft.	Ft.	In.	Ft.	In.		In.	
269	7.9	12	11	3	1	46	2½	1,340
328	9.6	14	0	3	4	55	,,	1,640
425	12.32	14	11	3	8	68	,,	2,100
505	15.12	16	2	4	0	79	,,	2,550
590	17.44	17	8	4	0	85	,,	2,950
684	19.11	18	10	4	2	94	,,	3,400
814	23.39	20	0	4	6½	105	,,	4,000
897	27.38	22	0	4	6½	105	,,	4,600

(iii) Simple Internal Flue Shell Boilers

One of the most popular boilers in this country for industrial steam raising is the simple internal flue shell-type boiler. It was first designed about 100 years ago and, except in detail, has altered but little since it was first introduced. The type has become firmly established in Great Britain because of its low cost, its long life and its general suitability to the needs of British industry.

The simple internal flue shell boiler may take one of two forms:

(a) The Cornish boiler, which has one internal flue, and
(b) The Lancashire boiler, which has two internal flues.

The boiler rests on and is enclosed in a brickwork setting, the fuel being burned on a grate in the internal flue or flues, which are, of course, surrounded by water. The combustion gases leaving the furnace tubes pass first into a bottom flue underneath the boiler, which they traverse to the front of the boiler, where they divide and pass into two side flues and thence to the main flue and chimney. A typical arrangement of Lancashire boiler and brickwork setting with economiser is shown in Figure 45. Under suitable conditions, a thermal efficiency of about 70 per cent. can be obtained with the Lancashire boiler alone, but by the addition of an economiser or air preheater, the plant efficiency can be raised to about 80 per cent. Typical figures for a number of standard sizes of Lancashire boilers, together with their rated capacities, are given in Table 15.

The simple shell boiler has a relatively large water capacity and is therefore able to cope with sudden fluctuations in steam demand. It is reliable as well as being efficient, and its maintenance costs are low. The type has the disadvantage that the combustion space is small, but many satisfactory forced draught grates and mechanical stokers have been developed to suit this restriction. The steam space in the Lancashire or Cornish boiler is large, and dry steam is produced over a wide range of ratings. An added advantage of the type is that it is much less sensitive to change in the quality of the feed water than many other types of steam generating plant.

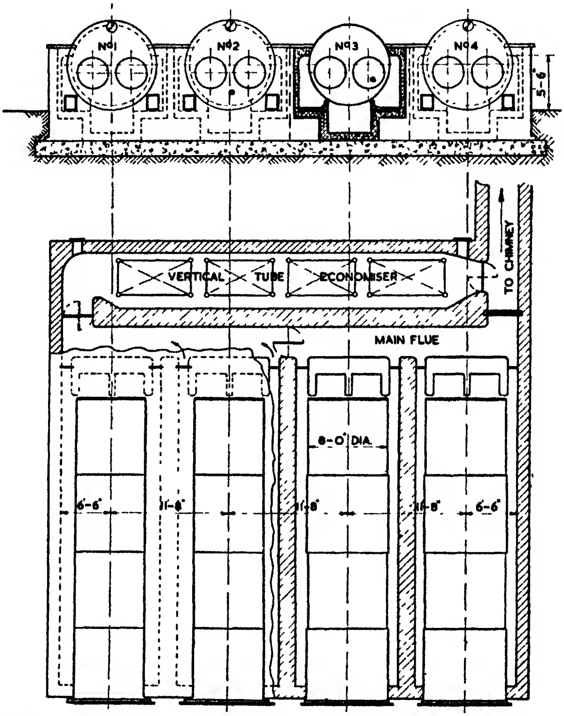


Figure 45.—Arrangement of 4 Lancashire boilers and brickwork setting with economisers

In the simple shell boiler, the greater part of the heat released by the combustion of the fuel is recovered in the internal flues, the side and bottom flues contributing but little to the total heat transfer. As the brickwork setting in such a boiler is expensive to build and costly to maintain, its elimination has certain advantages. Attempts to improve the Lancashire boiler from this point of view have led to the development of the Super-Lancashire boiler, in which the brickwork setting and the inefficient bottom and side flues are omitted and replaced by a series of smoke tubes incorporated in the boiler shell. After passing through these tubes, the gases are led back from the front to the rear of the boiler through an air heater, which preheats the combustion air. With this type of boiler, an induced draught fan is necessary to overcome the various gas resistances. With the Super-Lancashire boiler, efficiencies of over 80 per cent. are claimed.

TABLE 15

Sizes and Capacities of Lancashire Boilers.
Coal of 12,500 B.Th.U.

Length	Diameter	External diameter of flues	Grate area	Heating surface	Normal evaporation in lb. per hour	
Ft. In.	Ft. In.	Ft. In.	Sq. ft.	Sq. ft.	Feed at 60° F.	F. & A. 212° F.
20 0	6 0	2 3	21.67	510	2,860	3,430
24 0	6 0	2 3	24.9	630	3,530	4,230
24 0	6 6	2 6	27.7	675	3,850	4,620
26 0	6 6	2 6	29.0	735	4,190	5,050
28 0	6 6	2 6	29.0	795	4,530	5,440
28 0	7 0	2 9	32.0	860	4,980	5,980
30 0	7 0	2 9	32.0	925	5,370	6,450
28 0	7 6	3 0	35.0	940	5,640	6,760
30 0	7 6	3 0	35.0	1,000	6,000	7,200
30 0	8 0	3 3	38.0	1,085	6,850	8,220
30 0	8 6	3 6	41.0	1,160	7,650	9,200
30 0	9 0	3 9	44.0	1,230	8,500	10,200
30 0	9 6	4 0	47.0	1,310	9,450	11,350
30 0	10 0	4 3	51.0	1,385	10,400	12,500

(iv) Horizontal Multitubular Shell Boilers

In order to increase the amount of steam obtained per unit of floor space as well as to improve efficiency, the horizontal multitubular shell boiler has been developed. In this type, the heating surface has been augmented by replacing the inefficient side and bottom flues of the Lancashire boiler by smoke tubes, thus increasing the heat transfer by convection and lowering the exit gas temperatures with a corresponding gain in efficiency. This type of boiler, known as the Economic boiler, is usually self-contained, i.e., with no brickwork setting, the gases, after passing through the smoke tubes, being led by a duct to the chimney. An economiser or air preheater may be incorporateed, as in the Lancashire boiler.

Economic boilers are broadly of two types:

(a) Double-pass, and (b) Treble-pass.

In the double-pass type, the hot gases from the fuel bed pass through the internal furnace tube or tubes into a combustion chamber at the rear of the boiler and return along the smoke tubes to the smoke box in front of the boiler. From the smoke box the gases are taken to the chimney.

In the treble-pass type, the gases from the smoke box are made to return in the opposite direction through another series of smoke tubes to the back of the boiler, where they enter the main chimney flue. A typical design of a double-pass Economic boiler is shown in Figure 46, while Table 16 gives the leading dimensions and capacities of different sizes of this class of boiler.

The smoke tubes of an Economic boiler can be made more effective by the use of spiral retarders, which increase the " swirl " of the gases in the tubes, thus improving the rate of heat transfer. This is obtained, however, at the expense of increased draught loss. There are also certain specially designed smoke tubes which, it is claimed, give improved rates of heat transfer without the disadvantages of excessive draught loss.

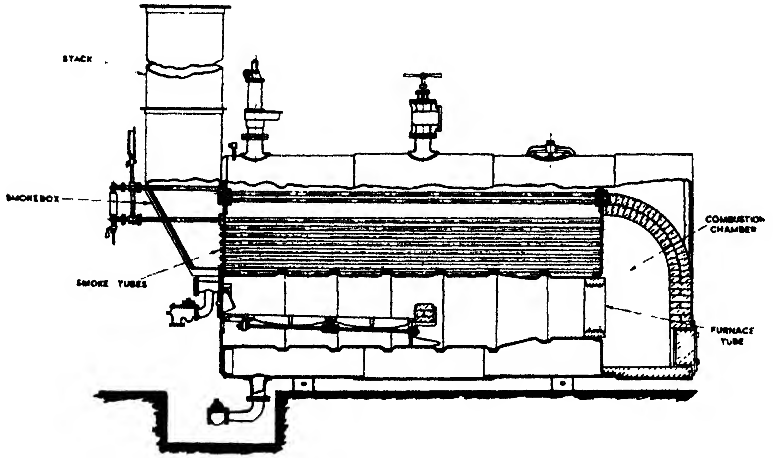


Figure 46.—Vertical section of double-pass Economic boiler

The Economic boiler has a smaller water capacity than the Lancashire boiler and is therefore, in this respect, not so well adapted to meet a widely fluctuating steam demand. On the other hand, the smoke tubes of the Economic boiler, by providing efficient convection heating surface, improve the response of the boiler to a change in firing rate. The Economic boiler is more economical in floor space and costs less to house than does the Lancashire boiler. The Economic boiler is made for evaporations up to about 20,000 lb./hr. and develops an efficiency which may be as high as 80 per cent., depending upon the number of passes.

(v) Water Tube Boilers

The feature which distinguishes water-tube boilers from the types previously discussed is that in this class of boiler the water circulates through the tubular heating surface and not around it, as in the case of the shell boiler. The water tube boiler is a comparatively modern development arising out of the endeavour to obtain larger unit outputs, higher steam pressures and improved thermal efficiencies. Water-tube boilers can now be built for capacities exceeding 1,000,000 lb. of steam per hour and for steam pressures up to or exceeding 2,000 lb./sq. in. This type of boiler contains a comparatively small quantity of water, and with it steam may be raised more rapidly than is possible with a cylindrical shell boiler.

TABLE 16

Sizes and Capacities of Double-pass Self-contained Economic Boilers. Coal of 12,500 B.Th.U.

Diameter		Length overall		No. of flues	Diameter of flues		Evaporation in lb. per hour	
							Feed 60° F.	F. & A. 212° F.
Ft.	In.	Ft.	In.		Ft.	In.		
5	3	10	3	1	2	6	1,250	1,500
5	3	10	9	1	2	6	1,350	1,590
5	6	11	3	1	2	6	1,475	1,770
5	9	11	9	1	2	9	1,770	2,040
5	9	11	9	1	3	0	2,100	2,520
6	6	13	3	1	3	2	2,425	2,910
6	9	15	0	1	3	2	2,950	3,540
7	0	15	0	1	3	9	3,450	4,140
7	6	16	9	2	2	6	4,475	5,370
8	0	17	3	2	2	8	5,875	7,050
8	6	17	3	2	2	10	6,700	8,040
8	10	18	9	2	3	0	7,650	9,180
9	0	18	9	2	3	0	8,370	10,044
9	6	18	9	2	3	2	9,130	10,956
9	9	18	9	2	3	2	10,250	12,300
10	0	19	3	2	3	3	11,085	13,302
10	6	19	6	2	3	6	12,555	15,066
11	0	19	9	2	3	9	13,440	16,128
11	6	19	9	2	4	0	15,050	18,060
12	0	19	9	2	4	3	17,050	20,460
12	6	19	9	2	4	6	20,000	24,000

One of the best-known water-tube boilers for industrial purposes is that illustrated in Figure 47. When fitted with air heaters and economisers, the efficiency of this type may be as high as 85 per cent. A variety of alternative designs of water tube boilers are available, including the two-drum or multi-drum type.

While the output of steam per unit of floor space with the water-tube boiler is higher than with any other type of boiler, the capital cost for a given steam output is also higher. By the provision of special equipment, fluctuating loads can be dealt with, but for normal industrial loads the shell boiler is probably more effective from this point of view, on account of its relatively high water capacity. Another important consideration is that with the water-tube boiler, the comparatively large number of small waterways necessitates much greater care in the conditioning of the feed water.

In the boilers mentioned above, natural water circulation is employed. In certain recent designs, however, the water is forcibly circulated through the water tubes by means of a pump. For this type, it is claimed that increased water velocity in the tubes ensures quick removal of steam from the heating surface, resulting in higher rates of heat transfer and improved thermal efficiencies for a given amount of heating surface.

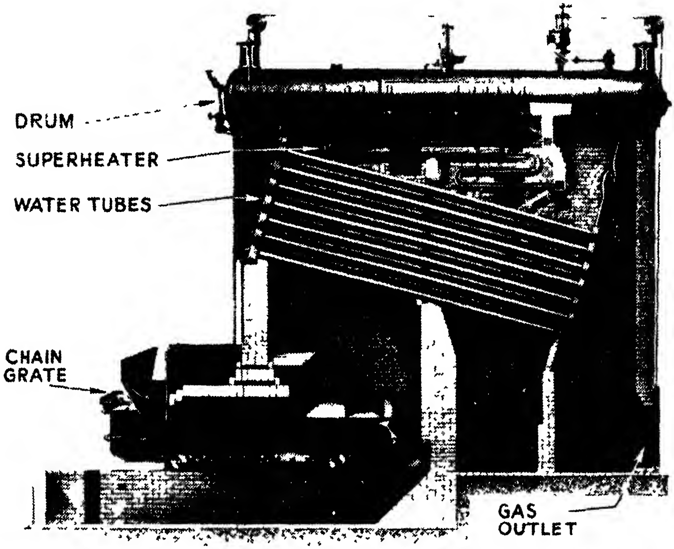
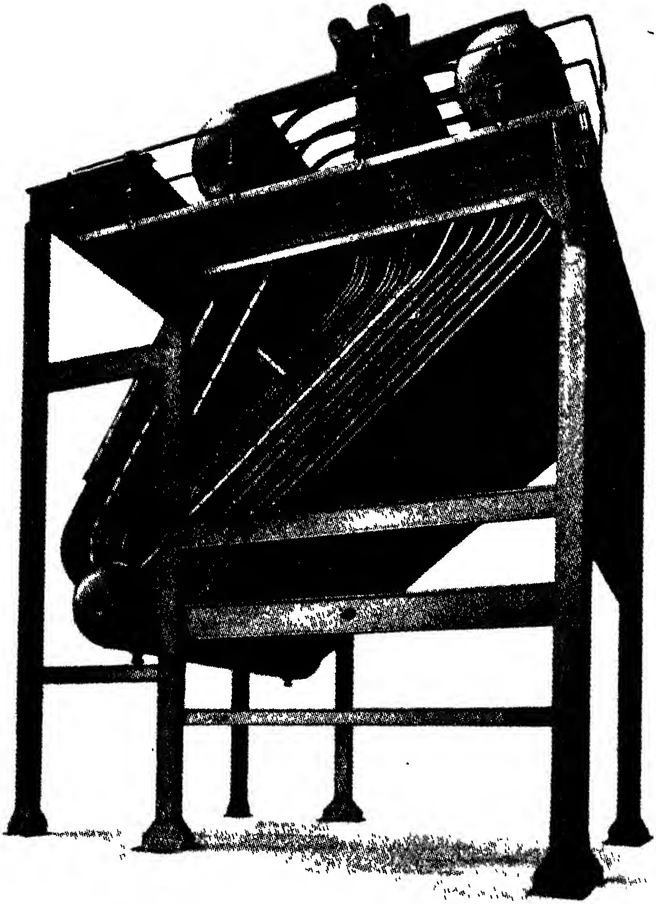


Figure 47.—Water-tube boiler for industrial purposes with chain-grate stoker

The field for water-tube boilers in this country is increasing, due to the demand for higher steam pressures than are possible with shell boilers, particularly in connection with combined power and process schemes for industrial plant.

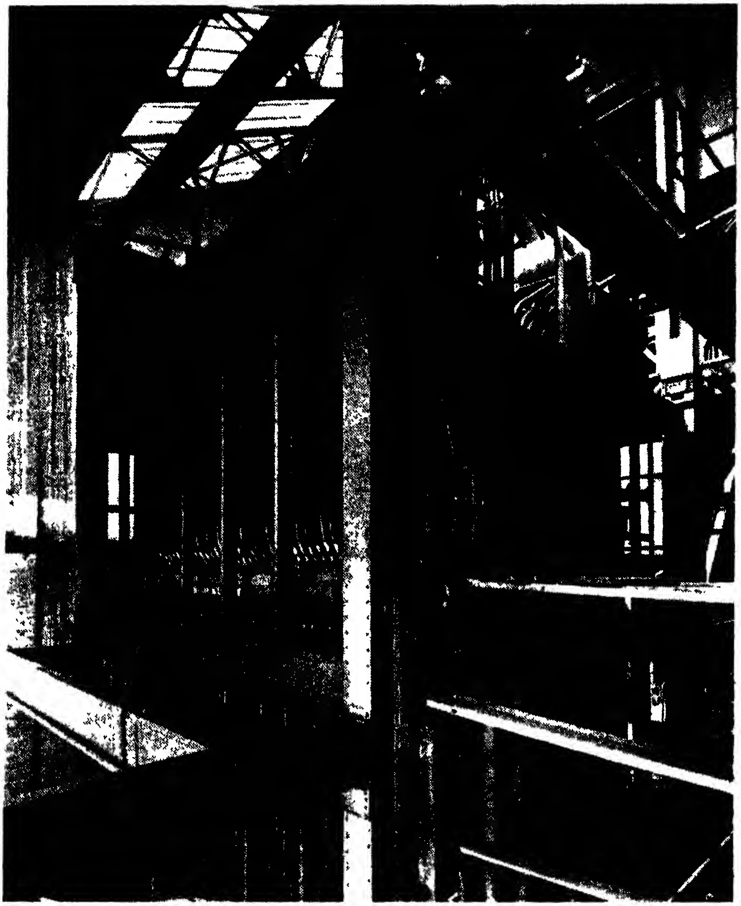
COMBUSTION IN BOILERS AND SUITABILITY OF COALS

The characteristics of coal as a fuel for steam raising are dealt with in Chapters I and II. So far as combustion is concerned, the fundamental principle is to burn the fuel as efficiently as possible and to transfer the maximum



(BY COURTESY OF STIRLING BOILER COMPANY

Figure 48.—Photograph of three-drum water-tube boiler showing arrangement of drums and water-tubes without grate



[BY COURTESY OF INTERNATIONAL COMBUSTION, LTD

Figure 49—Photograph of large industrial water-tube boiler during erection for large power station amount of heat to the water in the boiler. Efficient combustion depends primarily upon supplying the correct amount of air corresponding to the amount of fuel consumed. Insufficient air results in heat loss due to incomplete combustion with the production of soot and smoke. It is difficult to bring the requisite amount of oxygen into contact with the whole of the fuel in the short time available, and in order to burn the fuel completely, it is necessary to admit air in excess of that theoretically required. Excess air is, however, detrimental to efficiency, and its amount should be kept to a minimum. The theoretical amount of air required for combustion varies with the composition of the fuel, but for bituminous coal of 12,000 B.Th.U. per lb. is of the order of 9 lb./lb. (i.e., roughly 120 cu. ft. per lb.). Table 16a shows the relationship, with this coal, between the amount of excess air and the CO_2 in the flue gas.

TABLE 16A

Percentage of CO_2	Percentage of Excess Air
18.5	0
15.0	25
14.0	33
13.0	42
12.0	52
11 0	67
10 0	84
8.0	125
6.0	200

In a boiler furnace, air may be introduced under and through the fuel bed as "primary air," or over the fuel bed as "secondary air." The proportions of primary and secondary air are of very great importance in relation to combustion.

Unless sufficient air is mixed with the volatile matter, combustion is incomplete and smoke is produced. This can be alleviated by the correct use of secondary air.

No firing appliance or furnace of one design is capable of burning all fuels efficiently, although some can burn a wider variety of coals than others. Almost any class of coal can, however, be burned on a boiler, provided the firing appliance is designed to suit it. Washed and graded coals below about 1 in. give best results, but the ash content should not be less than about 5 per cent. to 7½ per cent., in order to prevent burning the firebars. Greatest difficulty is experienced with finely-divided low-grade fuels, such as dry smalls of high ash content, coke breeze, anthracite duff and slurry. Owing to the characteristics and reactivity of these fuels, much lower burning rates are generally obtainable with them than with washed and graded coals, and this, of course, adversely affects the maximum output of the boiler.

The suitability of a given fuel for steam raising cannot be gauged by its chemical composition alone. In addition to this and the determination of calorific value, the coking and swelling indices and the ash melting point should be ascertained. The latter is important, as a low melting point ash gives rise to trouble, due to clinkering on the grate with chokage of the air passages between the bars. From a consideration of these different factors, some idea as to the probable behaviour of a coal can be formed. The only true criterion, however, is the behaviour of the fuel under test on an actual firing appliance.

The types and classes of coal which can be burned with different firing appliances are dealt with briefly in the following section.

METHODS OF FIRING AND COMBUSTION EQUIPMENT

Boilers can be either (a) hand-fired, or (b) mechanically fired.

(a) Hand-firing

In hand-firing, the fuel is thrown on to the grate with a shovel, and the ash and clinker removed at intervals, depending on the ash content and character of the fuel and the rate of firing. For most efficient operation, the frequent firing of small quantities of fuel is essential and, generally speaking, the better the fireman, the more often he fires the boiler. Hand-firing is a skilled job, and a good fireman can not only get the best out of the plant, but also save fuel. The correct thickness of the fuel bed is an important factor in the efficient operation of a hand-fired grate. It depends largely on the quality of the fuel, and for each particular coal the most suitable fuel bed thickness should be determined by experiment.

There are three main methods of hand-firing, known as the

(1) sprinkling method,
(2) side-firing or wing-firing method, and
(3) coking method.

In the first method, the coal is sprinkled over the whole of the fuel bed. In this way, high boiler output can be obtained with quick response to sudden variations in steam demand. This method of firing is particularly useful with low-volatile fuels.

With the side- or wing-firing method, the grate is fired alternately on either side. This method is fairly widely used, as there is less tendency to produce smoke, although the steam output obtained is rather less than with the first method. For high-volatile " smoky " fuel, the coking method of firing is used. Here the fresh fuel is piled in front of the grate to a depth of about 10 inches and is allowed to coke, before being pushed forward on to the active part of the grate. In this way, very little smoke is produced, as the volatile matter is distilled off and burned as it passes over the hot fire at the back of the grate. The output obtained with this method of firing is lower than with the other two methods, and fluctuating loads cannot be dealt with so easily.

In the past, most hand-fired furnaces have been operated by natural draught, in which the air is drawn through the grate by the pull of the chimney. In an effort to increase the firing rate and for the purpose of dealing with a wider variety of fuels, forced draught produced by steam jets or fans is being increasingly employed. A typical forced draught hand-fired furnace as applied to a Lancashire boiler is shown in Figure 50. The air is forced up between specially shaped firebars by means of steam jets. While steam jets are not too efficient as a method of producing forced draught, the steam in the combustion air has a beneficial effect by keeping the fuel bed open, reducing the clinker and preventing the firebars from overheating. There are many ingenious designs of forced draught grate on the market, each of which possesses special advantages in relation to the burning of a particular class of fuel.

Best performance with many of the firing appliances available can only be obtained by the use of balanced draught, i.e., by a combination of induced and forced draught, so adjusted that the pressure over the fuel bed is substantially atmospheric, the forced draught fan overcoming the resistance through the fuel bed, and the induced draught supplying the suction necessary to overcome the resistance of the flues, the economiser and the chimney. The balanced draught system tends to reduce the amount of excess air entering the furnace or infiltrating through leaky brickwork, thus increasing the percentage of CO_2 in the flue gas, with a corresponding improvement in boiler efficiency.

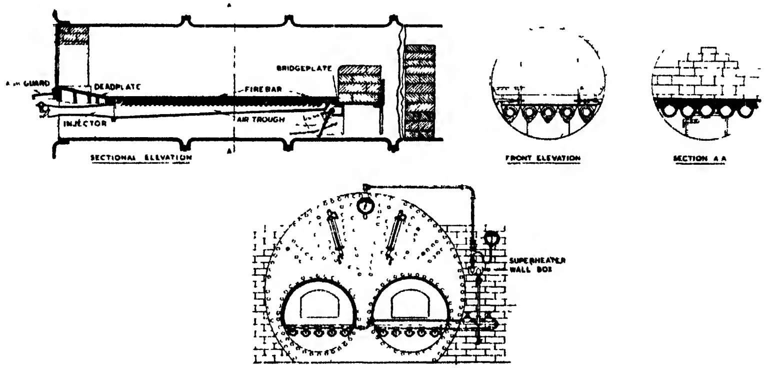


Figure 50.—Typical forced-draught, hand-fired furnace as applied to Lancashire boiler

(b) Mechanical Firing

The movement towards increased output and better performance from industrial boiler plant has resulted in the development of many types of mechanical stoker, some of which are combined with self-cleaning grates. By their use, the admission of excess air is reduced, as the furnace door does not have to be opened for fuelling or, in the case of self-cleaning stokers, for ashing. Thus, higher boiler outputs and higher efficiencies are obtained.

The choice of mechanical stokers is very wide, but they can be divided broadly into the following main groups:

(i) underfeed stokers,
(ii) overfeed stokers, and
(iii) chain grate stokers.

(i) Underfeed Stokers

In the underfeed type of coking stoker, the coal is conveyed from the hopper, along a retort trough and fed from underneath by means of a reciprocating ram or screw feeder. As the raw coal is forced up through the fuel bed, it is coked and combustion subsequently completed on an inclined grate, from which the solid residue is withdrawn. Air is supplied through tuyeres around the fuel bed, under the impulse of a forced draught fan. A cross-sectional view of a typical underfeed stoker is shown in Figure 51, while Figure 52 illustrates the application of a screw-type underfeed stoker to an Economic boiler.

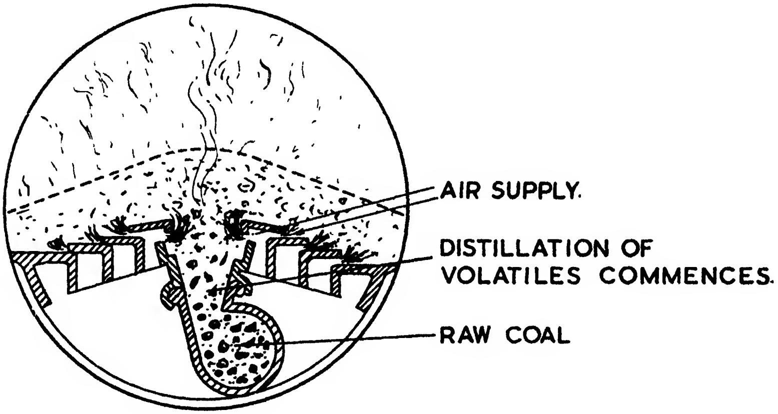


Figure 51.—Cross-sectional view of typical underfeed stoker of screw type

The underfeed type of stoker can be made in very small sizes, and while perhaps it finds widest application in boilers for central heating and hot water supply, it can also be applied successfully to shell boilers for steam raising. The most suitable fuel for this stoker is a graded, free-burning, bituminous coal of low swelling index. The grading of the fuel depends largely upon the size of the stoker. A highly swelling and coking coal gives rise to the formation of large masses of coke on the top of the fuel and the so-called phenomenon of "cauliflowering." The ash content of the fuel should not be excessive, as this often results in considerable heat loss due to unburned carbon in the ash and clinker.

(ii) Overfeed Stokers

This class of mechanical stoker can be sub-divided into three main types:

(a) Coking type,
(b) Sprinkler or spreader type,
(c) Chain-grate and travelling-grate stokers.

(a) Coking Type Overfeed Stokers

In the coking stoker, the coal is fed by means of a ram or other feeding device on to a coking plate. Here, it is coked in mass, the volatile matter being driven off and burned over the incandescent fuel bed. As feeding continues, the coked coal is pushed off the coking plate on to the grate. Combustion air is supplied either by natural or induced draught or by steam jet or fan forced draught. This type of stoker is usually made with a self-cleaning grate in which the fuel is moved forward by the reciprocating action of some or all of the firebars, the ash being dumped over the back of the grate into the ashpit.

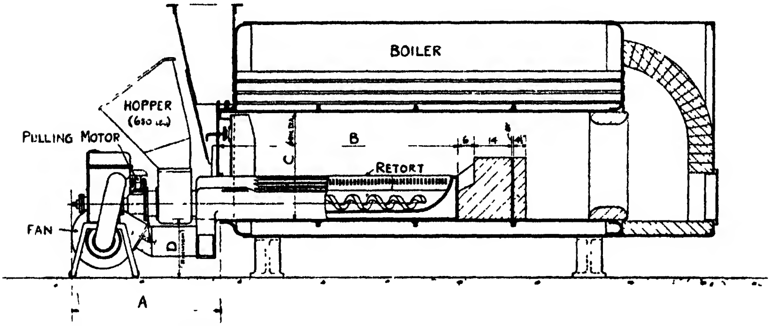


Figure 52.—Application of a screw type underfeed stoker to an Economic boiler

A typical coking stoker with a self-cleaning grate as fitted to a Lancashire boiler is shown in Figure 53. The fuel is fed into the hopper and delivered on to the dead plate by means of a pusher or ram. After coking, the fuel is moved forward by the specially shaped firebars which have a reciprocating motion imparted to them by a series of cams fitted to the driving shaft. The ram and the firebars are driven by a motor through gear boxes. The rate of coal feed and the speed of the firebars can be altered by varying the travel of the ram and changing the speed of the motor. There are also a number of other designs of coking stokers available, but they are not all fitted with self-cleaning grates. In one forced draught design, the feeding ram moves right through the burning fuel bed and thus prevents the formation of coked masses on the grate.

The coking stoker, as its name implies, was designed primarily for coking coals or coals with pronounced caking properties, but its use is by no means confined to this class of coal. Steam jets are not usually employed, except to combat clinkering with coals having a low melting point ash. While close uniform grading of the fuel is not of major importance, best results are obtained with 1 in. washed singles or ½ in. washed smalls of reasonable ash content.

(b) Sprinkler or Spreader Type Stokers

In this type of stoker, the coal is distributed over the fuel bed, emulating the conditions obtained with hand-firing.

In the sprinkler type, a mechanical " shovel " projects small quantities of coal at a time on to the fuel bed. The fuel is fed to the " shovel " by means of a feeder plate which can be regulated to supply the amount of fuel required. The movement of the shovel is controlled by cams and springs which regulate the distance to which the coal is thrown. By suitable adjustment, the fuel can be fed practically over the whole of the grate area. The sprinkler stoker can be operated on natural or forced draught, and certain designs have self-cleaning moving grates.

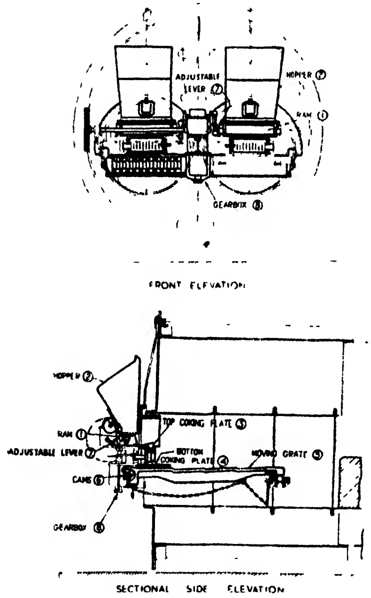


Figure 53. — Typical coking stoker with self-cleaning grate as fitted to Lancashire boiler

In the so-called " spreader " stoker, which is a recent development of the sprinkler stoker, the fuel is projected on to the grate by a revolving rotor so designed as to produce a uniform fuel bed of consistent thickness. An interesting modification of the type is shown in Figure 54. This has a special segmented grate in which the air supply to each element is controlled by automatically operated dampers. By this means, excess air admission is reduced when the fuel bed becomes thin, and therefore a high CO_2 can be maintained over a wide range of conditions. Spreader stokers are not usually made with moving grates, although dumping bars are sometimes employed. With these, the ash is periodically discharged by upturning separate segments of the grate in turn. Spreader stokers with dumping grates and chain conveyors to remove the ash have recently found favour in large water tube boiler installations.

The spreader type of stoker is capable of burning a wide variety of fuels, and can be adjusted quickly to suit rapid variations in load. Free burning and coking coals can be used and the grading is only limited by the size of fuel which will pass through the feeding device. As the coal is allowed to fall on to the fuel bed, there is a tendency for small particles to become airborne and to be carried forward with the combustion gases. Dust problems, particularly at high ratings, are therefore generally accentuated with this class of combustion appliance.

(c) Chain-grate and Travelling-grate Stokers

The chain-grate stoker consists essentially of a continuous chain, made up of special links, moving horizontally over end sprockets or rollers. As it passes under the feed hopper, at the front of the boiler, fuel is fed on to it and carried forward into the combustion chamber. Air is supplied through the spaces between the links and, by correct adjustment of grate speed and draught, the fuel is completely consumed by the time it reaches the back of the grate. The ash and clinker are discharged into the ashpit as the grate begins to make its return journey to the front of the boiler. Figures 47 and 55 show the application of a chain-grate stoker to a water-tube boiler.

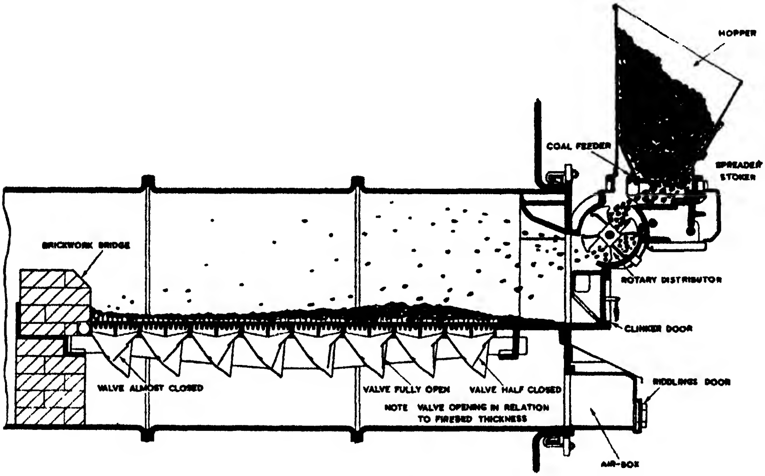
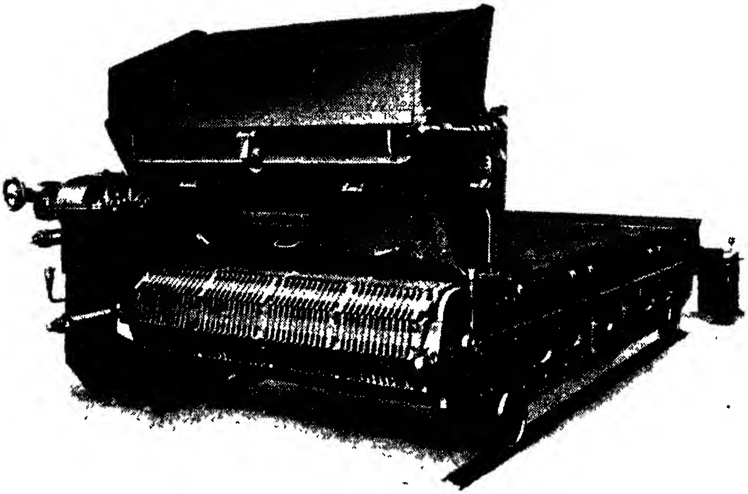


Figure 54.—Spreader stoker fitted to Lancashire boiler

This stoker can deal with a wide variety of fuels, provided the combustion chamber is designed to suit the range it is intended to burn. It is ideally suited to the combustion of medium ash, free-burning coals, but difficulty is often experienced with slow-burning and highly swelling coals. The chain-grate stoker is generally applied to water-tube boilers, but has recently been developed in its application to shell-type boilers.

PULVERISED FUEL FIRING

Reducing the coal to a fine powder by grinding makes it possible to obtain almost ideal combustion, without smoke and with the minimum amount of excess air. The pulverised coal is blown into the combustion chamber by the primary air supply through a suitable system of burners. Here it meets a secondary and, in some cases, a tertiary air supply, the fine particles of fuel being burned in suspension. The ash is removed, either in the form of a slag, or is deposited in powdered solid condition at the bottom of the combustion chamber. With pulverised fuel-firing thermal efficiencies of 90 per cent. and over have been obtained on large installations.



[BY COURTESY OF BABCOCK AND WILCOX, LTD

Figure 55.—Chain-grate stoker with coal hopper for fitting to water-tube boiler

OIL FIRING

Compared with the number of coal-fired installations, there are few oil-fired boilers in this country, but this method of firing is being increasingly employed. In order to burn fuel oil successfully, it is essential that it should be atomised.

This can be done by one of the following methods:

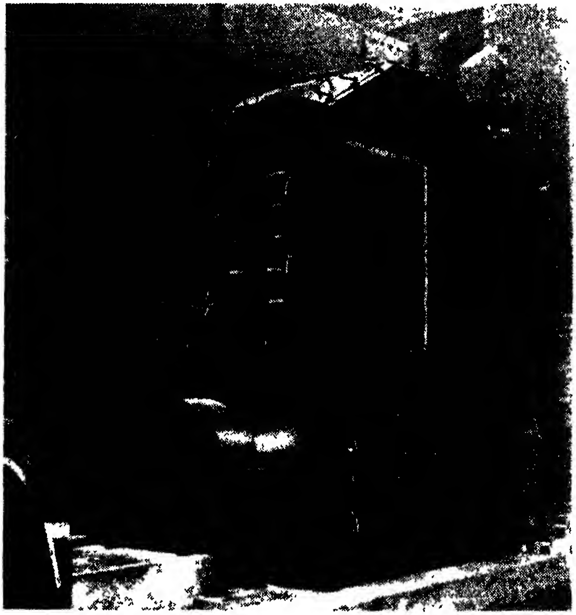
(a) By steam jets, the supply of steam being controlled by means of a valve attached to the air distributor;

(b) by compressed air, the oil being brought to the burner by gravity and sprayed by air under pressure; and

(c) by pressure-jet atomisation, in which the oil is sprayed under high pressure through a specially designed orifice. The oil is made to flow more readily by heating it in the storage tanks or on its way to the burner.

AUXILIARY EQUIPMENT FOR STEAM RAISING PLANT

The fundamental idea in the design and operation of a boiler plant is to extract the maximum possible quantity of heat from the fuel, which implies that the heat carried away by the products of combustion leaving the plant is reduced to a minimum. In a Lancashire boiler, the gases leave the boiler at a temperature which may be as high as 1,000° F., representing a possible loss to the atmosphere of about 30 per cent. of the total heat in the fuel. In an efficient plant, part of the heat in the escaping gases is recovered by passing them through an " economiser," in which the feed water is raised to a temperature approaching that of the water in the boiler. In this way, the overall thermal efficiency of the plant can be increased by 10 per cent. or more. An economiser, as applied to a Lancashire boiler, is shown in Figure 56. Economic boilers are usually operated without an economiser, as the temperature of the gases leaving the boiler is lower, but, even so, in certain cases, with this type of boiler, an economiser may often be fitted with advantage.



(BY COURTESY OF SENIOR ECONOMISERS, LTD

Figure 56. — Economiser for Lancashire boiler during erection before brickwork is completed

Where very high efficiency is sought, the exit flue gas temperature may be further reduced by passing the gases through an air heater, in which more heat is recovered and the overall efficiency of the plant correspondingly increased. Preheating the combustion air not only raises the furnace efficiency by reducing the loss due to excess air and to unburned carbon in the ash and clinker, but also improves the rate of heat transfer by raising the fuel bed temperature.

Most of the heat-using industrial processes employ saturated steam even where back pressure power generating plant is installed. In such cases every care should be exercised in obtaining dry steam from the boiler by avoiding the conditions favourable to priming, i.e., overloading the boiler, failing to control the quality of the boiler water, etc., as moisture in steam leads to the wrong assessment of boiler performance and to inefficiency and waste on the production end of the plant. In certain industries, especially where condensing power plant is installed, superheated steam is employed, the degree of superheat depending upon the needs of the case. In some instances, superheaters are fitted to the boiler plant merely to ensure that dry saturated steam reaches the point of usage.

In a Lancashire boiler the superheater, which is merely a bank of tubes through which the steam from the boiler passes on its way to the main header. picking up heat as it goes, is usually installed in the downtake, while in the Economic boiler the superheater is usually located in the combustion chamber and is often protected by refractory brickwork from direct impact of the combustion gases. In a water-tube boiler the superheater is usually placed behind the first bank of water tubes. It will be understood that as the superheater extracts additional heat from the flue gas, the efficiency of the boiler plant is correspondingly increased.

In the operation of a boiler it is important that the water level should be maintained constant and all boilers should be fitted with automatic feed regulators, several satisfactory designs of which are available to operate in conjunction with both steam driven reciprocating pumps or turbine or motor driven centrifugal pumps.

In the lay-out of a steam raising plant it is important that arrangements should be made for the return of all condensate to the boiler hot well as this results in substantial savings in fuel, apart from which it reduces the amount of make-up water required and lowers the cost of feed water treatment.

Every boiler is provided with a number of fittings, including a safety valve for preventing the development of excess pressure in the boiler, fusible plugs, high and low water alarm, water gauges, a steam stop valve and a feed check valve.

Finally, a word about instrumentation. A boiler house without instruments is like a ship without navigational equipment. Instruments assist the boiler operator to discover, estimate and often reduce or eliminate thermal loss. For satisfactory recording a boiler plant should be equipped with steam and feed water meters, draught gauges, CO_2 indicators and temperature indicators or recorders for water, steam and flue gas. In addition, means should be available for determining the quantity of fuel burned. From the readings of these instruments, and their intelligent interpretation, the efficiency of the plant can be checked from time to time and a high standard of performance maintained.

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Chapter XI

CARBONISATION AND GASIFICATION

by D. MACDOUGALL* *and* H. BARDGETT†

THE CARBONISATION OF COAL

Introduction

COAL is carbonised with the main object of converting it into products which can be utilised with improved efficiency, and of recovering valuable by-products which are generally lost when raw coal is consumed. The process involves heating of coal, out of contact with air in retorts, chambers or ovens, to a temperature well above that at which decomposition commences. As a result of the treatment the volatile products are distilled from the coal and recovered as gases and liquids, leaving coke as a carbonised residue. If the temperature of treatment does not exceed about 650° C. the process is referred to as Low Temperature Carbonisation in which the primary object is generally the production of a reactive smokeless coke suitable for domestic use. If, however, as is more general, the coal is heated to temperatures of 1,000° C. or higher, the process is that of High Temperature carbonisation as practised in both the Gas and Coking Industries. The main object in the Gas Industry is the production of " Towns " gas for lighting and heating in domestic and industrial use, while the Coking Industry aims mainly at the production of coke suitable for use in metallurgical furnaces and foundries and in industrial processes.

The carbonisation process is similar in principle in both of these industries, the main differences in practice being in the form of plant used and in the selection of the type of coal which will give a high yield of the main product having the desired properties.

It has been realised more fully in recent years that the functions of these two industries may overlap to a considerable extent and more attention is being devoted in each to the secondary products. The coke produced in gas manufacture is not in general suitable for replacement of the hard coke used in metallurgical processes, but the Gas Industry is paying increasing attention to the operation of its process and to the treatment of the coke produced

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so as to make " gas coke " more widely applicable, particularly in the domestic sphere to which market much coke-oven coke is also directed. An increasing proportion of the gas produced by the coking industry is being supplied as " Town's " gas and for industrial purposes. Whereas about half the gas produced in this industry used to be burned to waste, in 1945 nearly 25 per cent. of that produced was supplied to Gas Undertakings.

The scale of operations in high temperature carbonisation processes is indicated by the fact that of the total coal production of 183 million tons in 1945, 21 and 20 million tons were carbonised in the gas and coking industries respectively.

Gas Manufacture

The use of coal-gas for illumination dates back to about the end of the 18th century. The gas industry, which at present produces nearly 400 thousand million cu. ft. of gas per annum at over one thousand undertakings, may be said to have originated in 1812 with the grant of a charter to The London and Westminster Gas Light and Coke Co., now The Gas Light and Coke Co. In early days of the industry coal was carbonised in small horizontal cast-iron retorts heated to about 600° C., and the process was essentially that of low-temperature carbonisation. Under such conditions the yield of gas was low but the gas contained a high proportion of heavy hydrocarbons and had in consequence a high illuminating power. As gas was at that period supplied on a basis of its illuminating power, that property was desirable, and luminosity of the gas flame was often enhanced by using at least a proportion of cannel coal in its production. The low yield of gas resulting from the low temperature of treatment of the coal led to attempts at improvement by increase of carbonisation temperatures. A limiting factor, however, was the life of the metal retorts used, which was no more than a few months when they were heated to 800° C. Retorts of fireclay, allowing for temperatures up to about 950° C. began to be used about 1850. Progress towards the application of higher carbonising temperatures, with consequent increase of gaseous output, was much stimulated by the advent of the Bunsen burner and the Welsbach incandescent gas mantle, both of which decreased the importance of luminosity in the gas flame. These factors, together with improvements in the production of refractories to withstand much higher temperatures, led to progressive improvement of the yield of gas. Present day refractories allow of the application in modern carbonising plants of temperatures up to about 1400° C.

The increased use of gas for purposes in which its heating power, rather than its illuminating power, was of primary importance led early in the present century to the substitution of a heating value standard for the former illuminosity tests. The Gas Regulation Act of 1920 included a provision making it obligatory for gas companies to charge for gas on a heat unit basis. Gas companies now supply gas at declared calorific values which vary widely from 200 to 600 B.Th.U. per cu. ft., but which are mostly between 450 to 520 B.Th.U. per cu. ft. A company having selected its declared value is required to maintain this standard under penalty. The basis of charge is the " therm," equivalent to 100,000 British Thermal Units; 1,000 cu. ft. of gas of declared value 500 B.Th.U. per cu. ft. is thus equivalent to 5 therms.

Modern plants for coal-gas production may be classified broadly into two main types, static or continuous, depending upon whether the coal remains stationary or moves continuously during carbonisation. Plants of the former type include horizontal or inclined retorts and intermittent vertical chambers. Horizontal retorts are the most common of this type in the industry but they have been displaced to some extent in recent years by the intermittent vertical chambers. Inclined retorts are nowadays little used in this country and will, therefore, not be considered in this account.

Continuous carbonisation is effected invariably in vertical retorts—the so-called continuous vertical retort. During carbonisation in this type of plant steam is passed upwards through the descending charge of coal continuously during the whole process. Steam serves the double purpose of increasing the yield of gas by the formation of water-gas as the result of interaction with hot coke, and of cooling the coke before discharge. In intermittent systems steam may be introduced only during the last few hours of the period of carbonisation of the static charge when the coke has reached a high temperature. Steam is generally introduced in this way to intermittent vertical chambers but not usually to horizontal retorts.

A recent type of plant, the static vertical retort is an attempt to combine the advantages of the intermittent vertical chamber (for example the ability of the latter to treat coal of small size and to deal satisfactorily with crushed blends of coals) with those of the continuous vertical retort, namely continuous steaming and extraction of cool coke. It may well be that in future an increased proportion of the coal used for gas making will be used in retorts of this type.

Carbonisation in coke ovens is a form of static treatment used in this country mainly for coke production at collieries and ironworks and not generally for gas manufacture, although the largest London Gas Company has used coke ovens for several years in the production of a portion of its gas output and another is at present erecting coke ovens for this purpose.

Horizontal Retorts

Horizontal retorts have been superseded in recent years to a large extent by continuous vertical retorts and to some extent also by intermittent vertical chambers. They are, however, still used for the carbonisation of about 40 per cent. of the coal used in gas manufacture and have certain advantages, particularly in the smaller works. Modern horizontal retorts are made of high quality siliceous fireclay or silica and are usually about 20 ft. long and of section 23 × 16 in., the section being of ⌓ shape. Each end of the retort is fitted with a metal mouthpiece closed by a cast-iron door and with a water-sealed ascension pipe through which the volatile products of carbonisation are withdrawn. The retorts are erected in settings containing, for example, ten retorts in two vertical rows of five retorts each. A battery consists of a number of such settings.

Heating of the retorts is by means of producer-gas made from some of the coke produced. The producer-gas is burned with preheated air in a combustion chamber between the rows of retorts, the gaseous products of combustion passing round the retorts, and maintaining them at the working temperature. The combustion chamber temperature is generally about 1,350° C. Heat in the waste-gases is utilised, firstly to preheat the combustion air to about 700° C. in recuperators built under the retort setting and then to raise steam in a waste heat boiler, the waste gases finally being discharged to the stack at a temperature of about 230° C. The retorts are charged in rotation through the doors at one end by a charging machine which inserts a measured charge of coal, generally 12–13 cwt. Immediately on charging a retort the doors are closed and both ascension pipes, sealed while the retort doors were open, are put into communication with the collecting system. The charge is carbonised for a period which is generally about 12 hours. The volatile products of carbonisation are withdrawn continuously at both ends of the retorts. The tar and water vapours carried in the gas stream are first removed by cooling the gas, which is then further cleaned by water washing. Residual tar is removed in extractors, which in modern plants may take the form of electrostatic precipitators operating at very high voltage. Benzol may also be recovered from the gas by washing with oil or by passing the gas through active carbon. The gas is finally purified from sulphuretted hydrogen by passage through beds of iron oxide, contained in a series of metal purifier boxes, and is then passed to the storage holder for distribution. At the end of a carbonising period, the ascension pipes are sealed, the retort doors opened, and the hot coke discharged by means of a ram and quenched with water. When necessary, some of the hot coke is discharged directly to the producer. Figure 57 shows a battery of horizontal gas retorts in which can be seen the metal doors and the gas offtake pipes at one end.

Intermittent Vertical Chambers

Intermittent Vertical Chambers (sometimes called Chamber Ovens) are rectangular in section and carbonise static charges of coal of from 2 to 5 tons. They taper uniformly from bottom to top to facilitate discharge of the coke. A chamber 21 ft. high, 9 ft. 7½ in. × 8 in. at the top and 10 ft. × 12½ in. at the bottom will hold 3¾ tons of coal and will carbonise 5½ to 8¼ tons per day, depending upon the nature of the coal used and the calorific value of the gas required. The chambers are made of high quality silica and are heated by burning producer-gas with preheated air in a series of horizontal flues on each side of the chamber, the temperatures in the flues being generally 900°–950° C. at the top and 1,300–1,350° C. at the bottom. Each chamber is equipped with a hinged bottom door which can be swung back hydraulically to allow coke to drop out, and with two or more charging openings at the top. Gas offtakes are provided at both top and bottom of the chamber. The chambers are built in settings containing up to seven chambers each, each setting being heated by gas from a producer and being equipped with recuperators for preheating the air.

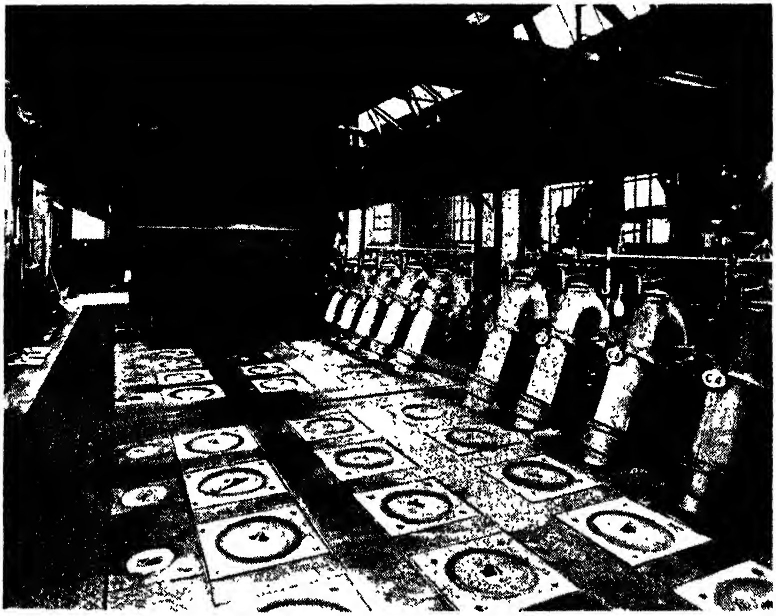
Before charging coal to a chamber, a pad of coke breeze is first introduced to cover the bottom door and to ensure that the bottom of the coal charge is within the heated zone of the chamber. The coal is then introduced and carbonised for a period which is frequently about 12 hours, during the last two or three hours of which steam is introduced at the bottom of the chamber. The steam reacting with the hot coke forms water gas which lowers the heating value of the gas from the charge but increases the overall output of therms. The required calorific value of the gas is controlled by adjustment of the proportion of steam used. When carbonisation is completed, the coke is discharged into a car and quenched with water. Figure 58 shows a photograph of the top of a setting of Woodall-Duckham intermittent vertical chambers in which can be seen the coal charging car, the charging openings and the top gas offtakes.

[BY COURTESY OF THE INSTITUTION OF GAS ENGINEERS

Figure 57.—Battery of horizontal gas retorts showing metal doors and gas off-takes

Continuous Vertical Retorts

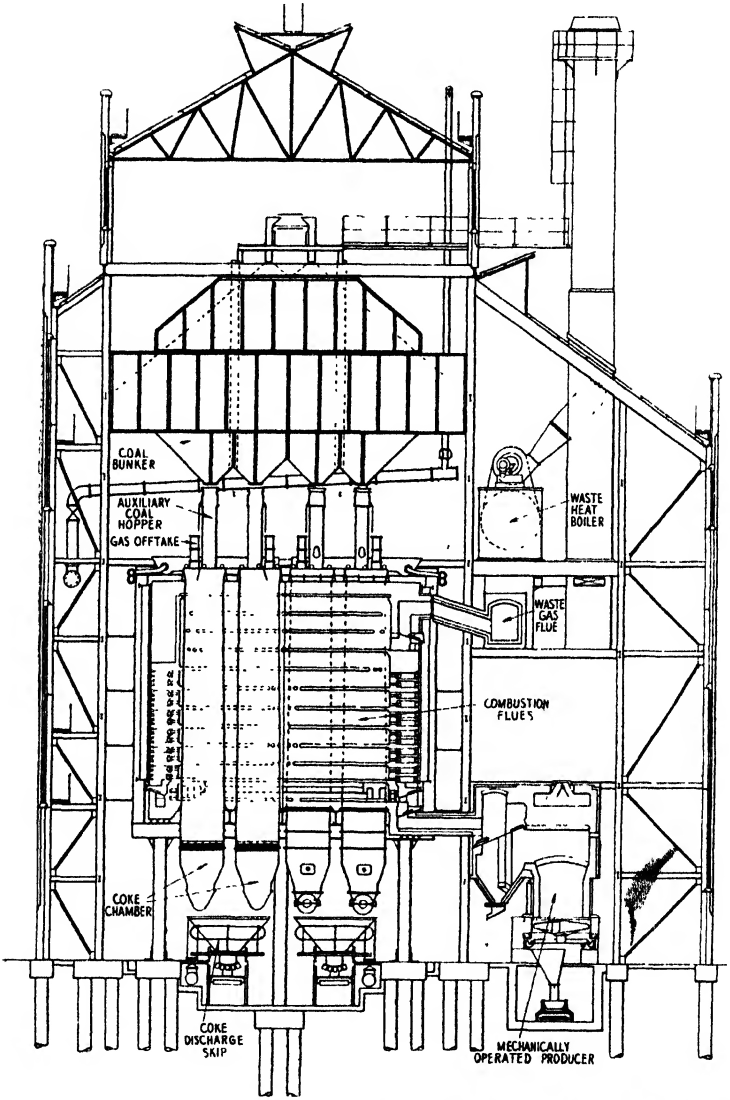
The system of carbonisation now most used for gas manufacture is the Continuous Vertical Retort, which since its introduction some 40 years ago has steadily gained favour and at present treats about 50 per cent. of the coal carbonised in the Gas Industry. It has many advantages over static systems, the most outstanding of which are perhaps cleanliness and absence of coal dust and smoke, flexibility from the point of view of producing gas over a wide range of calorific value, and a relatively large gas output from a given area of ground space. Modern retorts are of high grade silica and may be either rectangular or oval in cross-section, widening towards the bottom to facilitate uniform descent of the charge of coal. Throughput of coal may be up to 12 tons per day per retort in a retort 10 in. wide and of major axis 103 in. at the top.



BY COURTESY OF THE WOODALL-DUCKHAM COMPANY, LTD

Figure 58.—Top of a setting of Woodall-Duckham intermittent vertical chambers

Coal charged to the top of the retort moves continuously downwards by gravity at such a rate that by the time it reaches the bottom it is fully carbonised. The coke is discharged continuously from the base of the retort by means of an extractor mechanism and falls into a closed metal cooling chamber which forms an extension of the lower part of the retort. The coke is cooled by steam supplied continuously to the coke chamber. Steam



[BY COURTESY OF WEST'S GAS IMPROVEMENT COMPANY

Figure 59. — Vertical section of modern installation of Glover-West vertical retorts reacting with hot coke produces water-gas which mixes with the coal-gas and volatile matter evolved from the coal and the mixed gases and vapours rise through the charge and are withdrawn at the retort top. Cool coke is discharged at intervals from the cooling chamber. The rate of travel of coal through the retort is governed by the rate of extraction of coke into the cooling chamber, and can be varied by adjustment of the extractor speed. Coal falls into the retort from an auxiliary hopper which is charged at intervals and the rate of movement of coal through the retort is observed by noting the rate of fall in the auxiliary hopper.

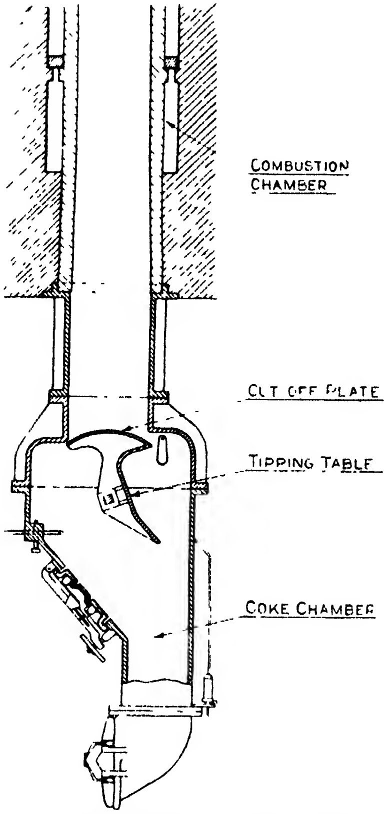
The latest type of Glover-West vertical retort is fitted with a new type of coke extracting mechanism known as the Sector Discharger, which operates in such a way that coke is discharged from the retort to the coke chamber at intervals, which may be set at from 30 to 60 minutes, instead of continuously. This discharger, which comprises a tipping table and cut-off plate, supports the charge on the table when in the normal at rest position. Rotation of the discharger to the tipped position allows a measured volume of coke to fall into the coke chamber, during which time the cut-off plate supports the charge. The table then returns to the original position, allowing the charge in the retort to fall and coal from the charging hopper to enter the top of the retort. With this type of extractor the coal in the retort thus remains static for periods and falls during the operation of the discharger.

Heating of the retorts is by producer-gas burned in either horizontal or vertical flues. The flue temperatures vary up to about 1,350° C. and the highest temperature may be either at the top or the bottom, depending upon the system adopted. In modern settings the retort seating and supporting steelwork are cooled by circulation of the air prior to its admission to the flues. Continuous vertical retort settings are not usually equipped with recuperators for air preheating, but the heat in the burned heating gases is utilised in waste-heat boilers for raising steam for process use. The calorific value of the gas produced in vertical retorts is controlled by regulation of flue temperatures, of coal throughput, and of the amount of steam supplied.

A vertical section of a modern installation of Glover-West vertical retorts is shown in Figure 59. Figure 60 illustrates the Sector Discharger in the tipped position.

Static Vertical Retorts

A type of retort which is intermediate in character between an intermittent vertical chamber and a continuous vertical retort and which aims at combining the advantages of both, is the Static Vertical retort of the Woodall-Duckham Company and the Westvertical of Messrs. West's Gas Improvement Co., Ltd. Both systems are similar in general principle and consist essentially of a vertical externally heated silica retort of rectangular section superimposed on a brick-lined metal coke cooling chamber. The process is intermittent, a static charge of coal being carbonised for some 10 hours in the upper section. At the end of the carbonisation period coke already in the cooling chamber from a previous charge is discharged and this allows the retort charge to fall. The coke cooling chamber and the lowest portion of the heated carbonising section are thus occupied with hot coke. A fresh charge of coal is then introduced to the retort. Steam introduced to the coke cooling chamber cools the initially hot coke and reacts with the coke in the lower part of the retort, the water-gas produced passing upwards and mixing with the coal gas.



[BY COURTESY OF WEST'S GAS IMPROVEMENT CO

Figure 60.—Vertical section of sector discharger in the tipped position

Such a system has the advantage of the other static retorts that small sized coal or blends of coals can be carbonised without difficulty together with the additional advantage that continuous steaming, as in the continuous vertical retort, increases the thermal yield of gas and cools the coke before discharge.

Selection of Coals for Gas Manufacture

The type of coal most suitable for making town's gas is the strongly-caking coal of 30–40 per cent. volatile matter which gives a high yield of gas and a strong non-friable coke. In plant where the charge is static the coal used is frequently of small size, and where this is the case it is necessary that the caking power should be sufficiently high to ensure lump coke of good strength. In continuous vertical retorts it is preferable, for ease of operation and high throughput, that the coal should be sized or contain a fair proportion of sized coal. Where sized coal is used the caking power need not necessarily be high, and non-caking or weakly-caking coal in lump form carbonised in vertical retorts will often give coke of size similar to that of the coal used. Modern continuous vertical retorts will, however, deal with strongly-caking coal of small size although with such coal the throughput and gaseous output per unit of plant are decreased. In recent years there has been a tendency to extend the range of coals used for gas-making, in the direction of coals of lower caking properties. The general results of such substitution are a lower thermal yield of gas of lower calorific value and of higher density and a weaker coke with a higher proportion of breeze in the coke.

It is desirable from the points of view of ease of operation of retorts and of satisfactory control of the gas-making process that supplies of coal fed to the plant should be as uniform as possible as regards type and size. Marked variation in successive batches causes considerable difficulties, particularly in control of retort temperatures and heat distribution, and gives erratic coke qualities.

Coke Manufacture

Although coal has been carbonised to produce coke for at least three hundred years, primitive methods were still used up to about the middle of last century, and developments in modern oven chambers have been concentrated in this country very largely over the past 50 years. The earliest process was similar to that used for the production of charcoal from wood. Coal in large pieces was stacked in heaps around a central chimney. The heap was ignited and a portion of the coal burned to provide the heat necessary for coking. Admission of air and some control of combustion was obtained by covering the heap as necessary with small coal or coke breeze. After about ten days the heap was quenched and the coke withdrawn.

The next development was the brick-built beehive oven, so-called on account of its shape, which appears to have been first used about 1760; it was for long the dominant type of oven, and is still used to some extent at the present day. In the beehive oven a layer of coal 2–3 ft. deep on the floor is coked by the heat provided by burning a portion of the charge with air. The heat is reflected from the domed roof and the charge carbonises downwards from the surface. An oven taking a charge of 10 tons requires up to 72 hours to complete the coking. The coke is quenched within the oven, which, however, still remains hot enough to start the coking of the next charge. In both the heap method and in the beehive oven the process is wasteful in that some of the coal is burned and the coke yield is lower than in modern methods. Moreover the by-products are not recovered. In the present day beehive oven the coke yield has been increased by some 10 per cent. by utilising gas produced in the process to provide the necessary heat in external sole flues.

The production of coke for use mainly in the metallurgical industry is today largely carried out in modern types of by-product recovery ovens in which the heating gases do not come in contact with the coal. The modern oven consists of a rectangular silica chamber which may be up to 45 ft. long, 14 ft. high and of width 12–20 in., having a slight taper on the length to facilitate coke discharge, and taking a charge of coal up to about 17 tons. The oven, heated by burning gas in a series of flues on each side, is fitted at each end with refractory-lined metal doors which are removed when the coke is ready for discharge. Coal is charged generally through a number of openings in the top but in some ovens is charged through the end door in the form of a compressed cake. If the oven is top-charged the surface of the charge, some 12–15 in. below the oven roof is levelled through special openings in the doors. After charging the oven, the charging and levelling openings are closed and the oven is connected to the by-product recovery system, the latter being similar to that in gas-making retorts. When coking is completed, the block of coke is pushed from the oven by means of a ram either on to an inclined wharf or into a coke car and is quenched with water.

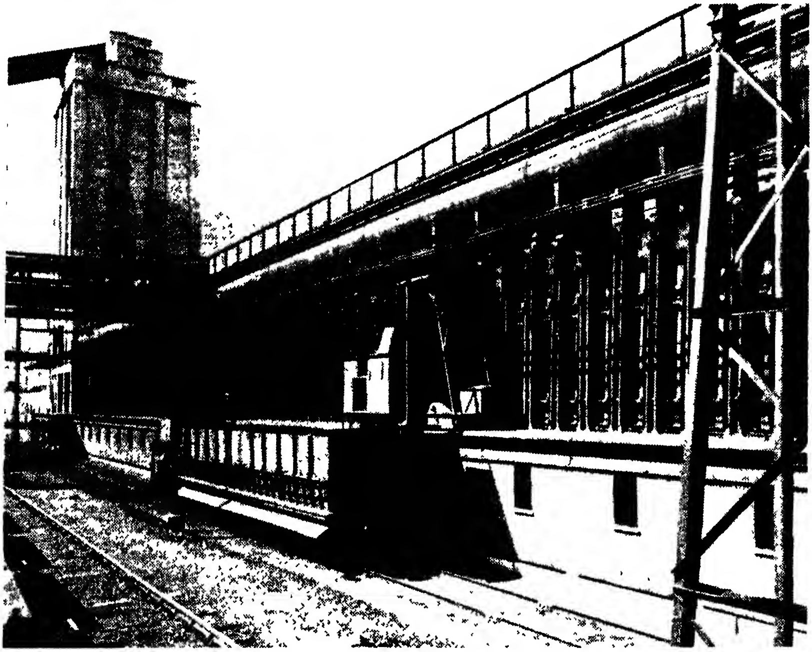
By-product ovens may be either of the regenerative or waste-heat types. The former make use of heat in the burned heating gases to preheat the air supplied for combustion of the fuel gas, while in the latter the heat recovered is used only for steam-raising. Regenerative ovens are equipped with regenerator blocks, built under the ovens, in which the hot waste gases give up heat to brickwork fillings. At intervals of 20–30 minutes, the direction of the flow of heating gases and air is reversed so that each regenerator is alternately being heated up by hot waste gases and is preheating the air. In compound regenerative ovens heating of the oven may be either by coal-gas produced in the process or by gas of lower calorific value such as blast-furnace-gas or producer-gas. If coal-gas is used, only the air for combustion is preheated, the coal-gas being supplied under control directly to the heating flues. When gas of low calorific value is used it is necessary to preheat both the gas and the air to ensure the required high flame temperature in the flues.

There are many different arrangements of heating flues and regenerators in the various makes of coke oven and the heating flues may be either vertical or horizontal. Ovens with vertical flues are the most popular type. Flue temperatures used are as high as possible up to about 1,400° C.

The period of coking depends upon the flue temperatures, the width of oven and the nature of the coal used; examples are 22 hours for an 18 in. wide oven holding a charge of 17 tons and 14 hours for a 14 in. oven taking 8 tons. The ovens are built side by side in batteries, the set of heating flues between the ovens each serving to heat one wall of adjacent ovens.

It is important, in order that the coke produced should be of good uniform quality and strength, that the coal charged should be of small size. Washed slack or run-of-mine coal crushed all below $\frac{1}{4}$ in. and having up to 80 per cent. below $\frac{1}{8}$ in. is generally used. The most suitable coals for the production of high-grade metallurgical coke are the strongly-coking coals of 20 to 30 per cent. volatile matter; those of Durham and South Wales giving the highest quality coke. Less strongly-caking coals of 30-35 per cent. volatile matter, such as in South Yorkshire, are much used and many coking plants are equipped with plant for blending different types of coals to give a mixture of suitable characteristics for the type of oven used. The narrower ovens appear to be well suited for the coking of the less strongly-coking coals at a high rate of coking. During recent years the preference in newly-built ovens has been towards widths of 17–18 in. and heights of some 13 ft. Of the 5,165 ovens in average monthly use in this country in 1945, 50 per cent. were of the regenerative type, 24 per cent. were compound regenerative, 21 per cent. were waste-heat ovens, and 5 per cent. were beehive ovens.

A photograph of the coke discharge side of a battery of 65 Woodall-Duckham Becker ovens is shown in Figure 61. The combined door-extractor and coke guide, quenching car and locomotive can be seen.



[BY COURTESY OF WOODALL-DUCKHAM COMPANY, LTD

Figure 61.—Coke discharge side of a battery of 65 Woodall-Duckham Becker coke ovens

PRODUCTS OF CARBONISATION

Typical yields of products and analyses of gases from Durham coal carbonised in different types of plant are shown in Table 17.

The characteristics of the coke depend both on the nature and size of coal carbonised and upon the plant. The strongly-caking coals give coke which is in general denser and less combustible than that produced from the weakly- or medium-caking types. With a given coal carbonisation in continuous vertical retorts, in which the coal is in constant motion and is continuously steamed, produces a coke which is appreciably more porous and more combustible than that produced in intermittent systems. The

TABLE 17

Products of Carbonisation in Different Types of Plant — Durham Coal

Type of Plant		Horizontal Retorts	Intermittent Vertical Chambers	Continuous Vertical Retorts	Static Vertical Retorts	Coke Ovens
Moisture in coal	per cent.	1.5	2.4	1.5	2.1	2.0
Steam supplied	per cent. of coal	nil	3.3	20.0	20.0	nil
Coke (total yield)	cwt. per ton of coal	14.5	13.9	13.8	13.1	15.1
(breeze)	” ” ” ” ”	2.0	1.5	1.4	1.9	1.6
Gas Volume	cu. ft. per ton of coal	13,180	14,320	18,640	18,710	11,000
Calorific value	B.Th.U. per cu. ft.	563	549	473	504	580
Specific gravity (air – 1)		0.40	0.43	0.42	0.40	0.40
Therms	per ton of coal	74.2	78.6	88.2	94.3	63.8
Tar	gal. per ton of coal	11.2	13.4	14.5	12.0	10.0
Specific gravity		1.121	1.124	1.108	1.178	1.150
Liquor	gal. per ton of coal	12.6	29.4	30.3	37.2	14.3
Ammonia as Sulphate	lb. per ton of coal	25	28	20	28	24
Fuel for heating	therms per ton of coal	41	37.7	35	—	32
	per cent. of coal	14	13.1	12	—	10.8
Gas Analyses						
Carbon dioxide		1.6	1.8	5.2	2.4	2.0
Oxygen		0.3	0.3	0.2	0.2	0.5
Unsaturated hydrocarbons		3.0	3.1	2.0	2.8	4.0
Carbon Monoxide		6.9	10.6	14.5	16.4	6.2
Hydrogen		52.9	55.3	54.2	52.9	53.2
Saturated hydrocarbons		30.2	23.1	19.2	19.9	26.7
Nitrogen		5.1	5.8	4.7	5.4	7.4

coke from coke ovens is characterised by exceptionally high strength and density, properties which are desirable in coke for metallurgical use.

Low Temperature Carbonisation

The term low temperature carbonisation implies the carbonisation of coal at temperatures up to 650° C. (1,080° F.). Carbonisation at low temperatures may be effected in retorts constructed of metal or firebrick, the retort being either heated externally by means of gas burned in combustion chambers surrounding the retorts or internally by hot combustion gases passed through the charge of coal. Retorts used have been of the vertical type with the charge of coal either stationary or in motion during its treatment and metal retorts of rotary type have also been employed. The products obtained are coke, gas, tar and aqueous ammoniacal liquor, each differing in properties from those obtained by treatment of coal at high temperatures.

The coal usually used is of medium-caking or non-caking bituminous type and may be of nut size or smalls. In plants in which the coal is carbonised by internal heating the coal employed must be of non-caking type so that the heating gases can pass easily and uniformly through the charge.

The coke is characterised by a high volatile matter content (about 10 per cent.), is more easily ignited and is more combustible than high temperature coke. It is smokeless and is a suitable fuel for burning in the open domestic grate, in modern type openable stoves, and in all types of small domestic boilers.

The gas produced in externally heated retorts is of high calorific value, 800–900 B.Th.U. per cu. ft. compared with gas of 450–560 B.Th.U. per cu. ft. usually made in gas retorts or in coke ovens. It contains relatively high proportions of unsaturated hydrocarbons such as ethylene, propylene, butylene, and of saturated hydrocarbons, methane, and ethane. When carbonisation is effected by passing hot gases through the charge the calorific value of the gas is low owing to dilution of the coal gas produced with the combustion gases used for heating the charge.

The tars produced differ appreciably in properties from those produced at high temperatures. They are of lower specific gravity and are mainly paraffinic in nature. They contain higher members of the series of compounds present in high temperature tars and contain a higher proportion of phenolic bodies and less free carbon. On distillation they give a lower yield of pitch. The liquor contains a low percentage of ammonia and is not utilised for the manufacture of ammonium sulphate. From plants carbonising coal at low temperatures, the yields of products vary appreciably, depending on the process adopted. Typical yields are shown together with those obtained in normal gas-works practice. (Table 18.)

In Great Britain, the quantity of coal carbonised at low temperatures in 1938 was approximately 0.5 million tons compared with about 38 million tons carbonised at high temperatures in the Gas and Coking Industries.

TABLE 18

Yields of Carbonisation Products at Low and High Temperatures

System	Low temperature carbonisation		High temperature Carbonisation
	External heating	Internal heating	External heating
Moisture in coal, per cent.	6—10	10—15	2—3
Coke, cwt. per ton of coal	13.5—15.5	8—12	13—15
Gas Volume, cu. ft. per ton of coal	2,500—4,000	30,000—50,000	13,000—20,000
Calorific value, B.Th.U. per cu. ft.	800—900	180—230	470—560
Therms per ton of coal	22.5—32	69—90	73—94
Tar, gal. per ton of coal	18—22	16—18	10—14.5
Specific gravity ..	1.00—1.04	1.04—1.06	1.09—1.18

PRODUCER-GAS

Producer-gas is manufactured by passing a mixture of air and steam through an incandescent bed of fuel, the oxygen of the air and the steam reacting with the carbon of the fuel to give a gas containing mainly carbon monoxide (CO), hydrogen (H_2), and nitrogen (N_2). The gas also contains carbon dioxide (CO_2) and methane (CH_4). As all the fuels employed contain sulphur, hydrogen sulphide (H_2S) is present in the gas but usually only to the extent of 0.10 to 0.15 per cent. by volume. The nitrogen and carbon dioxide contents together amount to about 60 per cent. by volume and as these are inert gases, the calorific value of producer-gas is low. When coal is employed as the fuel the calorific value of the gas varies from 140–160 B.Th.U. per cu. ft.

The gas is widely used in many industrial processes both for high and moderate temperatures. It is used in the steel industry for heating open-hearth furnaces, for heat treatment and annealing furnaces and in many different types of kilns and ovens. It is used in the gas industry for heating the retorts and for this purpose is manufactured from coke gasified in step-grate producers frequently built into the retort settings. It is also used in gas engines for the generation of power.

The generator for the manufacture of producer-gas usually consists of a vertical steel shell provided with a grate for supporting the fuel and with means for admitting air and steam at the base of the fuel bed with an outlet at the top for the gas generated. It may be entirely lined with firebrick or completely water-jacketed or partly lined for firebrick and partly water-jacketed. So many different types of producers have been designed to operate on various classes of fuels that it is not possible to classify them rigidly, but it has been suggested that the following classification includes most types at present in use:

1. Static—hand fed, hand poked and hand ashed.

2. Static or semi-mechanical—mechanically fed, mechanically agitated and levelled and hand ashed.
3. Mechanical—mechanically ashed, mechanically fed and mechanically agitated and levelled.

A further difference in types of producers relates to the method of raising the steam used in the blast.

(a) From an independent source.
(b) Generated in a water-jacket surrounding the producer shell.
(c) Generated in a vapouriser in which water is heated by the hot producer-gas after it leaves the generator.

The method of removal of ash from the producer, whether by manual labour or by mechanical means, defines the producer as either of the static or mechanical type. Many static producers of comparatively simple design can be operated successfully for the production of gas of uniform composition, provided good quality coal is employed and skilled labour is available, but the rate of gasification of the fuel is relatively low. With mechanical aids appreciably higher gasification rates can be achieved for producers of equal grate area; there is better control of gas quality, appreciable reduction in labour costs with better working conditions for the operators and the quality and type of coal which can be employed is less critical. With suitable coal a static type producer wholly manually operated can achieve with good practice a gasification rate of 15–20 lb. of coal per sq. ft. of grate area per hour, whereas with similar coal and mechanical aids a gasification rate up to 50 lb. can often be attained.

The Generation of Producer-Gas

The chemical reactions which take place when air and steam are passed through an incandescent bed of carbon are governed mainly by the temperature attained in the fuel bed and by the reactivity of the carbon to oxygen and steam. The uniformity of packing of the fuel bed, and the uniform distribution of the air and steam through the fuel bed are also important factors and require careful control if gas of steady composition containing a high percentage of combustible gases is to be obtained.

In Figure 62 a diagram of a producer is shown. The fuel bed may be subdivided into four zones: (a) the ash zone, (b) the oxidation zone, (c) the reduction zone, and (d) the distillation zone. These zones cannot be rigidly defined as they merge one into the other and vary in depth depending on the gasification rate, the size and the type of fuel, the type and quantity of the ash, etc. ✓The ash zone extends above the air-steam inlet and thus protects the distributor from the hot oxidation zone. The air and steam pass through the distributor, the ash is cooled and the air and steam preheated. It is important that the ash should be of relatively small size, free from large masses of clinker, so that uniform distribution of the air and steam can be obtained. In the oxidation zone the oxygen of the air reacts with the carbon generating heat and first forming carbon dioxide

(CO_2). The CO_2 thus formed reacts with a further quantity of carbon in the reduction zone with formation of carbon monoxide (CO). At the same time the steam is decomposed by the incandescent carbon with formation of carbon dioxide (CO_2), carbon monoxide (CO) and hydrogen (H_2), the amount of carbon dioxide formed depending largely on the temperature maintained in the bed of fuel. Interaction between hot carbon and steam absorbs heat and it is important that the bed of carbon should be maintained at a high temperature, at least 1,000° C., if the steam is to be decomposed efficiently and gas of high quality and of uniform composition produced.

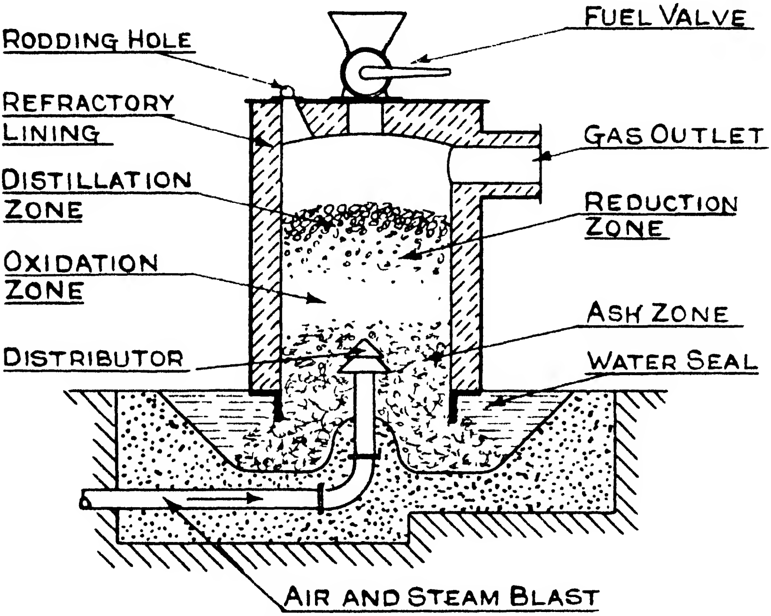


Figure 62.—Diagram of a gas-producer

The hot gases leaving the reduction zone pass upwards through the bed of fuel and come in contact with the raw coal, raising its temperature. By this means the volatile matter is distilled from the coal and mixes with the gases generated in the lower zones of the producer. The gas leaving the producer carries with it tar evolved from the coal, water of decomposition and any undecomposed steam. For certain industrial purposes, e.g. open hearth-steel furnaces, it is advantageous to utilise the hot gas in its tar-laden state. In such cases producers are operated with shallow fuel beds and are located as near as possible to the furnace in order that the sensible heat of the gas and the potential heat of the tar can be utilised. The calorific value of the gas containing tar is about 15 B.Th.U. per cu. ft. higher than that of gas which is cleaned by removing the tar and sulphur compounds.

Coals and Fuels Used

The quantity of coal used in this country for the manufacture of producer-gas has been estimated at 6–7 million tons per annum. In addition, high temperature coke and carbonised briquettes are used as producer fuels. Most types of coal can be utilised for the manufacture of producer-gas in mechanically operated producers, but with coals of strongly-caking properties, highly friable coals and coals containing ash which fuses at low temperatures, special methods are necessary for satisfactory producer operation and reasonable output of gas. The most suitable coals are those of weakly-caking type (Gray-King Assay Types C-E). (See Chart p. 132.)

Typical analyses of anthracite, low volatile steam coal and different types of bituminous coals are tabulated (Table 19).

Size Grading. Uniformity in size of coal for producer-gas manufacture is important. If coal of wide size range is employed, segregation will occur on charging, the larger sizes of coal tending to roll to the walls of the producer with the smaller sizes towards the centre. If this occurs the fuel near the walls of the producer will have a lower resistance to the passage of the gases and the major portion of the blast will pass upwards near the walls of the producer, resulting in uneven temperatures across the fuel bed. It is recommended that the maximum size should not much exceed twice the minimum size if highly efficient operation is to be accomplished. Suitable size gradings are $2\frac{1}{2}$ in.–$1\frac{1}{4}$ in. and $1\frac{1}{2}$ in.–$\frac{3}{4}$ in. for plants from which high outputs are desired. Graded coals of smaller sizes can be employed, however, in producers specially designed for the purpose, but the output of gas is lower than with coals of similar properties and of larger sizes. The presence of more than about 15 per cent. of fines (say below $\frac{1}{8}$ in.), should be avoided as their presence leads to decreased output, increased operating difficulties and other troubles resulting from carry-over of fine dust in the gas stream.

Moisture. It is important from several aspects that the moisture content of the coal should be as low as possible. The presence of moisture has no effect on actual operation of the producer, but it requires heat for its evaporation which must be obtained from the fuel. When raw producer-gas from high moisture coals is used, the presence of water vapour lowers the flame temperature of the gas.

Volatile Matter. The volatile matter of coals varies appreciably in amount and also in composition. Referring to Table 19, coals of the anthracite type on heating evolve volatile matter which is mainly gas with only relatively small amounts of tar and water of decomposition. As the volatile matter increases the amounts of tar and water evolved on heating increase. Anthracites are therefore more suitable for the production of cold, clean producer-gas as less elaborate cleaning plant is required. All the coals listed in Table 19 can be used for producer-gas manufacture, but the strongly-caking types which, when slowly heated in a producer, agglomerate to form large masses of coke, can only be gasified at satisfactory rates in producers

TABLE 19

Analyses of British Coals

Coal	Anthracite	Welsh Steam	Bituminous			
			Non-caking	Weakly-caking	Medium-caking	Strongly-caking
Analysis of dry ash-free coal						
Carbon, per cent. ..	90—94	89—93	78—81	81—82.5	82.5—84	84—89
Hydrogen, per cent. ..	3 0—3 5	3.5—4.0	5.1—5.6	5.2—5.6	5.2—5.6	4.5—5.5
Sulphur, per cent. ..	0.7—1.2	0.7—1 2	0.7—2.0	0.5—1.5	1 0—2.0	0.8—3.0
Volatile matter, per cent. ..	9 5—5 0	14—9	45—40	42—38	39—35	37—25
Calorific value, B.Th.U./lb.	15,250—15,600	15,500—15,750	13,860—14,400	14,400—14,670	14,670—15,030	15,030—15,660
Inherent moisture, per cent.	3—2	1 5—0 5	16—10	10—7	7—4	4—2
Ash, per cent.	7—2	7—3	11—4	12—1.5	9—3	13—6
Type of coke, Gray-King Assay	A	A—C	AB	C—E	F to G5	G2 to G9
Fusion temperature of ash In oxidising atmosphere ° C.	1310—>1450	1350—>1450	1200—1350	1250—1400	1300—1400	1350—>1450
In reducing atmosphere ° C.	1210—>1450	1300—>1450	1100—1350	1100—1300	1200—1350	1150—>1450

with mechanical aids to break up the coke as formed and thus give a uniform bed of fuel.

The coals most suitable and most commonly employed for producer-gas manufacture are those of the weakly-caking types (Gray-King Assay C-E) containing about 40 per cent. volatile matter. These coals evolve considerable quantities of tar on heating and the gas made is therefore most efficiently employed as hot raw gas in furnaces situated very near the producer. Cold, clean gas may also be prepared from weakly caking coals which give high yields of tar, but elaborate cleaning plant with purifiers, condensers, scrubbers, etc., is necessary to free the gas from the last traces of tar. The tar yield may in such cases amount to as much as 18 gallons per ton of coal gasified.

Ash. The temperature of fusion of coal ash varies considerably. Some coal ashes fuse at comparatively low temperatures, less than 1,100° C., while with others the fusion temperature may be 1,400° C. or higher. The fusion temperature is lower in a reducing atmosphere than in an oxidising atmosphere and it is the former value which must be taken into account when coals are being chosen for producer-gas manufacture. The difference may be as much as 200° C.

The minimum ash fusion temperature which will avoid formation of clinker cannot be stated with any certainty as many factors relating to the operation of the producer require to be taken into consideration. Formation of clinker is largely dependent on the manner in which the producer is operated but in general it is agreed that ash with a fusion temperature lower than 1,200° C. in a reducing atmosphere is likely to give trouble during operation at high rates of gasification. Coals which contain ash of this nature can, however, be utilised for producer-gas manufacture, but generally speaking such coals can only be gasified at reduced rates with a higher proportion of steam in the blast, which means a lower fuel bed temperature and thus the production of gas of low calorific value containing a high percentage of carbon dioxide. On the other hand, coal which contains ash having a fusion temperature above 1,300° C. should cause little trouble in operation.

Ash which forms clinker is objectionable as in the first place it traps carbon which is lost to the process. Secondly, when clinker is formed it causes the formation of a non-uniform fuel bed in the producer and thus a non-uniform resistance to the air-steam blast. This is likely to result in the formation of passages in the fuel bed (channelling). The formation of channels will result in hot spots in the fuel bed with resultant production of low quality gas, due to insufficient time of contact of the air-steam blast and the highly heated fuel. In addition, the formation of clinker results in increased wear of the brick lining of the producer.

Generally speaking, if it were possible to have a choice of fuels for producer-gas manufacture, the fuel to choose would be one containing a low ash content (below 10 per cent.) and with an ash fusion temperature of 1,400° C. or higher.

Sulphur. The sulphur content of coal is normally of the order of 1–2 per cent. Some of the sulphur is evolved from the coal on heating and some during gasification mainly as sulphuretted hydrogen (H_2S) and a small amount remains as sulphur compounds combined chemically with the ash of the coal. The amount present in producer-gas is usually 50–70 grains per 100 cu. ft. H_2S when burned forms sulphur dioxide (SO_2), which may be injurious to materials undergoing heat treatment. H_2S can be removed from the gas by water washing followed by passage through purifier boxes containing iron oxide.

Yields and Compositions of Producer-Gas

The yield of gas per ton of coal or coke gasified varies with the moisture and ash contents of the fuels fired. Under good operating conditions with bituminous coals of weakly-caking type and containing about 10 per cent moisture, and 6 per cent. ash a yield of 140,000–150,000 cu. ft. of calorific value 160 B.Th.U. per cu. ft. can be considered good practice. With anthracites, which normally contain less moisture and ash than bituminous coals, a yield of 165,000 cu. ft. can be obtained, but the calorific value of of the gas is slightly lower at 150 B.Th.U. per cu. ft.

Typical analyses of producer-gases obtained from coal and coke are given in Table 20.

TABLE 20

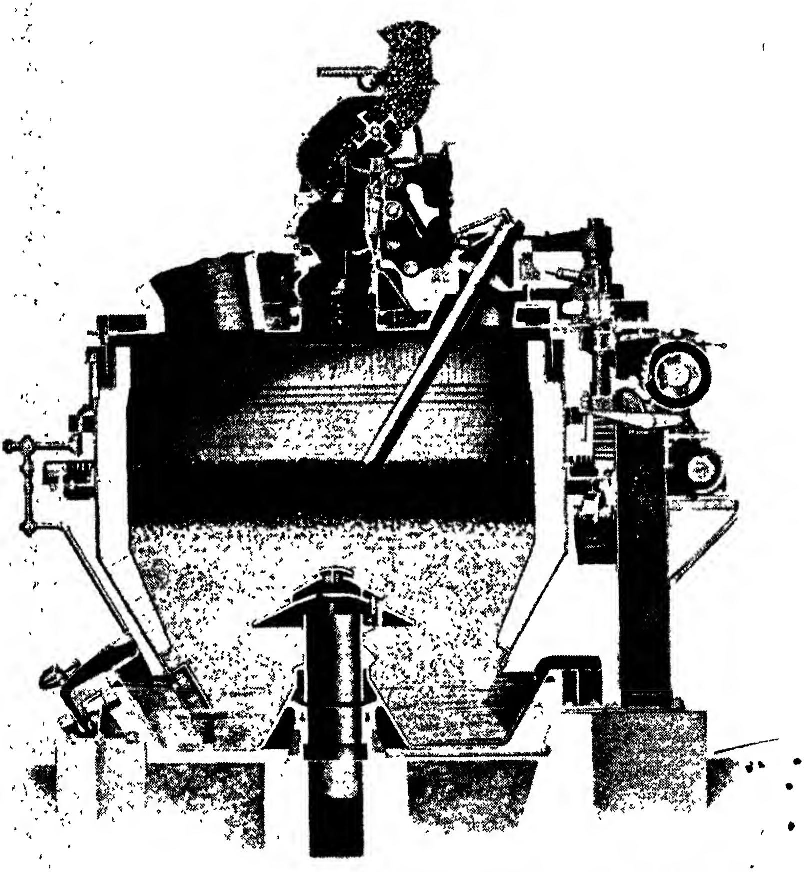
Analyses of Producer-Gases

Fuel	Anthracite	Non-caking bituminous coal		Coke
Gas analysis per cent. by volume		Static producer	Mechanical producer	
Carbon dioxide (CO_2)	5	9	5	5
Carbon monoxide (CO)	26	23	27	28
Hydrogen (H_2)	16	13	15	10
Methane (CH_4)	1	3	3	0.5
Nitrogen (N_2)	52	52	50	56.5
Calorific value, B.Th.U. per cu. ft.	150	145	165	130

Illustrations of Producers

Figure 63 illustrates the Wellman mechanical gas producer. Producers in use vary from 8 to 11 ft. in internal diameter, the largest size having a nominal capacity up to 60 lb. of coal per sq. ft. of cross sectional area per hour or about 55 tons of coal per day with a gas output of approximately 8 million cu. ft. In this type of producer the shell is rotated continuously. Other features are the automatic coal feed and automatic poker.

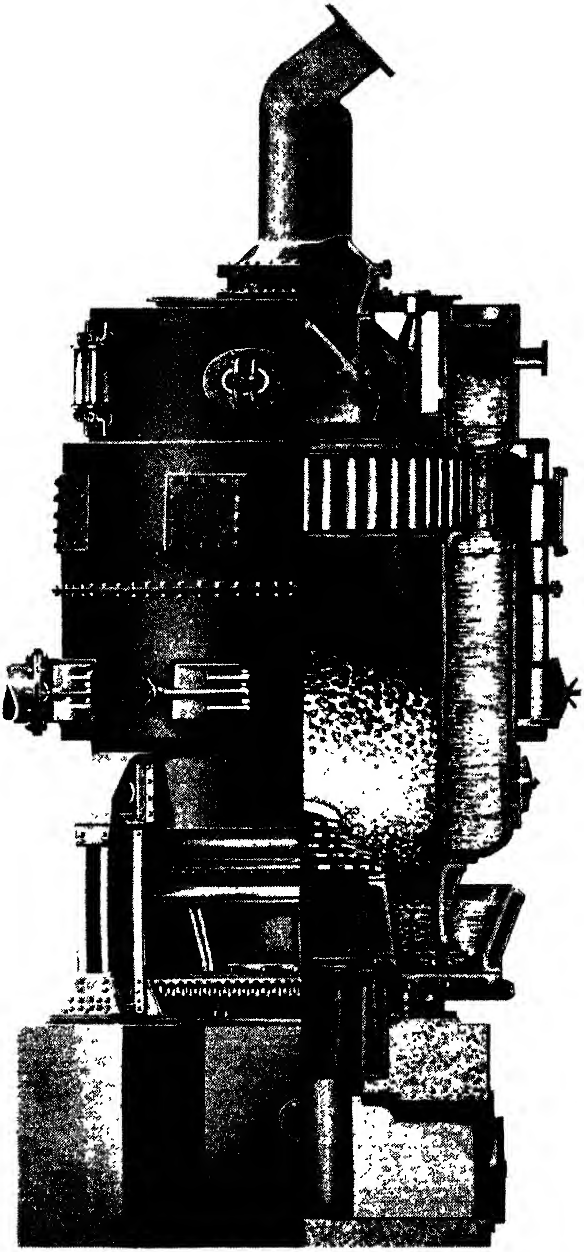
The Wellman-Galusha producer for the gasification of anthracite or coke is capable of using any reasonable grade of fuel from 1½ in. downwards, for example, 1½–¾ in., ¾–½ in., or ⅜–$\frac{3}{16}$in. or similar size ranges. Results published for the gasification of anthracite in a 10 ft. producer are:—



[BY COURTESY OF WELLMAN-SMITH-OWEN ENGINEERING CO.

Figure 63.—Wellman mechanical gas-producer

Gasification rating 2,150 lb. of fuel per hour: gas yield 150,000 cu. ft. per hour: calorific value 150 B.Th.U. per cu. ft. The special features of the producer are (a) the overhead two-compartment fuel bin and the method of feeding fuel to the producers which ensures a constant level of fuel, (b) the completely water-jacketed mild steel producer shell, (c) the mechanically-operated revolving grate, and (d) the bin for collection and automatic discharge of ash.



[BY COURTESY OF HUMPHREYS AND GLASGOW, LTD

Figure 64.—Part sectional view of Marishka producer

Figure 64 illustrates the high pressure steam raising Marishka producer, suitable for the gasification of anthracite or coke. Using anthracite 2¼–1¼ in. in a producer 6 ft. 6 in. diameter, a gasification capacity of 55 lb. per sq. ft. of cross-sectional area per hour has been obtained and with coke 2–1 in. up to 65 lb. with an output of 2.5–3.5 million cu ft. of gas per day.

Special features of the producer are the annular boiler with upper and lower sections connected by two closely placed concentric rows of water tubes within the producer. The hot gases leaving the producer pass into a chamber external to the lower steam jacket and leave near the base of the producer. The steam raised at 100 lb. per sq. in. amounts to 1.0–1.4 lb. per lb. of fuel gasified.

WATER-GAS

In producer-gas manufacture the fuel is gasified by passing a mixture of air and steam together and continuously through a highly heated bed of fuel. In water-gas manufacture air and steam are also used, but the process is intermittent. Air is first blown upwards through the bed of fuel, thus raising it to a high temperature; the air is then shut off and steam is passed, first upwards, then downwards and finally upwards through the hot bed of fuel. The gas made in the steaming period is the water-gas of the process.

The periods of blowing with air, normally referred to as the "blow" periods, vary in duration from 1–2 minutes and the steaming periods, referred to as the "run" periods, are usually of total duration of 3–5 minutes. At the end of each run period the fire is again blown with air and the steaming cycle is then repeated. Coke is charged at intervals to the generator and between chargings of coke a number of cycles, i.e. blow followed by run periods, each of about 5–6 minutes' duration, are carried out. The water-gas produced is higher in calorific value (about 300 B.Th.U. per cu. ft.) than producer-gas and contains only relatively small percentages of carbon dioxide and nitrogen, being mainly composed of carbon monoxide (CO) and hydrogen (H_2) which together amount to 90–95 per cent. by volume of the water-gas. Water-gas is manufactured in Great Britain and in continental countries from coke produced in gas retorts and in coke ovens. In the United States anthracite coals have mainly been employed and bituminous coals have also been used. Some small use has recently been made of anthracite in Great Britain.

Water-gas is manufactured in plant of somewhat similar design to that employed for producer-gas manufacture. The generator consists of a cylindrical steel shell which may be entirely lined with firebrick or partly brick-lined and partly water-jacketed. Usually in plants of large capacity the generator is water-jacketed round the lower half. The plants may be manually or mechanically operated, but normally plants of 2 million cu. ft. of gas per day and of higher capacities are entirely mechanically operated, with mechanical grates for the removal of ash. With manually operated plants the controls for air and steam supplies are conveniently arranged centrally on an operating platform so that the minimum time is occupied by the operator in moving from one control to another. With such plants it is normal practice to remove ash and clinker from the generator at intervals of about 8 hours. The generator is provided with top and bottom gas off-takes.

In the operation of water-gas plants a deep, highly-heated fuel bed (5 to 9 ft. in depth) is used and both the blow gases and run gases leave the generator at high temperatures. With a deep fuel bed the blow-gases contain a relatively high percentage of carbon monoxide (up to 12 per cent.) and for efficient operation it is necessary to utilise the potential and sensible heat in these gases. The potential heat in the blow gases is recovered by burning the gas with air in a firebrick-lined apparatus following the generator. All the hot gases subsequently pass through a waste heat boiler in which steam is generated for the process.

Water-gas is utilised in several industrial processes. It is used in the Gas Industry for mixing with coal-gas and the flexibility of the plant provides a quick means for increasing the gas required to meet sudden demands of output necessary in the event of fog or other abnormal weather conditions. Such demands cannot be met quickly by bringing stand-by carbonising plant into use. Other uses are the production of methanol and the production of pure nickel. Water-gas also provides one of the cheapest sources of hydrogen for large scale chemical manufacture, e.g. for the production of ammonia. For the manufacture of hydrogen from water-gas the carbon monoxide is preferentially oxidised to carbon dioxide which is removed from the gas by washing with water under pressure.

Water-gas was largely used in Germany for preparing synthesis-gas for the production of oils by the Fischer-Tropsch process and it was also utilised for hydrogen manufacture for the hydrogenation of tars for the production of motor spirit. The outputs of water-gas plant vary appreciably, the largest plants being capable of generating up to 10 million cu. ft. of gas per day. Plants of this abnormally high capacity were operated in Germany for the purposes of manufacturing synthesis gas for the Fischer-Tropsch process and hydrogen for hydrogenation.

The yield, calorific value and composition of the gas made vary to some extent, depending on the fuel used. The yield varies from 50,000–55,000 cu. ft. per ton of coke gasified, and the calorific value from 290–300 B.Th.U. per cu. ft. The following analysis is typical of the gas normally manufactured: carbon dioxide (CO_2) 5 per cent., carbon monoxide (CO) 40 per cent., hydrogen (H_2) 51 per cent., methane (CH_4) 0.5 per cent., nitrogen (N_2) 3.5 per cent. The steam used is about 35 lb. per 1,000 cu. ft. of water-gas manufactured.

Carburetted Water-Gas

Carburetted water-gas (C.W.G.) is a mixture of water-gas and hydrocarbon gases, the latter being produced by " cracking " petroleum oil in a separate apparatus attached to the water-gas plant and installed immediately after the water-gas generator. By variation in the quantity of oil used, the calorific value of the mixed gases can be varied and the process thus provides a suitable means for the manufacture of high calorific value gas which can be mixed with gas for towns use or for industrial purposes. Flexibility in gas manufacture is of the utmost importance and C.W.G. manufacture meets this requirement, as the plant can very quickly be brought up to rated output and can be quickly reduced to low output.

In Great Britain C.W.G. is manufactured only in the Gas Industry. In recent years the volume of C.W.G. produced has increased considerably and has largely replaced water-gas for admixture with coal gas. During 1939 the quantity of petroleum oil used was 34.03 million gallons and this increased in 1945 to 102.33 million gallons. Published figures for the yield of hydrocarbon gases per gallon of oil show an average value of 1.33 therms.

The capacities of C.W.G. plants vary from 1 million to 4 million cu. ft. of gas per day and they are usually mechanically operated. The plant consists essentially of a water-gas generator followed by a carburettor or oil " cracking " chamber, which is a cylindrical shell of similar size to the generator filled with chequer brickwork and having provision for supplying oil at the top. Following the carburettor is the superheater, also filled with chequer brickwork, and then the waste heat boiler in which steam is raised for the process.

The generator is operated as described for the manufacture of water-gas. During blow periods when the fuel is raised in temperature, the blow gases enter the top of the carburettor, pass downwards through the chequer brickwork to the base of the superheater, upwards through the superheater and thence downwards through the waste heat boiler to atmosphere. During blow periods air in controlled quantities is supplied to the top of the carburettor and sometimes also at the top of the superheater to burn combustible gases in the blow gases. By the passage of hot gases through these two chambers the temperature of the brickwork is raised to the level necessary for effective cracking of the oil. Following the blow periods steam is supplied at the base of the generator and the water-gas made enters the top of the carburettor. Oil supplied to the top of the carburettor at this stage is carried over the heated brickwork by the water-gas and is " cracked " to gas which mixes with the water-gas. Following this carburetting period, steam preheated by passage through the superheater and carburettor, enters the top of the water-gas generator. During this period oil is not supplied to the carburettor and the gas produced is normal water-gas. Alternatively, steam may be supplied at the top of the generator, the gas produced again being carburetted. As in water-gas manufacture, a short steam up-run completes the gas making period.

For efficient " cracking " of the oil to gas it is sprayed into the carburettor in atomised form and uniformly distributed over the heated brickwork. Careful control of temperature both in the carburettor and superheater is necessary for if the temperature is too high oil will be " cracked " to carbon, and if too low some oil will escape " cracking." The optimum temperature to give maximum conversion of oil to permanent gases depends on the properties of the oil used and to some extent on the output of the water-gas generator. Generally the temperature is of the order of 750°–850° C.

In Figure 65 a plant for the production of 1 million cu. ft. of gas per day is illustrated. The plant is mechanically operated except for the charging of coke. On the right is the water-gas generator, followed by the carburettor, then the superheater followed by the waste heat boiler. Typical results for the operation of C.W.G. plants under test conditions are shown in Table 21.

TABLE 21

Test Results on Carburetted Water-gas Plants

Plant	1	2	3
Daily rate of gas production cu ft.	4,031,000	2,394,000	2,535,000
Calorific value of gas B.Th.U. per cu. ft.	404	462	503.5
Oil used per 1,000 cu. ft. gal.	0.97	1.53	1.996
Dry coke charged into generator per 1,000 cu. ft. lb.	30.60	30.05	27.10
Carbon consumed in generator per 1,000 cu. ft. lb.	24.60	26.19	22.86
Concurrent steam production (from and at 212° F.) per 1,000 cu. ft. lb.	60.50	65.00	57.10
Carbon content of coke charged to plant, per cent.	66.70	84.50	74.80
Thermal yields corresponding to the above :			
(a) From oil, therms as oil gas per gal. ..	1.40	1.32	1.28
(b) From coke, therms as blue gas per 1,000 lb. dry coke	87.60	86.40	92.10

C.W.G. of calorific value, 500 B.Th.U. per cu. ft., would have the following approximate percentage composition: carbon dioxide (CO_2) 3.5, unsaturated hydrocarbons 7.5, hydrogen (H_2) 38.0, carbon monoxide (CO) 35.0, methane (CH_4) and ethane (C_2H_6) 10.0, nitrogen 6.0.

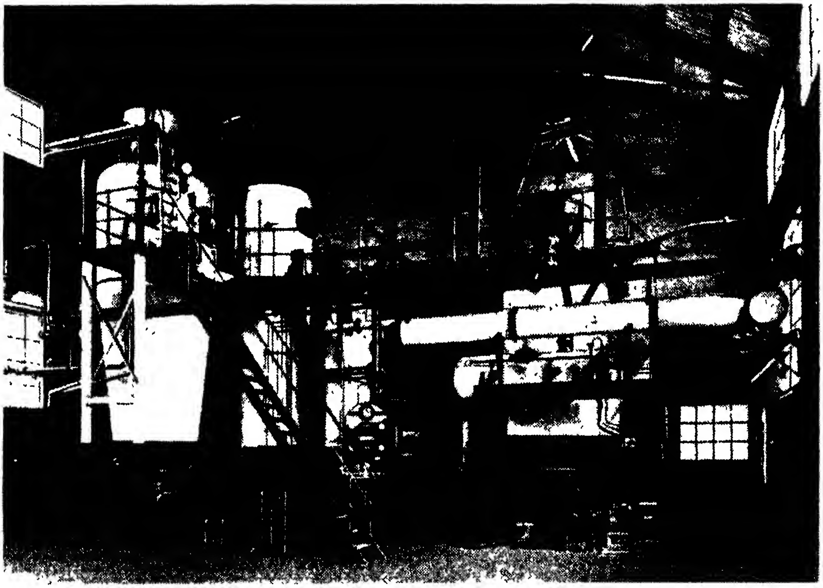
UNDERGROUND GASIFICATION OF COAL

The suggestion has frequently been made that it should be practicable to gasify coal underground, so that a combustible gas and not solid coal would be brought to the surface. It has been claimed that existing coal reserves could thus be utilised more efficiently, at a lower cost to the consumer, than by conventional mining methods. At the same time, the social benefits which would result from the reduction of underground labour have frequently been stressed.

Underground gasification has never been tried on a practical scale in this country, although it was first suggested by Sir William Siemens in 1868.

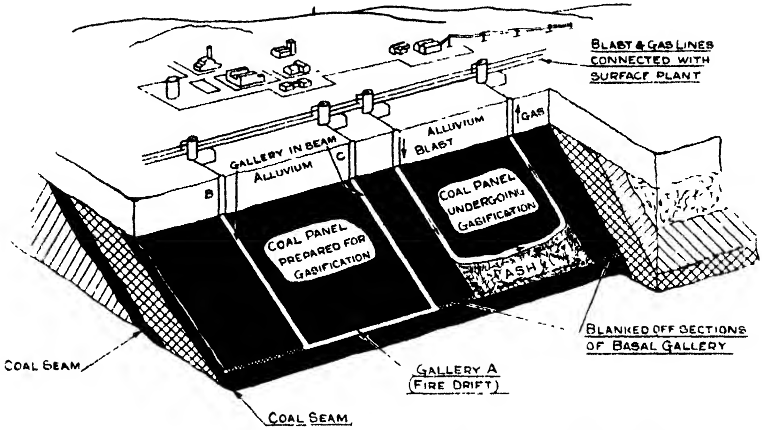
In the U.S.S.R., however, an extensive series of trials has been in progress since 1934, and certain types of coal seams appear to have given encouraging results. At least one industrial-scale plant has been operated, and others have been planned to produce gas for heating, power generation, and chemical processes. A preliminary field trial has been carried out in U.S.A. It is also understood that large-scale trials are being planned in Belgium.

The essential feature of all underground gasification processes is that a gas producer is set up in the seam by starting a fire in the virgin coal and supplying air, steam, or oxygen through a shaft. Gas approximating to producer-gas in composition is withdrawn from the seat of combustion through another shaft. Several methods, applicable to different types of seam, have been proposed. The one which has been developed on an industrial scale is the so-called " stream " method, which is applicable to steeply-dipping seams (Figure 66). Two shafts are sunk along the dip of the seam, and their lower ends are connected by a horizontal gallery in the seam. A fire is started in this gallery, and an air blast, with or without oxygen or steam, is passed down one shaft. The exposed face of the coal becomes the seat of successive oxidation, reduction and distillation zones, corresponding to those in a gas producer, and combustible gas is withdrawn from the second shaft. The coal seam is thus progressively burnt out from the bottom upwards, the ash falling from the burning face into the burnt-out zone beneath it.



[BY COURTESY OF HUMPHREYS AND GLASGOW, LTD

Figure 65.—Carburetted water-gas plant



[BY COURTESY OF THE FUEL RESEARCH STATION

Figure 66—Underground gasification of coal. Layout of stream method

A second method has been proposed for horizontal or slightly inclined seams, which would have the advantage of completely eliminating underground labour. A series of boreholes is drilled from the surface in concentric rings, and a fire is started at the bottom of one borehole. The heat opens up fissures in the coal mass, so that it becomes possible to pass gas from the first to a neighbouring borehole. When the process is established, air is pumped down the first borehole and combustible gas is withdrawn from the second. When the coal between these two boreholes is consumed, a further section of the seam is brought into operation by withdrawing gas from a third borehole, and so on.

The third method suggested is to drive two parallel galleries in the seam and make a series of narrow cross-borings between them. The coal surrounding each of the latter is then gasified in a manner similar to that used in the " stream " method.

The gas produced in the U.S.S.R. trials has usually been a producer-gas with a high carbon dioxide content, the calorific value depending on the proportion of oxygen added to the air blast. Typical gas compositions are shown in the table below.

It is clear that enrichment of the blast with oxygen is of considerable

Per cent. oxygen in blast	Composition of gas (per cent.)						Calorific value (B.Th.U. per cu. ft.)
	CO_2	O_2	CO	H_2	CH_4	N_2	
21 (no added oxygen) ..	8	0.2	12	14	2.5	63.3	108
30	12	0.2	20	19	3.5	45.3	160
70	20	0.2	28	30	10.0	11.8	286

advantage, but this could be feasible only if oxygen were produced at a low cost.

It is probable that the most important application of underground gasification methods will be for seams which are unsuitable for normal mining, or which would not provide coal of marketable quality. It may also provide a means of utilising the residual coal in worked-out seams. Since the range of usefulness of the gas produced would be limited, however, it may be regarded as unlikely that underground gasification could completely supersede the production of high-grade solid coal from seams which are easily worked.

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Chapter XII

OILS, CHEMICALS AND OTHER PRODUCTS FROM COAL

by A. PARKER*

DURING the three years before 1939, the quantity of coal produced in Great Britain was about 230 million tons a year. Of this annual production, 30 to 40 million tons were exported, 12 million tons were supplied to ships' bunkers for foreign and coastal trade, and the remainder, roughly 180 million tons, was used within the country mainly for the production of heat and power. Most of the 180 million tons of coal used in Great Britain was burnt as coal, only about 40 million tons being submitted to processes of carbonisation to provide coke and gas as the main products, with oils and chemicals as by-products.

The general idea of obtaining oils and chemicals from coal is not new. Interest in the subject began more than 100 years ago with the establishment of the gas industry. This interest was aroused in the first place largely because the tar and ammonia liquor, inevitably produced on making coke and gas, were difficult of disposal without causing a nuisance. From these early attempts to make use of otherwise waste materials, the great dyestuffs and fine chemical industries have been built up, large quantities of the fertiliser ammonium sulphate have been produced, and the sulphur extracted in purifying the coal gas for public supply has been used for the manufacture of sulphuric acid. To indicate the extent of the developments which have occurred, it may be mentioned that in Great Britain in 1938, the carbonisation of 40 million tons of coal gave as important by-products as much as 2 million tons of tar and benzole, ammonia equivalent to 300,000 tons of ammonium sulphate, and sulphur for the production of more than 200,000 tons of sulphuric acid. The quantity of crude benzole recovered was 80 million gallons, and this was raised during World War II to about 100 million gallons or roughly 350,000 tons a year. Large as is this quantity of benzole, it is small in relation to the 11 million tons of petroleum oils imported by Great Britain in 1938, and it provided only about 3 per cent. of the petrol we used. Most of the benzole was used as motor spirit and only a small proportion (about 10 per cent.) served as raw material for the

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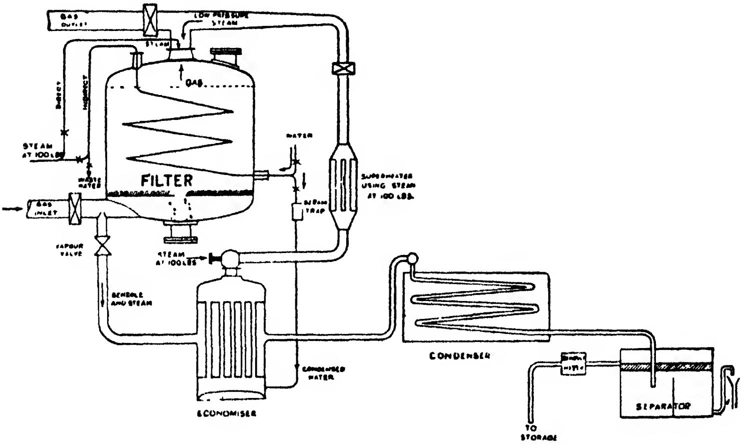


Figure 67.—COAL TAR DISTILLATION. Fractionating equipment, Koppers continuous pipe still installation, The Gas Light and Coke Co., Products Works, Beckton, London. Throughput, 400 tons crude tar per day

[BY COURTESY OF THE GAS LIGHT AND COKE COMPANY AND BRITISH CARBO-UNION, LTD

Figure 68.—Photograph of an active carbon plant for benzole recovery production of various chemicals, including synthetic phenol. If required; a larger quantity of benzole could be made available as a raw material for chemicals, with a corresponding reduction in the amount for motor spirit.

With the development of the internal combustion engine during the last 50 years, the demand for petroleum oils has increased rapidly. For example, the world production of petroleum oils rose from 50 million tons a year during the five years 1909 to 1913, to 270 million tons in 1938, or roughly a five-fold increase in only about 25 years. All this experience showed the advantages of oil fuels in many respects over solid fuels.

Though there is no precise information about world reserves of oil, what data are available lead to the conclusion that they are very much less than world reserves of coal. Further, certain countries, though possessing good reserves of coal, possess little natural petroleum, which has in consequence to be imported, often from sources under foreign contol. There have also been considerable developments, particularly in America, in the production from petroleum of a variety of chemicals and synthetic products, in addition to the usual range of aviation spirit, motor spirit and other fuel oils, lubricating oils, and bitumens.

It is not surprising, therefore, that during the last 40 years there has been great interest in any scheme for providing large yields of oils and chemicals as main products from coal, instead of the small quantities recovered merely as by-products in coal carbonisation. This interest has been particularly marked in Germany, especially during the inter-war years, partly because there is little natural petroleum in that country and partly because of a desire for " self-sufficiency " or independence of supplies under the control of other countries.

Within the last 40 years, two new types of process have been developed whereby oils are obtained as the main product from coal. The first to be introduced was hydrogenation and the second was the synthesis of liquid, solid, and gaseous hydrocarbons from mixtures of the two gases carbon monoxide and hydrogen, which can readily be made from coal and coke. Both processes were discovered and developed in Germany.

Hydrogenation

The liquefaction of coal through the agency of hydrogen at high temperatures and pressures was intensively studied by Bergius over the period 1910 to 1927. After the 1914-18 war, the I.G. syndicate began work independently and by 1927 German development had passed entirely into their hands. In that year the first commercial plant was started in Leuna and by 1939 that plant had reached a production in the region of 400,000 tons a year. It was designed to treat brown coal at a pressure of 200 to 250 atmospheres (roughly 1½ tons per sq. inch) and temperatures in the range 400° to 500° C.

By September, 1939, seven hydrogenation plants had been erected in Germany, with a total rated capacity of about 1.4 million tons of oil and liquefied gas a year; the actual production was at the rate of 1.15 million tons. The raw materials used included brown coal, brown coal tar, bituminous coal, and bituminous coal tar pitch. During World War II, several additional plants were constructed and brought into operation, until by 1944 there were eighteen hydrogenation plants of various kinds. The main developments in the later plants were the use of higher pressures, in some cases as high as 700 atmospheres (4½ tons per sq. inch), but otherwise there was no fundamental departure from the process as known before the war. By 1944 the capacity of the whole of the hydrogenation plants in Germany had been increased to 4 million tons a year; the greatest recorded production of these plants was at the rate of roughly 3.5 million tons a year in the spring of 1944.

From this total of 3.5 million tons for the oils and liquefied gases from the hydrogenation process, there were obtained nearly 2 million tons of aviation spirit, 350,000 tons of motor spirit, and nearly 700,000 tons of diesel oil, with smaller quantities of other products. In fact, practically the whole of the aviation spirit made in Germany in 1944 was from the hydrogenation plants.

So far as Great Britain is concerned, the importance of coal hydrogenation as a method of obtaining oils, in the event of shortage of natural petroleum from overseas, was early recognised. No appreciable reserves of natural petroleum have been discovered in Great Britain, though there has been considerable exploratory boring for oil. Experimental work on the hydrogenation of coal was begun at the Fuel Research Station at Greenwich in 1923. In the following year, the British Bergius Syndicate was formed and an option on the patent rights in the Bergius process was obtained for the British Empire. As a result of tests carried out on British coals in Germany, it was decided to expand the work at the Fuel Research Station. A pilot plant was erected there in 1926 and experimental work with this and smaller-scale plants was carried on until 1939. Over the period 1930 to 1939, attention was directed also to the hydrogenation of tars and tar distillates from the carbonisation of coal at both high and low temperatures. Successful experiments on a scale of 400 gallons of tar per day at pressures up to 400 atmospheres were carried out towards the end of this period.

The main credit for solving the problems associated with the hydrogenation of British bituminous coals on a commercial scale undoubtedly goes to Imperial Chemical Industries, Ltd., whose plant at Billingham was brought into full-scale operation in 1935. To indicate the size of this plant, it may be mentioned that in 1938 the quantity of petrol produced was 52,000 tons from the hydrogenation of coal and 91,000 tons from the hydrogenation of creosote. The process as applied to the treatment of creosote is more simple and less costly than with bituminous coal as the raw material. Since 1939, only creosote has been used as the raw material for the plant at Billingham, and the production of petrol, much of which has been high-grade aviation spirit, has ranged between 75,000 and 150,000 tons a year.

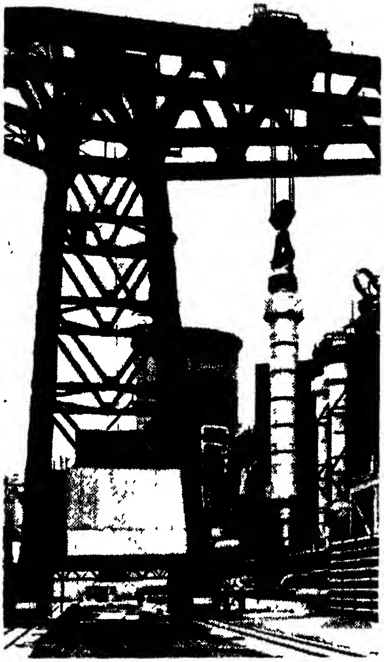
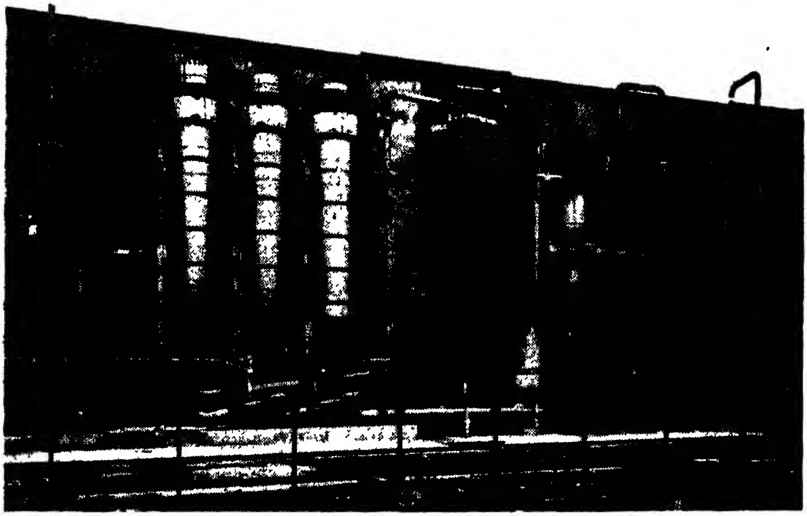


Figure 69.—Lifting a 160-ton converter in the I.C.I. hydrogenation plant

It is not possible in this brief account to describe the hydrogenation process in detail and it is intended to describe it only in simple outline. As used at Billingham with coal as the raw material, the process can be divided broadly into three stages operated at temperatures in the range 400° to 500° C. and pressures in the region of 250 atmospheres. In the first stage, the coal, which is first carefully cleaned to remove as much ash as possible, is made into a paste by mixing it with oil. This mixture is then treated with hydrogen to produce a mixture of heavy, middle, and light oils. In the second stage, heavy oil is hydrogenated to yield a middle oil as the main product, with some light spirit. The middle oil is separated and in the third stage, which is divided into two parts, the vaporised oil is passed with hydrogen over a bed of catalyst to produce petrol as the main



[BY COURTESY OF IMPERIAL CHEMICAL INDUSTRIES, LTD

Figure 70.—General arrangement of a hydrogenation stall final product. Modifications of temperature and pressure, and the nature of the catalysts, permit considerable flexibility in the process and thus in the characteristics of the final main product, which can be either mainly aromatic or mainly paraffinic and naphthenic in nature. High-grade aviation fuel can readily be produced in this way. The diesel oil fraction of the product from the hydrogenation of bituminous coal is superior to tar diesel oils, but does not reach the standard of the petroleum oils used in high-speed diesel engines. It has not yet been possible from bituminous coal to produce by this process lubricating oils of high quality. In fact, hydrogenation as so far developed must be regarded primarily as a method of making high-octane petrol.

A yield of petrol equal to 60 per cent. of the weight of the coal submitted to the action of hydrogen can be obtained, but the overall consumption of coal, including that required for the manufacture of hydrogen, production of power, etc., is in the region of 5 or 6 tons for every ton of final product.

There are certain by-products, in addition to the main product from the hydrogenation process. The sulphur and nitrogen of the coal are converted to hydrogen sulphide and ammonia. The hydrocarbon gases methane, ethane, propane, and butane, which represent roughly one-quarter of the weight of the coal treated, could be utilised as raw material for chemical syntheses, as an alternative to the more usual practice of converting them to hydrogen for the main process. Some of the butane has been converted to butylene and then to iso-octane for addition to spirit to raise the octane number; and some of the propane and butane has been compressed for sale and distribution as " bottled " gas. Phenol, cresols, and higher phenols can be recovered from the initial products of coal hydrogenation in amounts up to ten times those obtained by the carbonisation of coal.

In attempting to assess the future possibilities of the hydrogenation process, cost is a factor of considerable importance. Even in Germany with cheap brown coal, the production cost of motor spirit, without any allowance for profit, was more than one shilling a gallon. With bituminous coal as the raw material, the cost was higher than with brown coal. On the basis of 1946 prices in Great Britain and using British bituminous coal, it has been estimated that the overall cost of the main product would be in the region of two shillings a gallon, whereas petrol can be imported at about 6d. a gallon. This means that unless there are developments leading to considerable reduction in cost, the process would not be economic with coal in Great Britain, even allowing for the duty of 9d. a gallon on petrol. If coal costs £2 a ton this is equivalent to about one shilling a gallon on the product for coal alone.

Hydrocarbon Synthesis

Fischer-Tropsch

The other type of process for obtaining oils as the main product from coal is that associated with the names of the originators—Fischer and

Figure 71.—FISCHER-TROPSCH PLANT IN GERMANY. Atmospheric-pressure reaction vessels during installation

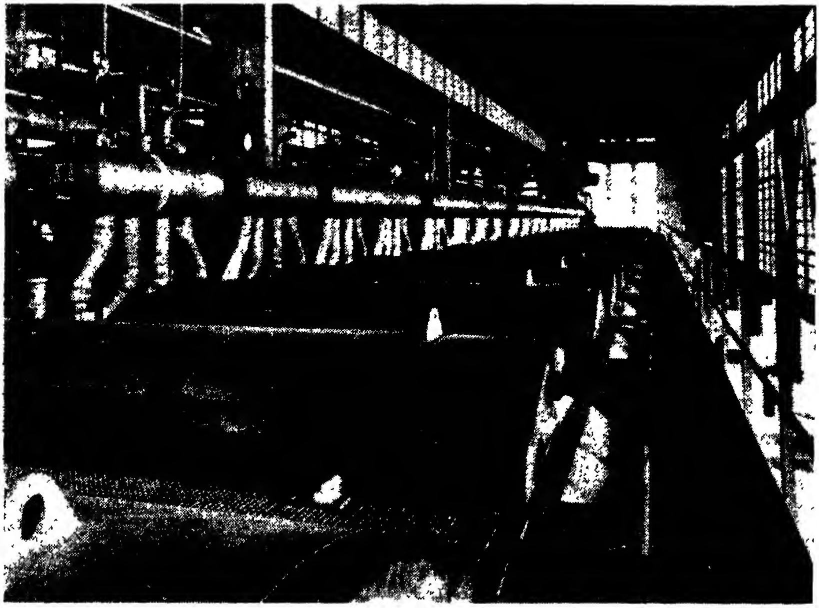


Figure 72.—FISCHER-TROPSCH PLANT IN GERMANY. Atmospheric-pressure reaction vessels showing steam drums

Tropsch—who in 1925 published an account of their early work on the synthesis of hydrocarbons from carbon monoxide and hydrogen in the presence of a catalyst at 180° to 200° C. The first full-scale plant was erected in 1935 by the Ruhrchemie A.G. Development was rapid and by 1939 there were nine Fischer-Tropsch plants in Germany with a total rated annual capacity of rather more than 700,000 tons of product. There was also a similar plant in France. The actual production of the plants in Germany was 335,000 tons in 1939; this was raised to 570,000 tons in 1943, with a slightly higher rate during the first six months of 1944, but there was no fundamental change during these years in the nature of the process, nor were any new plants constructed after 1939.

During the first half of 1944 the annual rate of production of about 580,000 tons from the nine Fischer-Tropsch plants in Germany included about 270,000 tons of motor spirit and 135,000 tons of diesel oil. One point of interest is that about 180,000 tons of the product were used for making lubricants and to some extent for the manufacture of soaps and a synthetic margarine.

The products obtained by the hydrogenation and Fischer-Tropsch processes are different in many respects, so that the two processes are complementary rather than competitive. Hydrogenation gives good yields of aviation and motor spirit, whereas the Fischer-Tropsch process as so far operated provides motor spirit of lower quality, diesel oil of high quality, and oils and waxes which are excellent starting materials for lubricating oils and various fats and chemicals. As the urgent need in Germany during World War II was for large quantities of aviation spirit and motor spirit, it is clear why the hydrogenation plants were greatly extended, while there was little expansion in the capacity of Fischer-Tropsch plants.

There has so far been no full-scale commercial development of the Fischer-Tropsch process in Great Britain, but since 1934 the process and its products have been studied continuously at the Fuel Research Station, in the laboratory and on a semi-technical scale.

In the normal Fischer-Tropsch process the raw material is a mixture of two volumes of hydrogen with one volume of carbon monoxide. There are many ways of making this mixture of gases, which can be produced from coal by complete gasification, from coke, from coke and coal gas, or from coal gas alone; it can also be made from the natural gases from petroleum oil wells. The synthesis gas, after purification to remove compounds of sulphur, is passed into reaction chambers containing the catalyst maintained at a temperature of 180° to 200° C. Ordinarily, the reaction is allowed to take place at atmospheric pressure, but pressures of 5 to 20 atmospheres, which are very much lower than the pressures used in hydrogenation, have been employed in several plants. During the synthesis reaction, a considerable amount of heat is generated. As it is important to ensure that the temperature of the catalyst does not rise appreciably above 200° C., special arrangements are necessary to ensure that the heat generated is absorbed and carried away rapidly from the reaction vessel. In consequence the catalyst reaction chambers in the German plants so far erected have been complex in design and construction. Recent investigations, particularly in America, have indicated that by following the principles of technique adopted in certain catalytic processes of "cracking" in the petroleum industry, the design of the catalyst chambers can be greatly simplified and the synthesis process much improved.

By the process as developed in Germany, to produce 1 ton of primary product requires the consumption of 5 or 6 tons of coal to cover all requirements, as in the hydrogenation process.

With regard to the economics of the process, the cost of the primary products from the Fischer-Tropsch plants in Germany was rather greater than the cost of corresponding products from the hydrogenation plants. On the basis of 1946 prices in Great Britain with British bituminous coal as the raw material, it has been estimated that the overall cost of the primary product from the Fischer-Tropsch process as operated in Germany would be in the region of two shillings to two shillings and sixpence a gallon. There are good prospects, however, of greatly improving on German technique, with a reduction in cost. Even so, the process is likely to be costly with British bituminous coal as the raw material at a price of not less than about £2 a ton. There is much greater prospect of economic success in those parts of the world, including certain parts of the Empire overseas, where coal can be produced at only a few shillings a ton, or where there are ample supplies of petroleum-well gases at a low price as a raw material in place of coal for the manufacture of the synthesis gas.

Methane

By another process of synthesis, similar in broad principle to the Fischer-Tropsch process, practically pure methane can be obtained by passing a mixture of carbon monoxide and hydrogen over a catalyst maintained at a temperature somewhat higher than that used in the Fischer-Tropsch synthesis. In this method of synthesis of methane, which has been studied over a period of several years at the Fuel Research Station, latterly in co-operation with the Gas Research Board, the main active constituent of the catalyst is nickel, whereas in the Fischer-Tropsch process catalysts containing cobalt have generally been employed, though iron can be used in place of cobalt. In the experiments on methane synthesis the temperature of the catalyst has been in the range 200° to 400° C. The velocity of the reaction is much greater than in the Fischer-Tropsch process, and there is a similar generation of heat, which must be absorbed and carried away if over-heating and rapid deterioration of the catalyst is to be avoided. One reason why the temperature of the catalyst in the Fischer-Tropsch process must not be allowed to rise appreciably above 200° C., is that if such a rise in temperature does occur the product contains much larger quantities of methane and smaller quantities of the oils and waxes desired.

Methane is an excellent fuel for internal combustion engines, but for road vehicles it would have to be carried in cylinders under pressure, or liquefied and carried in containers of special design to prevent excessive loss by evaporation. It has been used to a small extent in place of petrol for road transport. Its calorific value is about 1,000 B.Th.U. per cubic foot or about twice that of the gas distributed by gas supply undertakings. Methane can also be used as a starting point for the preparation of chemicals of many kinds.

Synthesis of methane from carbon monoxide and hydrogen is not yet economically attractive, but there is another source in the gas obtained in the carbonisation of coal at gas works and coke ovens, which usually contains 25 to 30 per cent. of methane by volume. If desired, the methane can be separated from the other constituents by cooling the gas in stages to a low temperature, about −160° C.; in this way liquid methane can be obtained.

Methanol

Yet another process of obtaining chemicals from coal is that developed about thirty years ago, partly in France and partly in Germany, for the synthesis of methanol (methyl alcohol) from mixtures of carbon monoxide and hydrogen. In this process, the mixture is passed over a catalyst at a temperature of 350° to 400° C., and at a pressure of about 200 atmospheres. There is a commercial plant in operation at the Billingham works of Imperial Chemical Industries. This plant has a production capacity of about 6 million gallons of methanol a year. If operated at full capacity the coal consumption to produce the synthesis gas and power for the process is in the region of 50,000 tons a year. By modification in the conditions of operation and in the nature of the catalyst an appreciable proportion of a mixture of several higher alcohols can be obtained; this modification has been exploited to some extent in America. In Great Britain, methanol has been absorbed mainly by the chemical industry. Two important modern uses are in the manufacture of certain synthetic resins, of which " Perspex " is an example, and as the main source of formaldehyde, which is required in large quantities in the phenol-plastics industry.

Ethylene

Ethylene is an example of a constituent of coal gas which could be extracted to serve as a raw material for the production of solvents, plastics, and chemicals. It is present in the gas made at coke ovens and gas works to the extent of 2 to 3 per cent. by volume. During the last few years plant has been erected at one coke-oven works in Great Britain for the extraction of ethylene from the gas. The commercial future of this method of obtaining ethylene will depend upon cost in relation to the corresponding cost of obtaining it from commercial alcohol and from certain methods of treatment of petroleum oils.

The opinion has been expressed that it might be economic to extract ethylene at those coal carbonisation plants each large enough to yield at least 5 tons of ethylene per day. There are about 40 carbonisation plants of this size in Great Britain, and the gas they produce in a year contains a total quantity of about 120,000 tons of ethylene. This figure is given to indicate the very large quantity of ethylene available if it can be extracted at a competitive price.

Carbide and Acetylene

In North America and Germany there has been a substantial chemical industry on the basis of acetylene from calcium carbide, since acetylene is a raw material for such substances as acetic acid, acetaldehyde, and acetone, which are much used as solvents and chemical intermediates, for example in the manufacture of rayon and plastics. In addition, acetylene with other products or by-products of coal provides all the raw material necessary in the manufacture of synthetic rubber. There is also the wide demand for acetylene for welding and cutting metals.

Calcium carbide is made by heating together coke or anthracite and lime to a high temperature in an electric furnace. The amount of coal directly required for each ton of carbide, including the burning of limestone, is roughly 1 ton. The consumption of electricity is about 3,500 kilowatt hours per ton. If the electricity is generated at coal-fired electricity stations, there will be required for this purpose about 2 tons of coal, making a total of 3 tons for each ton of carbide.

With the large consumption of electricity, it is clear that the most favourable sites for carbide factories are those at which cheap electricity is available. This explains why carbide is generally made in areas in which electricity can be generated at a low price from suitable sources of water power, and why there was no large quantity of carbide made in Great Britain before 1939, though we have good reserves of the raw materials coal and limestone. In 1938 we imported 65,000 tons of carbide. Because of the importance of a home supply of carbide for acetylene during the war, a factory producing about 75,000 tons per annum was established in South Wales.

Active Carbon

Active carbon is used in a variety of industries, for example in purifying or decolorising sugar, glycerol, and edible oils, in the recovery of benzole and solvents from gases, and in the purification of air from toxic gases as in respirators. It is also used in the treatment of certain waters to render them suitable for drinking.

It is made from a variety of substances, including wood and coco̊anut shells, but active carbon suitable for many purposes can be made from coal. With selected coals as the raw material, the coal is carbonised at a low temperature in the region of 500° C., and the coke so obtained is treated with steam or with steam and air at a temperature in the region of 900° C.

Electrode Carbon

Carbon of high quality is required for the manufacture of the electrodes for electrolytic processes and electric furnaces such as those used in the manufacture of aluminium from bauxite. The electrodes are often made from coal tar pitch, petroleum pitch, and bitumen, but to meet some requirements they can be made from the carbonisation of selected anthracite and coals, which have been specially cleaned to remove as much ash as possible.

Concluding Note

Though the main use of coal for a long time to come will continue to be for the generation of heat and power, it seems probable that as a result of further scientific researches there will be a gradual and steady development in the use of coal for the manufacture of oils, chemicals, and other products such as those mentioned in this chapter, and these substances in turn will serve as raw materials for a variety of expanding and new industries.

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Chapter XIII

THE DOMESTIC UTILISATION OF SOLID FUEL

by D. A. WINTER*

PRIOR to 1939, the Mines Department of the Board of Trade published each year a return of the quantities of coal mined in Great Britain and used for various purposes. For the decade previous to 1940 the amount used for domestic purposes was about 45 million tons a year or between 18 and 22 per cent. of the total mined. In addition, the household use of gas, electricity and coke for lighting, heating and cooking accounted for a further 18 million tons of coal per annum. Thus, a total of 63 million tons a year(1) of coal was needed to provide domestic heat services of all kinds, which was about 1½ tons per head of population. Over 70 per cent. was used as raw coal, and, with approximately 6 million tons of coke also, about 80 per cent. of domestic fuel was in the solid form. This consumption was higher than for Europe and only slightly less than for the U.S.A., yet the standards of comfort attained were much less. Extremes of climate in Britain are also much less than in those other countries, so that this higher consumption must be attributed to the extensive use of thermally inefficient appliances.

It is increasingly recognised that such a usage is wasteful, and must be stopped. Coal is a valuable mineral, source of many useful derivatives when properly treated, and must not be squandered. The smoke produced by the domestic fire contains many of these derivatives and so represents a waste in itself, besides which it causes a great amount of material damage in attacking and disfiguring buildings, fabrics and vegetation, and leads to a wasteful, high expenditure in general maintenance costs, washing, cleaning and artificial lighting. In addition, smoke prevents the full benefit of the ultra-violet light from the sun being available to dwellers in towns and cities.

The mining of coal presents considerable difficulties which become no less but rather increase as more and more coal is won from the pits. In the national interest unnecessary, uneconomic and inefficient use of coal must cease, for our coal reserves are constantly diminishing and the very best use possible must be made of that which we do consume. The general tendency in the past few years has been for the price of coal to increase considerably,

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(1) *Post-War Building Study No. 10—Solid Fuel Installations.*

and it is very unlikely that 1939 prices will ever be reinstated. As the result of recent investigations, the demand for an improved domestic heating service can be satisfied at a reasonable cost, due to reduced coal consumption, by using new designs of more efficient apparatus. It will be necessary, however, to replace the majority of existing solid fuel appliances which may cost more in original outlay, and to use better heat insulating materials in building construction to reduce heat loss. The Simon report indicates that by such means a saving of 35 per cent. in heat requirements may be realised.

The developments in the harnessing of atomic energy are still in their infancy and great advances are possible. The use of raw coal in the home may in course of time be eliminated by the new source of power and coal will then be treated as a raw chemical. Other systems, as for instance district heating, may become commercially possible for large areas at competitive prices. These improvements, however, will take time to come to fruition, and in the interim we must rely on what we have to hand and use it economically.

At the present time, in spite of the great increase in price, solid fuel is still appreciably cheaper for continuous domestic heating services than either gas or electricity, and in consequence it will be called upon to provide the bulk of the space and water heating. Technical improvements have been directed to the reduction of smoke emission from burning bituminous coals and to the satisfactory use of steam coals and anthracites as well as a wide variety of cokes. There is a general tendency for solid fuel appliances to be designed for continuous burning, thus going far to eliminate the criticism of slowness in starting up and warming a room previously levelled at them with some justification.

Considerable attention has been paid to heating the house as a whole rather than individual rooms, and many modern developments focus on a centralised heat unit, from which space heating by both radiant and convected heat as well as water heating (which may also in part serve as space heating through hot water radiators) are achieved.

The centralised plumbing duct with its concentration of all the house services has been developed in conjunction with this concept. It enables hot water services to be grouped in an economical and heat-saving manner, cold water and drainage pipes to be kept warm in winter (and therefore free from freezing) and, with the application of lagging and modern appliances, a fuel saving to be realised to an extent which can result in a reduction of one-third in fuel consumption. If in addition building materials with greater thermal insulating properties are used appropriately, a greatly improved standard of heating comfort is available in the small home at a cost in fuel which is little, if anything, more than with earlier systems—and may materially assist in offsetting the increasing price of fuel. This in itself represents a great advance in the efficient use of fuel.

In most of these instances where gas and electricity services are available, cooking will be carried out with one of these fuels rather than by solid fuel.

Where gas and electricity are not available, solid fuel is used and modern designs of appliances have been developed for this service, either for cooking alone or more frequently combining cooking with water heating or space heating or both. The combination of cooking and hot water is particularly good since both are in constant demand all the year round.

In the detailed considerations which follow, brief descriptions of the principles of appliances are given which show how the fundamental requirements of space heating, water heating and cooking are fulfilled.

THE COMBUSTION OF FUELS

When any type of fuel is burned heat is generated. It is the object of the appliance in which the burning takes place to make as much use as possible of this heat. The first requirement for effective heat generation is that the fuel shall be burned completely, and to do this an adequate supply of oxygen must be brought into intimate contact with the fuel. The natural source of oxygen is, of course, the air. If there be insufficient air supply incomplete combustion results, or, in extreme cases, no combustion at all. Excess air may remove too much of the heat generated or may chill the burning zone so much that again burning cannot be complete. It is therefore necessary to design the fuel-burning appliance to operate between these limits. With gas appliances this is a relatively easy matter since both the combustible and the air, being of the same physical nature, can be more readily mixed intimately. With solid fuel, however, the matter is rather more difficult since the air can come into contact only with the surface of the fuel. This has a two-fold result—solid fuel takes appreciable time and effort to ignite, and the conditions of burning are less uniform.

A combustible mixture of gases may be ignited readily, provided the temperature of a portion is initially raised above a certain minimum, referred to as the ignition temperature. If the heat generated is then sufficient to maintain further portions of the mixture above the ignition temperature, the inflammation will spread through the mixture and burning will be maintained so long as there is the necessary supply of combustible mixture. Inflammation is usually very rapid and sources which are only momentarily intensely hot, such as an electric spark or a glowing particle from a flint, may be used to bring about ignition. With solid fuel the position is very different. It is not possible to make the same intimate homogeneous mixture of fuel and air as with gases and burning must proceed at the surface of the fuel. Ignition also must first take place at the surface, where the physical nature of the materials concerned prevents rapid temperature rise and results in slow ignition. The air necessary for promoting combustion must flow in continuously to replace the hot rising products of combustion. The latter are usually led away by a vertical flue, the up-draught of which may be used to vary the air flow through the fuel bed and so to vary the rate of combustion of the fuel. In general, provided the air necessary for combustion can come into intimate contact with it, the greater the surface, within limits, of any solid fuel in relation to its weight, the more freely and rapidly will the fuel burn. The limits to this are set by the degree of resistance to air flowing through the fuel bed set up by the fineness of the fuel particles. If, for instance, fine dust is charged, although the great surface offers freedom for burning, the resistance to air flow is very great and adequate access of air is impossible, with the result that burning is difficult. Too tight packing or too fine division of the fuel can both interfere with free burning. A somewhat similar result is produced when ash is allowed to accumulate in a grate, for then the ash chokes the airways and, by preventing free air access, interferes with the burning.

The course of combustion is determined not only by the amount but also by the manner in which the air is supplied to the fuel. In practice the air supply is frequently divided into two parts. The first of these, known as primary air, partly burns the fuel, leaving the completion of the combustion process to be effected by the residue, the secondary air. The total amount of air theoretically required for the complete combustion of any fuel is known. In practice it is necessary to supply more air than is theoretically required in order to achieve complete combustion.

There is a difference between the smokeless fuels, high temperature coke or anthracite, and bituminous coals in their method of burning under the usual domestic conditions. The latter decompose at temperatures below their ignition point and emit a complex mixture of combustible gases and tarry vapours amounting to from 25 to 35 per cent. by weight of the total coal substance. This high proportion of volatile matter makes bituminous coals easy to ignite, since the flame produced by the burning gases helps to bring the surrounding fuel itself to the temperature at which it can burn and produce heat independently. Anthracite and high temperature coke, on the other hand, burn almost without evolution of volatile matter and are relatively difficult to ignite. Low temperature coke also retains a proportion of volatile matter which assists ignition, although the absence of tarry vapours makes it smokeless.

The gases and liquid droplets given off from coal in the early stages of the fire do not light it at once. Even when they burn, the flames may be chilled by cold air, so giving rise to the production of smoke consisting of particles of carbon. The heat loss in the gases, liquid droplets and carbon will often be from 10–15 per cent. of the heat in the coal supplied to the fire but in unfavourable cases it may rise to 20 or 25 per cent. The loss due to the visible smoke, that is the liquid droplets and carbon particles, accounts for a loss of heat of only about 3 per cent. of the heat in the coal but the production of visible smoke is closely associated with the much higher losses due to the unburnt gases. Much of the recent development work on the open fire has been concerned with reducing the chimney losses. Although anthracite, which contains only a small amount of volatile matter, and coke, from which most of the volatile matter in the parent coal has been driven off in the gas-making process, can be burned without smoke emission, their combustion in domestic grates is seldom complete and under certain conditions invisible gaseous products may be lost up the flue accounting for thermal losses of from 10 to 15 per cent.

Mention should be made of the technical test which gives the Critical Air Blast (C.A.B.) value and indicates the readiness of a fuel to burn. In practice its use is confined to cokes and anthracite, since bituminous and semi-bituminous coals contain sufficient volatile matter to be fairly freely ignitable. Cokes differ widely in their burning propensities. Bulk density is an important factor affecting their free burning and an open structure coke is usually readily ignited and easy to burn. The combustibility (reactivity) of coke may be altered by such means as blending coals before carbonisation, treatment during carbonisation,(2) or treatment of the final product. An example of the last-named is the alkali activation process sponsored by Messrs. I.C.I.(3)

DOMESTIC HEATING SERVICES

Research and development work in the past few years have been directed towards producing appliances which may be operated satisfactorily on all types of solid fuel, especially the less reactive types such as coke, Welsh steam coal and anthracite. It is thus more convenient to consider solid fuel appliances in general with notes of any special provisions concerning the different types of solid fuel, than to deal with coal- and coke-burning appliances individually.

The service which is normally expected from solid fuel is often of a multiple character. Such is typified by the open grate with back boiler, where both space heating and water heating are required from the same appliance. In this respect solid fuel appliances differ fundamentally from those using gas or electricity. With gas or electricity each appliance is designed to fulfil one specific purpose at the highest efficiency and not to combine two or more functions.

The types of service required are:—

(1) Space heating.
(2) Space heating plus water heating.
(3) Water heating.
(4) Cooking.
(5) Cooking plus water heating.
(6) Cooking plus water heating plus space heating.

(1) Space Heating

(a) Open Fire. The open fire grate has in the past been the most common and probably one of the least efficient of solid fuel appliances. The reason for its extensive use is found in the universal practice of providing a fire grate as a part of the house structure and the consequent acceptance of very

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(2) *Trans. I.G.E. 1938/9, 88, 387 (Comm. 199).*
(3) *Trans. I.G.E. 1939/40, 89, 539 (Comm. 233).*

cheap designs which in many cases were very poor technically. Special attention has therefore been directed to this type of appliance and the view is becoming more widely accepted that low first cost is not an economy if it is accompanied by high fuel consumption for small effect.

Investigations have shown the effect of various factors upon the heat output and thermal efficiency and have indicated how the best results may be attained. Such factors as types of fuel, size of fuel, and the effects of chimney draught upon the performance, and the rate of burning upon radiant efficiency for short and long term use, have been examined.(4)

High moisture and high ash contents are disadvantageous, the former because heat is expended in evaporating the water, and the latter because the ash screens the surface of the fuel from access of air. With carbonised fuels low bulk density is generally an advantage, although it means that less weight of fuel can be charged into a given size of grate, with the result that the life of the fire between refuellings is shorter. Tests upon the effect of chimney pull on the performance of open coke grates have indicated that the initial rate of kindling, the rate of recovery after refuelling, the rate of combustion and overall radiant efficiency are unaffected by the usual variations in draught experienced in domestic chimneys.

The size of the fuel has an appreciable effect. With high temperature coke, highest efficiencies are given with the smallest size, but the kindling and recovery rates are the lowest; normally for the open fire coke of size 1–2 in. would be used. If there is an appreciable percentage below 1 in., although the radiant efficiency is unaltered, rates of kindling, of recovery after refuelling, and of combustion are reduced. If there is an appreciable percentage over 2 in., all these four factors are reduced. A similar sort of effect is found with coal. With both types of fuel this is undoubtedly bound up with freedom for air access and the amount of reactive surface.

For coke, anthracite and Welsh steam coal fires the rate of burning does not materially affect the radiant efficiency if the grate is kept full. The less the charge in the grate, however, the more pronounced is the variation in heat output, and latest designs of open grate show this effect even more. The effect with bituminous coal is a little more complicated, long period tests showing little effect but short period results being influenced by the initial loading. The low efficiency of solid fuel fires when used for short periods is an important reason for the use of gas and electric fires for short period heating.

It is of the first importance to have an adequate and accurate control of the rate of burning. Much attention has been given to this aspect in modern designs and the primary air controls of open grates for all fuels are today more accurately made, usually with machined faces and with means of accurately varying, within appropriate limits, the primary air opening.

Other important features have been investigated, bearing on ability to

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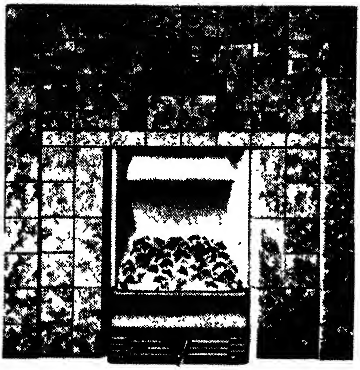
(4) Trans. I.G.E. 1938/9. 88, 441—" Some results attained with solid fuels in open grates for heating living rooms."



[BY COURTESY OF RADIATION, LTD

Figure 73.—Eagle Sutton open fire

burn all types of fuels, to maintain the life of the fire for much longer periods (and even overnight) and to increase the radiant efficiency. The fuel bed is designed to be deep and narrow rather than shallow and wide, and the back brick is made of as low conductivity a material as possible. In addition, heat is conserved in the fuel bed itself by providing a refractory insulating lining inside the fire front. Ash removal from the fuel bed is made simpler by sloping the special-section fire bars towards the back with an adequate clearance at the back to allow accumulation of ash, even during 24 hours' use, without risk of building up to bar level. There is great danger in allowing ash to build up to bar level, for overheating and rusting of the bars then results, with growth, distortion and rapid failure of the iron, even if it be of special heat-resisting quality. Special bottom grate supporting frames enable all ash to be deflected into the ash pan and the capacity of the pan itself is made adequate to accommodate 24 hours' accumulation. The bull nose of the back brick is designed in contour and in relation to the throat of the flue such that it prevents excessive chilling of the gases above the fuel bed and allows the excess air to pass freely to the chimney without appreciably cooling the back brick. The most recent development is a means of enabling a larger charge to be accommodated and of limiting severely the access of secondary air in addition to the close control of primary air, whereby the fire may be maintained overnight. This is achieved by the use of some form of fire cover.

A criticism of the use of bituminous coal has always been that smoke is produced, the evils of which have already been referred to. Research upon the subject of smoke emission has indicated how this effect can be reduced and designs of grate are now available which embody the salient features. In principle, the air supply to the fuel is arranged in such a way that it is pre-heated to a certain extent by passing it over already-heated surfaces before it reaches the fuel bed itself, either as primary or secondary air. In the case of the last-named, the intention is to raise the temperature of the smoke vapours as rapidly as possible to ignition point, and is connected with the function of the bull nose noted above.

A typical example of the application of these principles is seen in the B.C.U.R.A. "Hales" grate. The accompanying Figures 74 and 75 indicate the insulation of the fire front to retain heat in the deep fuel bed, the positive control of primary air supply, the contour of the bull nose and its relation to the chimney throat and to the fire opening and the overnight burning plate which, coupled with the minimum setting of the primary air control, maintains the fire overnight at the minimum combustion rate.

The latest open grate is thus very different from older grates in the service it renders. This is reflected in the radiant efficiency, typical values of which are:—

Gas or oven coke	33%
Low temperature coke ...	29%
Anthracite	30%
Bituminous coal	25%

The working efficiency in the home will be less than the test-bench efficiency, depending upon such factors as the controllability of the fire and the duration for which it is used.

Attention should be directed to B.S.1251: 1945, " Open Fires for Domestic Purposes," for recommendations on salient features of design and dimensions for this class of apparatus.

(b) The Open Convector Fire. An appreciable quantity of heat from the normal open fire passes through the back brick to waste. It is possible to recover some of this heat if special provision is made. In the convector fire the fire unit is surrounded by a sealed casing which is built into the fireplace opening. Means are provided for passing cold air into the space between the rear of this sealed casing and the walls of the opening. This warmed air is then passed through louvred openings into the same or adjacent rooms to yield convected heat. This air carries with it the heat which passes

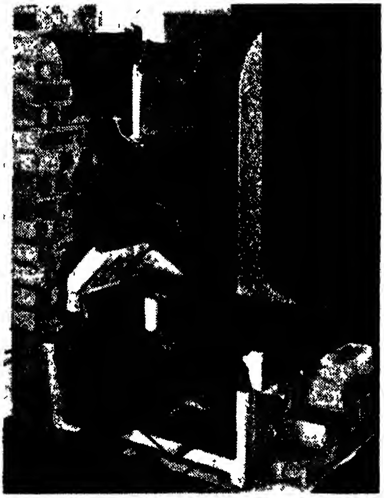
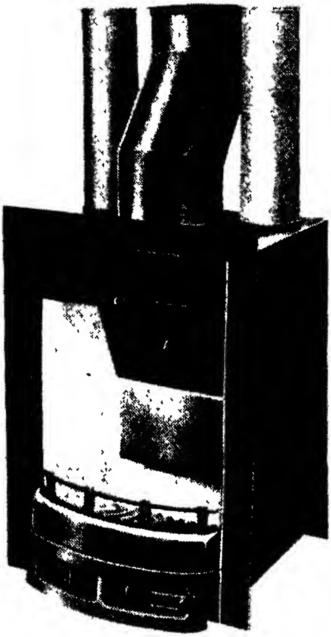


Figure 74.—Photograph of cut-away model of Hales convector fire, showing internal construction

[BY COURTESY OF BRITISH COAL UTILISATION RESEARCH ASSOCIATION

Figure 75.—Hales convector fire

through the sides and back of the fire. Baffles or other heat exchange promoters may be included and appropriate damper fittings may give control of the warm air delivery. In this way an extra 10–20 per cent. of heat output may be realised and background heating may be provided.



[BY COURTESY OF SIDNEY FLAVELL, LTD

Figure 76.—Metro smokeless fuel open fire convector unit

The open fires described in the previous section, as well as the openable stoves described subsequently, may be modified in this way. An example of an open fire combining many modern features of design in a special manner is seen in the B.C.U.R.A. "Hales" convector grate shown in Figure 75(5).

The chief characteristics are provision of positive control of rate of burning by means of an accurately-made air supply damper in the hearth; continuous burning day and night with a minimum combustion rate of $\frac{1}{3}$ lb. of coal per hour with rapid recovery; ability to burn anthracite, coal and most cokes; provision of pre-heated secondary air and a special form of fire back to encourage ignition and partial combustion of smoke; a specially-housed ash box of sufficient capacity such that it normally needs emptying only once a week, with consequent saving in dust emission; provision for heating incoming air and supplying this convected heat either to the same room or to adjacent rooms, thus supplementing the radiant heat output; and the minimising of draughts in the room by drawing air for combustion and convection from the outside through ducts to the fireplace. Structural features include a deep fire bed with specially sloped back brick and insulating fire-brick front, an overnight burning closure in the form of a hinged cover, and a Venturi-shaped throat delivering into the flue. The fire grate and ash pan cavity form a boxed-in unit which is set in an opening constructed to receive it. The surrounding space of this opening forms the convector box and has ducts with louvred outlets appropriately situated for delivering warmed air. Efficiencies of 25 per cent. radiation and 20 per cent. convection are claimed for this arrangement, thus providing a very much superior heat service. These figures are typical of the improvements which may be attained by attention to technical design.

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(5) *See also J.R.I.B.A., June 1945, p. 219.*

(c) The Openable Stove. This type of appliance was one of the first to be continuously burning and various models are available, including those designed for the generation of convected heat on the lines indicated in the last section. The intention is to provide an appliance which will keep alight day and night to give a continuous heat output and to arrange that during the day, when rooms are normally occupied, the fire may be of the open type.

[BY COURTESY OF MITCHELL, RUSSELL AND CO.

Figure 77. — Freestanding Courtier openable stove

In principle, the openable stove contains a rectangular fire box, of reasonable depth, lined with firebrick and having both accurate control of primary air and tightly fitting doors over the front of a fire opening which may be closed during the night to restrict secondary air flow and so achieve the lowest rate of combustion. During the day the doors can be opened and the fire permitted to burn at a higher combustion rate to give the open fire effect. The doors may be hinged to swing back or they may be arranged to disappear completely from sight when open.

Very often the openable stove is provided with a boiler, whereby the dual purpose of space heating and water heating is achieved. This type of service is dealt with in the next section.

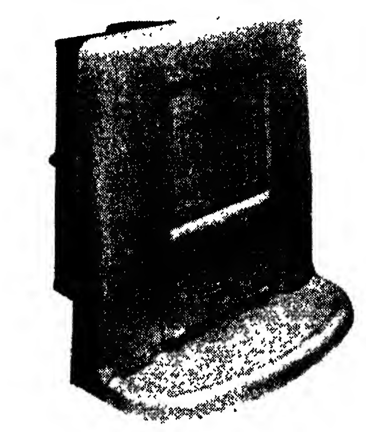
This form of appliance gives a most economical means of providing radiant and convected heat in the living room, and where a large boiler is fitted, some of the hot water output may be used for supplying radiator background heating in other parts of the house. Under normal conditions overall efficiencies of 55 per cent. with coke and 35 per cent. with bituminous coal are attainable.

(2) Space Heating and Water Heating

A boiler can be provided with openable stoves or open fires. Some control over the boiler output is possible with open fires but with openable stoves this control can only be provided, if the boiler is large enough, by means of radiators or a towel rail. A boiler satisfactory for all normal household requirements should be capable of generating 70,000 B.Th.U. per day. The presence of the boiler detracts a little from the radiant efficiency but increases the overall efficiency of the appliance; thus for the various appliances mentioned in section (1) above, the addition of a boiler would be expected to yield at least the following figures:

	Coal		Coke	
	Space Heating Eff. %	Water Heating Eff. %	Space Heating Eff. %	Water Heating Eff. %
Open Fire with boiler ..	17	14	22	20
Openable Stove ..	20	16	28	25
Open Convector Fire Rad.	17	15	Rad. 22	20
Conv.	10		Conv. 10	

Particular attention might be directed to the openable slow combustion stove with boiler since this gives a most economical means of providing radiant and convected heat to the living room with hot water for domestic purposes. This type of appliance has been chosen for installation in Ministry of Works Temporary Houses and many other houses. With a small boiler, suitable for domestic hot water only, additional background heating by means of hot air distributed through ducts may be obtained when the convector box design *(see 1 (b))* is used. With a fire box of about 0.6 cu. ft. capacity and a boiler output of 100,000 B.Th.U. per day, background heating by means of radiators and a towel rail may readily be achieved in addition to heating the living room and providing domestic hot water. With a three-bedroomed type of house with outside walls, floors and roof of low thermal conductivity and of approximately 1,000 sq. ft. total floor area, such a stove should provide a rise of 35° F. in the living room in addition to taking the chill off the remainder of the house. The maximum overall output for all purposes (space and water heating) with such a stove should be 25,000–30,000 B.Th.U./hr. burning either coke or coal. With coal the efficiency is lower, but the maximum combustion rate is higher.



(BY COURTESY OF SMITH AND WELLSTOOD, LTD

Figure 78.—Esse openable stove

A stove with a smaller fire box capacity (about 0.5 cu. ft.), suitable more particularly for dense fuels, would have an overall maximum output of approximately 20,000–25,000 B.Th.U./hr. Overall efficiencies of both these types are likely to be 60–65 per cent. with coke and 40–45 per cent. with bituminous coal, the exact output of radiant heat, convected heat, and hot water depending on the design of the stove, the method of use and rate of combustion.

It might again be emphasised with most of the above that they are designed to burn a variety of solid fuels and are not confined, as were their predecessors, to the use of one type of fuel only.

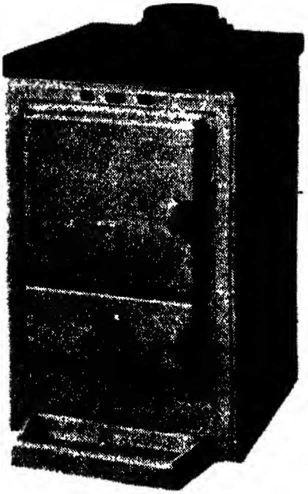
Although the solid fuel appliance for combined space heating and water heating provides an efficient and cheap service and one which is in great demand in the colder weather (since space heating is then always required), it is somewhat inconvenient in the warmer weather if it is the sole means of generating hot water, for then the space heating function could well be dispensed with. To meet this requirement it is customary to provide in such cases auxiliary sources of hot water using either gas or electricity as the heating medium. These alternatives are both more convenient and more economical for summer use.

Unless hot water is to be supplied to radiator systems for background heating, a considerable waste of heat may result from hot water systems which are not adequately insulated. The extent of the loss which can occur is indicated in Post-war Building Studies, No. 19—" Heating and Ventilation of Buildings," Table 3 (10), page 40, where in the three cases cited the heat in the actual water used with the system unlagged amounts to 28.6, 16.6 and 25.8 per cent. of the heat of the fuel burned, whereas with a lagged system the figures are respectively 58.2, 43.9 and 51.9 per cent. Designs are intended to meet average weather conditions, when both space heating and water heating will be adequate but in colder weather space heating will predominate and rates of combustion will tend to be higher with an increased hot water output, whereas in milder weather space heating will be at a lower level and water heating less in consequence. It is therefore necessary for the user to exercise a little discretion in the use of the appliance and to anticipate his needs for hot water as well as for space heating by adjusting the rate of burning appropriately.

The connexion of a radiator to the hot water system will confer greater flexibility provided the boiler is capable of fulfilling the heat demands.

(3) Water Heating

Independent boilers, whose prime function is generation of hot water but which may be used for a certain measure of direct space heating, provide an inexpensive source of hot water. They are very effective and, when designed to burn coke or anthracite, are also smokeless. In such appliances it is of supreme importance that the control of rate of combustion shall be adequate and effective, since a combustion rate of $\frac{1}{3}$ lb./hr. is all that is necessary to provide a complete domestic hot water service with a boiler of good design appropriately installed, with the hot water system compact and well insulated. It is thus essential that the quality of the construction shall be of a sufficiently high standard to give an absolute control of the air admitted to the fuel bed. Independent domestic boilers should conform with B.S.S. No. 758. This specification is applicable to boilers with a heating surface between 2 sq. ft. and 5 sq. ft. and recommends the rating, fuel capacity and heating surface to be adopted, with requirements respecting individual parts of the boiler materials, construction, finish and marking. Notes are also given on recommended practice for installation, for a test code and for compliance with other requirements and to determine the water heating efficiency. A recent provision has been that for post-war boilers the capacity of the fire box shall be 0.6 cu. ft. minimum instead of the 0.49 cu. ft. hitherto required.



[BY COURTESY OF CRANE, LTD

Figure 79.—Independent hot water boiler

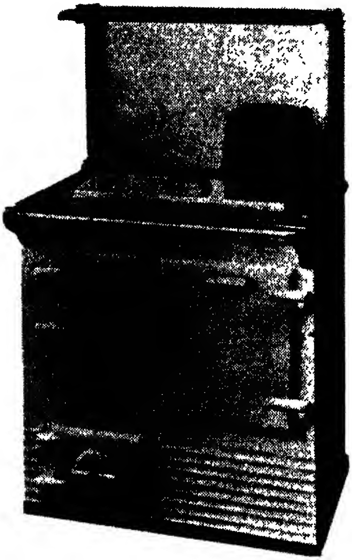
(4) Cooking

The design of the solid fuel cooker has advanced considerably. There are many domestic ranges which fall far short of desirable thermal efficiency but new designs have eliminated the earlier defects with conspicuous success.

Two series of independent solid fuel cookers have been developed, the first of heavy and the second of light construction.

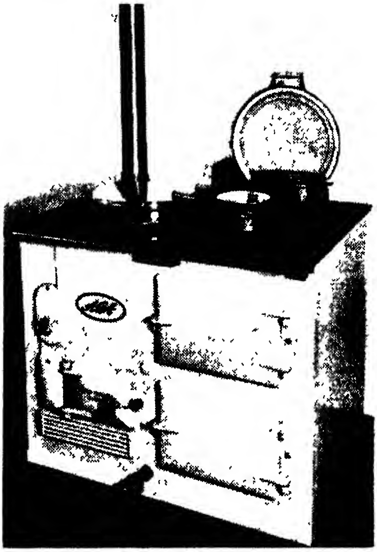
In the heat storage cookers, heat is accumulated and stored in massive castings and is conserved by very thick insulation. The cookers are continuous-burning, with accurate air controls, sometimes thermostatically operated, and consume fuel at the rate of approximately 15–20 lb. per day. Oven and hotplate temperatures are always maintained ready for use, hotplates having hinged insulated covers. Smokeless fuels only may be used, however, for deposits from coal will interfere with correct working. In these appliances a steady rate of burning is aimed at, although not necessarily the minimum rate. By limiting the heat losses and especially by eliminating the effect of the variable heat demand required for hot water generation, high fuel consumptions are avoided while still permitting the oven and hotplate to be maintained always at usable temperature.

The second type, the light construction cooker, is designed to give flexibility in use. The same high standard of construction of damper controls is required, but the ovens, hotplates, etc., are of lighter material and can be rapidly heated at will when the air supply is opened. This type is therefore very different in principle from the heat storage cooker. The energy is stored in the fire box in the form of fuel, from which it can be released quickly by increasing the rate of combustion. Even though comparatively light insulation is provided, considerable economy in use can be effected while the cost of construction is much less than with the heavily insulated heat storage type.



[BY COURTESY OF ALLIED IRON FOUNDERS, LTD

Figure 80.—Rayburn insulated cooker



[BY COURTESY OF AGA HEAT, LTD

Figure 81.—Aga heat-storage cooker

These latter appliances are designed for use with any type of fuel and may readily be fitted with a boiler for domestic hot water supply, which, however, will slightly increase the running cost. Such a cooker, designed for six to ten persons with a use for three cooking periods during the day totalling 2½ hours, generating 90,000 B.Th.U. per day as hot water, and stand-by between cooking periods and overnight, requires a consumption of about 25 lb. of fuel per day. Appliances of both types should be in accordance with B.S.1252, which specifies requirements for construction and performance.

(5) Cooking and Water Heating

The possibility of fitting a boiler to independent cookers has been dealt with above. The services of cooking and water heating can be very satisfactorily combined in principle, since the demand for each is approximately constant throughout the year and can therefore be met at a steady rate, which is not subject to the type of fluctuations encountered in the space heating load.

With adequate insulation of the appliance the space heating effect in the kitchen is not objectionable in the summer. For the small household, if the cooking is to be done by solid fuel, it is much more economical to combine the cooking and water heating functions than to make use of separate appliances for this purpose.

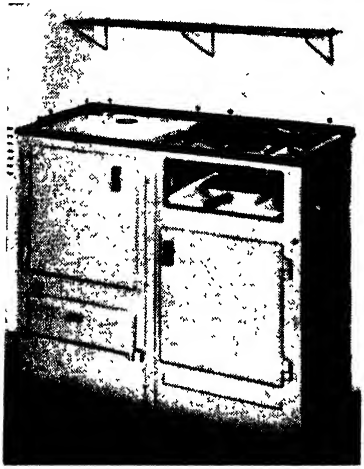
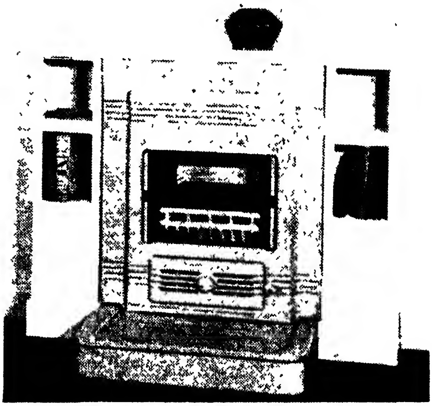


Figure 82.—Yorkdale back-to-back cooker

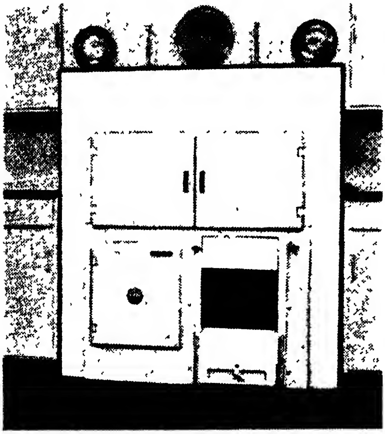


[BY COURTESY OF WILSON'S AND MATHIESONS, LTD

Figure 83.—Open fire in living room at back of Yorkdale cooker

(6) Cooking, Water Heating and Space Heating

Various types of appliance to combine the three functions of cooking, water heating and space heating have been on the market in the past but many of them, especially those of the earlier " kitchener " type, have suffered from gross thermal inefficiency. As a result considerable attention has been paid in the inter-war period to the development of the combination grate. Still further improvements have been effected in the last few years. These appliances are made in three forms—side-oven, oven-over-fire, and back-to-back. Technically there are difficulties in combining all functions with high efficiency. This is clearly reflected in the greater demand for such appliances in the North and Midlands, where coal, hitherto, has been much cheaper and more plentiful than in the South. A contributory factor is undoubtedly the need for more space heating in the North. In the South and South-East there is more general reliance upon appliances specifically designed for one purpose and operated by gas or electricity. With these two fuels it is unprofitable to attempt to combine two services in one appliance, for



[BY COURTESY OF FEDERATED FOUNDRIES, LTD

Figure 84.—Signet combination grate

the efficiency of either service suffers if this is done, and the cost of running, already increased by the inevitable higher prime cost of these refined fuels, puts them at a decided disadvantage and does not enable the best use to be made of them. A disadvantage with solid fuel combination grates is that it is not always comfortable to have the fire burning at a high rate for cooking when space heating is not required, and there is sometimes difficulty in keeping hot water generation within reasonable limits. There is considerable advantage in being able to close the fire box in such designs, and some types of combination grate have made use of the openable stove for the space heating and fire box rather than the open fire itself. Either this or the open fire with overnight burning device may, however, be satisfactorily applied. In addition, the convector arrangements described in section 1 (b) may also be included. Once again B.S.1252 gives a basis for constructional and performance requirements.

Chapter XIV

THE DOMESTIC UTILISATION OF GAS

by D. A. WINTER*

THE latest figures for annual consumption of coal for gas making (1944) show that 20,000,000 tons are used distributed among the 680 authorised undertakings responsible for 97.8 per cent. of the total gas made. Over 68,000 miles of mains supply gas to 10¾ million domestic and industrial consumers. Seven and a quarter million domestic consumers have prepayment meters and about 2 million of the remaining 3½ million are domestic consumers with " ordinary " meters. The estimated number of 9 million gas cookers in use today out of the approximate 12 million families in the country gives a fair guide to the size and importance of the Gas Industry's services to the general public.

In 1944 (the last year for which figures are available) over 400,000 million cu. ft. of gas, 13¾ million tons of coke and 247 million gallons of tar were produced by the Gas Industry. About 92 per cent. of this gas was actually sold to the public for domestic and industrial purposes.

When the Gas Industry was first established it was concerned solely with supplying light, and for many years this remained practically the only use. The titles of many gas undertakings which still bear the name " Gas Light " are a relic of this. Legislation early prescribed regulations for the supply of gas and was consolidated in 1871, when there were enacted such important matters as a legal definition of the cubic foot for measurement of gas, rules for the certification, fitting and use of meters, and the institution of official testing places and of gas examiners for checking the quality of the gas supplied. The supply of gas was thus removed from the realms of the usual commercial enterprise and was regulated by Act of Parliament to ensure that a public service under adequate safeguards was provided.

Research and discovery meantime had shown means of using gas more efficiently and variously and especially how the heat of a flame could best be used. Domestic gas appliances were developed to apply this heat and the growth of the Gas Suppliers and of Appliance Makers went hand in hand as more and more methods of application were devised.

It was not until 1920, however, that the heating rather than the lighting function of gas was officially recognised. In that year the Gas Regulation

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* *Assistant to Technical Director, Radiation, Ltd.*

Act was passed, making a complete change in the basis of charge and specifying ancillary requirements. The " therm "—100,000 British Thermal Units—was made the standard basis of charge instead of the price per 1,000 cubic feet. Regulations were laid down as to calorific value, pressure of supply and freedom from sulphuretted hydrogen. Gas examiners were given the task of checking the heat content instead of the illuminating value, and authorised undertakings were required to supply gas closely conforming, on the average, to a declared calorific value and at adequate pressure. Thus, from being a supplier of light, the Industry has become a supplier of heat, and consumers are guaranteed by Parliament a uniform service for the money they expend on gas. Today the Industry supplies a flexible, smokeless fuel, always available at the turn of a tap, and of a guaranteed quality. Even the price charged is regulated by Act of Parliament and not by the usual commercial operation of supply and demand.

DOMESTIC GAS APPLIANCES

The main domestic services provided by gas are for cooking, space heating, water heating and, to a lesser extent, lighting. There are also one or two additional minor yet important services. These will all be described later. At the moment attention is directed to certain features of general importance which pertain to fundamental principles in the use of gas for the generation of heat.

In the domestic appliance gas is always burned in the form of a flame, and requires an adequate supply of air to maintain that flame and to burn the gas completely. The type of flame given is determined by the method by which the air is supplied to the flame. The two types are the Bunsen (aerated) and the luminous (non-aerated, neat).

If all the air is supplied outside the flame, the " luminous," " non-aerated," or " neat " gas flame results. The first of these names refers to the bright luminous appearance associated with the batswing flame of coal gas rich in hydrocarbons; the second, which is not at all technically correct, is merely the antithesis of the " aerated " or Bunsen flame, and attaches a specialised meaning to the term " non-aerated," while the third is of recent origin to indicate non-admixture of the gas with air until the flame zone is reached.

By passing the coal gas through a fine orifice situated at the open mouth of a burner tube, an injection effect is produced, whereby an admixture of gas with air is made. This mixture, which contains less air than is required to burn the gas completely (roughly half), may then be passed to the burner jets where, upon ignition, the well-recognised Bunsen flame results, with its well-defined blue inner cone, at the outer surface of which burning commences, and the outer mantle, where burning is completed. Each type has its special applications and can best be considered in conjunction with the various appliances themselves.

Utilisation of the heat generated by the burning must be as efficient as possible to make the appliance effective. This is one of the chief objects of research and design in the application of heat from gas flames. An important factor is the establishment of a criterion showing when the gas is completely burned, since, to be effective, the air supply to the flames must be sufficient to ensure complete combustion without being so excessive that heat is wasted. There is a British Standard Specification No. 717 which specifies minimum requirements in this respect, and all gas apparatus must conform to this standard. In actual fact, for design purposes, manufacturers adopt considerably higher standards, in the design stages, in order to permit themselves a safety margin for appliances in everyday domestic household use. There are other British Standard Specifications which lay down minimum standards of performance and effectiveness, and the art of the appliance designer lies in his being able to achieve as high a standard above this minimum as possible. Modern domestic gas appliances embody to a high degree the results of extensive scientific research and development work to make the best use of a fuel which itself results from a highly technical method for processing coal.

Gas Cookers

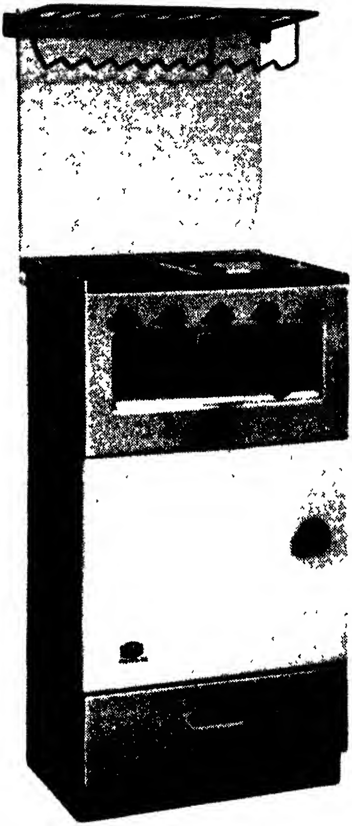
It has been reliably estimated that there are 9 million gas cookers in use today. This represents the most numerous class of domestic gas appliance. The modern cooker is a highly effective and thermally efficient apparatus, upon which a considerable amount of work has been carried out to change it from the heavy, black, cast iron structure which was common before 1920.

A domestic cooker consists generally of two parts—the oven and the hotplate—and a brief consideration will be given to each.

Oven. The object in the development of the gas oven has been to render the process of cooking—which is in essence the art of applying heat to food to make it more palatable and edible and to soften the tissues—as effective, simple, reliable and repeatable as possible without the need for exceptional skill in the art. In consequence research has been conducted concurrently on the distribution of heat and its application to food in the oven, and on cooking processes themselves. The resulting knowledge has enabled a cooker oven to be designed which is a reliable tool for the housewife.

The oven consists of a box-like enclosure which has to be heated. The heat is supplied by gas flames on a burner, and the resultant hot gases, mixed with air, circulate throughout the oven space and over the food, eventually finding a way out through the flue outlet. There is thus a steady stream of hot gases passing through the oven, and careful design is required to ensure that the circulation produces the results desired. A further British Standard Specification, No. 1115, is now in vogue which specifies cooking tests designed to indicate whether this heat flow is satisfactory in the various respects required. This standard also in effect specifies the minimum requirements, and manufacturers endeavour to exceed the standard by as much as possible.

The use of thermostatic control in the oven when the Regulo was introduced in 1923 was a milestone in oven design. By this means the gas supply is controlled according to the temperature existing in the oven, and it operates in an attempt to hold this temperature condition stable. During the cooking process absolute constancy of temperature is never realised, but the instrument, working as it does within close limits, ensures that repeatable conditions may be attained, and that compensation is made for unforeseen or unavoidable fluctuations of any factor, such as variations in supply pressure, which would tend to disturb the heating. A thermostat has become a universal standard component on modern ovens of all makes.



[BY COURTESY OF R. AND A. MAIN, LTD

Figure 85.—Gas cooker

The first gas ovens made use of luminous flames, but difficulties associated with irregularity of size of the small flame holes, and consequent unevenness of circulation of the hot gases, caused a change over to Bunsen flames. This latter type has held the field for many years, but latest developments have indicated that, when due precautions are taken as to protection and spacing of the luminous flames, they may be used just as satisfactorily for oven heating as the well-established aerated flame. In general it is not possible to effect a direct substitution unless the burner arrangements are specially designed, but when such arrangements are made, both types are equally effective.

Hotplate. The hotplate comprises a series of pan supports under which are situated the boiling burners and grill, each with adequate controls of both aeration and pressure of gas supply, so that the best form of flame may be attained. The boiling burners are mostly used for boiling water for beverages or for cooking at the temperature of boiling water and, for this purpose, gas offers a very flexible service. The burners themselves are designed, in conjunction with the bars, to attain the highest thermal efficiency with good combustion of the gas. Since flame contact is desired, aerated flames are most frequently used, although luminous flames under carefully controlled conditions may be satisfactory. Subsidiary points concern freedom from extinction when vessels boil over and speedy operation.

More recently, burners with non-lighting back features have been devised. The principle underlying the design of such burners is that more stable conditions are established inside the aerated burner, so that even when the flames are turned down there is much less fear of flash back occurring, or of the burner remaining lighted back. There are also available duplex burners in which either the full-on burner for rapid heating, or a small part of the burner for simmering, may be operated at will by the turn of the tap handle.

Hotplate bars must be carefully chosen in relation to burner design and position. They must form a stable pan support for even small diameter vessels and yet must not absorb so much heat that the thermal efficiency suffers. Especially must they not interfere with the air supply to the flame. Five points require to be reconciled—high thermal efficiency, complete combustion of the gas, speed of operation, pan stability, simple form (for ease of cleaning)—and it is sometimes necessary to sacrifice something of one or two in order to gain advantages in others.

The hotplate usually carries a grill which enables toast and grilled foods to be prepared. Of recent years grill design has been appreciably improved and the performance, although still capable of further improvement, is much better than that of even 10 years ago.

Mention should be made of the use of heat-resisting steel in both perforated and expanded mesh forms for grill frets. Although more expensive, such steels (generally containing at least 12 per cent. and preferably 20 per cent. of chromium) heat up rapidly by virtue of the lighter-weight construction possible, besides retaining their shape and effectiveness indefinitely.

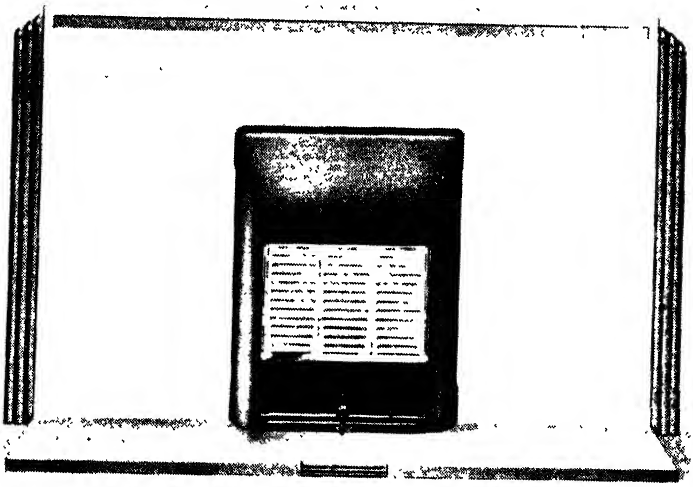
Combustion standards and cooking performance for the grills are subject to the same close scrutiny as for boiling burners, and special tests are designed to indicate whether there is interference with one burner by the operation of another. Once again B.S.S. 1115 and 1250 give an indication of minimum requirements.

The gas cooker has improved considerably in general appearance, a fact which may be particularly attributed to the successful introduction of stain-resisting vitreous enamels on both cast and sheet iron. These finishes, being in effect a form of glass, confer obvious advantages in cleanliness and decoration. With the choice of vitreous enamel colours available, the cooker can well tone with any colour scheme of the modern kitchen.

Space Heaters

It was early suggested that coal gas might be used as a means of heating rooms to replace coal and wood fires. Objections to coal on account of the smoke for which it was responsible have long been raised but the relatively high price of gas has been a potent argument against its general adoption for this purpose. The coal fire, particularly when large and well alight, is responsible for the emission of an appreciable quantity of radiant heat, and the combined effects upon comfort of the high rate of consumption of fuel and of the considerable emission of radiation, has secured for coal a strong position which has not been seriously assailed even today.

When in the early days the luminous flame burner alone was available, heating was carried out by allowing the flame to burn freely and the hot gases to mix with the atmosphere to produce a large bulk of warm air. The next stage was to enclose these flames loosely in metal surrounds so that the hot gases heated an appreciable area of metal, which in turn warmed air by contact and gave rise to a continuous circulation. Thus the so-called " radiator," or what is better termed the convection heater, was developed. The main point to notice is that the products of combustion, instead of being vented through a chimney to the outside air, were able, in the absence of smoke and acrid vapours, to be mixed with the air of the room. However, both in appearance and in producing comfort, this type of heater was found to be lacking, and means were sought of simulating the comfort-producing coal fire. High air temperatures alone were found by experience to produce discomfort, and when, to attain high temperatures, appreciable quantities of gas were burned fluelessly, the air became oppressive. It was gradually realised that the principal advantage of the coal fire lay in its radiant heat emission, in conjunction with the ventilation of the room induced by the chimney flue. It was soon evident that the red hot surfaces were largely



[BY COURTESY OF RADIATION, LTD

86.—GAS FIRE. New World silent beam

responsible for the radiation effects and efforts were made to achieve these with coal gas. Nothing much was possible until after 1855 when the Bunsen flame was invented. Prior to this, contact of luminous flame with solids, which is necessary to give an incandescent appearance, could not be permitted on account of the too-ready deposition of soot. The Bunsen flame gave a new impetus to development work on radiant heat emission from red hot surfaces.

There were thus made available two types of appliance for space heating—the convection heater or " radiator," which, when used in a well-ventilated room, would impart all its heat to the surroundings with an efficiency of approximately 90 per cent., and the radiant heat emitter, which experience showed to be more comfortable but which experience also showed must be connected to a chimney. This latter requirement was due to the fact that the early type of burners failed to attain complete combustion of the gas—a failure which was understandable when it is realised that the chemistry of combustion was in its early stages in 1880 and only advanced appreciably in the period between 1880 and 1920.

The columnar radiant for gas fires was introduced early in the present century, with each column heated by its own individual aerated flame. This disclosed ancillary problems—burner design, even distribution of gas to the burner flames, attainment of good primary aeration, prevention of lighting back or noisy extinction, and reduction of injector noise—the solution of which occupied most of the next 30 years.

In 1909 there was published a classical paper on heat emission from gas fires(6) which caused research work to be concentrated upon the gas fire itself. In the first instance these investigations were concerned with devising a method for reliably estimating the radiant heat output, and, until such was available, there was no standard for comparison. At the same time attention was paid to hygienic conditions of operation. The amount of gas burned in a fire to produce reasonable heating was recognised as being so great as to cause uncomfortable conditions if the products of combustion were permitted to vent into the room, and various tests were devised to indicate when removal of all the products of combustion by the chimney flue to which the fire was fitted was satisfactorily achieved. The " Shadowgraph " test in 1912(7) and the " Lancet " test in 1914(8), both of which are standard criteria today, helped considerably in improving performance of gas fires in this respect. The placing of a bowl of water in front of the fire, in the belief that this would " purify " the atmosphere, could now be relegated to the class of mistaken traditions to which it belongs. In spite of this, the habit dies hard, and there are still found a few people who religiously practise this quite unnecessary and ineffective rite. We now recognise that the discomfort experienced was a combination of the results of imperfect combustion of the gas coupled with inadequate ventilation and

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(6) *Report of Gas Heating Research Committee of the Institution of Gas Engineers, 1909.*
(7) *J. Gas Light, July 30, 1912.*
(8) *" The Lancet," February 7, 1914*

overheating of the air, and that this can be cured absolutely by providing the fire with an adequate flue outlet communicating with a well-ventilated chimney. Fire designs were modified appropriately to achieve this end, and the modern hygienic gas fire, which warms as well as assists ventilation, developed from this work.

The factors contributing to comfort by the use of radiant or convected heat are still not fully understood and appear to be very complex, so that it is impossible merely to specify conditions which are likely in any one case to produce the maximum degree of comfort. Further, there is individual reaction to be taken into account and an ultimate aim of design is that considerable latitude as regards temperatures attained and the proportion of convected and radiated heat be permitted in any heating system in order to accommodate individual requirements.

Research also on the effects of radiant heat on the human body has been carried out and methods devised for producing the maximum quantity of the shorter wavelength infra-red radiation, which was shown to be a potent comfort-producing factor. During this period great advances were made in raising the radiant efficiency, improving the heat distribution and ensuring complete combustion of the gas. Developments also occurred in the design of, and material for, radiants and their effect both on quantity and quality of radiant heat emitted, so that, by 1930, gas fires had become highly efficient hygienic appliances, very different from those of 20 years before.

Following these improvements, two radically different ideas were developed—the attainment of complete silence and the elimination of the former columnar radiant. To achieve this, luminous flames of the special type associated with the Bray jet were used and an intensely hot combustion chamber acted as the radiant source. The Cobble Beam fire of 1931/32 embodied these principles. The aerated flame, however, was still not neglected and even further increases in efficiency were attained by paying great attention to air control. In 1938 the latest type of luminous flame fire was devised, using the same form of jet as before, burning in a combustion chamber formed by a perfectly flat rear back brick and a lattice-like refractory front structure with the ribs projecting into the flame zone. Very accurate control of the air supply is incorporated and the fire, when fully heated, gives a glowing appearance with the semblance of depth, characteristic of large high-temperature furnaces. Complete silence is attained and a pressure governor is incorporated in order to compensate for any pressure fluctuations in the supply. All danger of lighting back is eliminated and extinction is quite silent. Choking of the jets, due to atmospheric dust from carpets or fluff from blankets—a serious maintenance problem in hospitals and nursing homes in particular—is avoided.

On both types of fire the problem of lighting received attention. Ignition by catalysts of the platinum black type had been proposed prior to 1900, but difficulties with "poisoning" from sulphur compounds in the gas operated against their general adoption. Since 1930 hot-wire ignition of lighting pilots, operated by small dry cells through an automatic switch on the control tap, and flint-operated spark ignition, either controlled by the tap or independently operated through a pilot, have been satisfactorily applied. Improved catalytic ignition has been attempted (9) but still presents problems to be solved.

Future developments are likely to be concerned with the provision of means for generating an appreciable amount of convected heat in addition to radiant heat, and particularly in preventing this warmed air passing directly up the chimney. Overall efficiency of at least 60 per cent. is aimed at, which will go far to neutralising the disadvantage of initial high cost of fuel in recommending the gas fire for domestic heating.

Water Heaters

The need for an abundant supply of hot water is more evident as people become accustomed to having hot water on tap. It is to be regretted that a laid-on supply of hot water has been the exception rather than the rule in housing. Although housing developments since 1920 have been concerned with remedying this defect, there still remain many houses with no bulk hot water supply and for these town gas, either as the sole means of providing hot water or as an auxiliary, can offer a wide and complete service. The ability of a gas burner in a properly designed appliance to consume a large amount of gas in a relatively small space and to apply the resulting heat to water with high thermal efficiency gives to gas an outstanding advantage over other fuels in providing bulk supplies rapidly and cheaply. The other properties of gas—smokelessness, flexibility, constant availability, possibility of thermostatic control, and convenience—all find their place in modern water heaters to provide a rapid, trouble-free service.

The types of heater available are most conveniently divided into the two main categories of Storage and Instantaneous Heaters. In the former class water is heated and stored in bulk, withdrawals taking place from the storage with automatic arrangements for heating fresh supplies and for maintaining the temperature of the heated water by thermostatic control. In the Instantaneous Appliance cold water enters and is heated during passage through the appliance, emerging as hot water at the point where it is to be used. Arrangements in the latter appliance are made whereby the gas is turned full on and lighted automatically when the water taps are turned on.

Each type comprises several varieties distinguished by their functions and methods of operation.

Storage Water Heaters. These are described as Single-point Storage, Multipoint Storage and Bulk Heaters.

Single-point Storage Heaters of about 2 gallons storage capacity, thermostatically controlled, consume gas at a full-on rate of 5,000 – 10,000 B.Th.U./hr. They are fitted closely adjacent to the point of use and are

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(9) *Ignition of gas by cold catalyst. Trans. I.G E* 1937/8, 87, 474.

usually lagged. They are not required to withstand any appreciable water pressure, since they embody a water control tap on the inlet with a broken feed, and hot water is delivered by gravity from an open spout through displacement by cold water entering the bottom of the storage chamber. The heating unit is surrounded by the water. It is, of course, necessary to allow a little time after first lighting before usable quantities of hot water can be drawn, but this period rarely exceeds a quarter of an hour. The thermostat is set to maintain a steady hot water temperature of 140° F. and is so placed that it immediately increases the gas consumption when even small quantities of water are withdrawn. When the storage is full the gas consumption is reduced to maintenance rate, which is just sufficient to maintain the water temperature at about 140° F.

Multipoint Storage Heaters combine a heating unit and bulk storage cylinder or tank in the one framework. These appliances are required to be connected to a system similar to the house circulation system and, in fact, may replace the customary solid-fuel-fired boiler and storage cylinder. They therefore need to withstand moderate water pressure and are constructed with this end in view. They are effectively lagged and thermostatically controlled, and may vary in storage capacity between 5 and 40 gallons. Gas ratings may be anything between 5,000 and 50,000 B.Th.U./hr. input with appropriately designed heater units. The rate of generation of hot water is roughly proportional directly to the rated heat input and, in consequence, the greater the demand the greater should be the rated input.

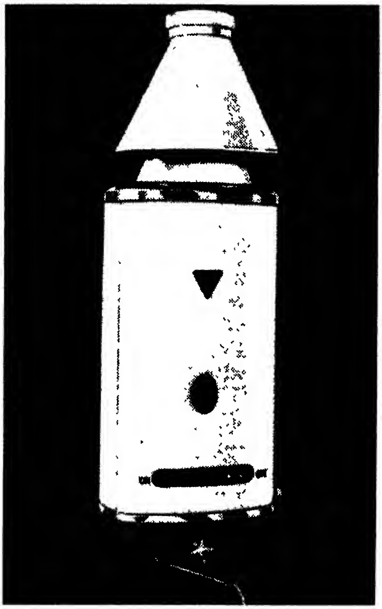
The storage capacity gives a margin of flexibility whereby abnormal demands may be met, hot water being generated and stored in bulk in the lagged cylinder against future withdrawals. When the storage is full the gas is reduced to a small fraction of the full-on rate — 1,000 - 1,500 B.Th.U./hr.—so as to maintain the stored water at an average 140° F. It is thus possible to realise a very effective service, even with a low rated consumption, if the storage capacity is adequate to meet the largest hot water demand. The low consumption heater usually shows the greater overall thermal efficiency because the full-on gas supply, at the maximum heating efficiency, is required for a greater proportion of the running time. It is an important function of the hot water supply expert to assess the probable and maximum demands, and to specify both storage capacity and full-on consumption appropriately to satisfy these. This function can be satisfactorily exercised only after appreciable experience has been gained.

The gas-heated circulator is a relative of the Multipoint Storage Heater and may be likened to the heating unit of such an appliance separated from the storage cylinder. It is intended for fitting to the household storage circulation system, either in place of, or in addition to, the solid-fuel-fired boiler. It requires connexion by flow and return pipes to the existing cylinder and is thermostatically controlled. The gas rating varies similarly to that for multipoint storage appliances.

Special attention has been paid in the latest designs to low servicing costs, and materials for the heat exchanger are of heat- and corrosion-resisting alloys which reduce the need for service visits to very infrequent intervals.

On all storage appliance burners special thermo-cut-off valves, operated by heat conducted from one burner flame or a pilot, protect the gas supply, and shut off the burner in the event of the flames becoming extinguished through any unforeseen cause.

Bulk Heaters are fairly simple in construction and consist usually of a pan capable of holding 6–10 gallons, or even more in larger appliances, heated by gas flames underneath. Typical examples are wash boilers for household use. The gas rating is of the order of 15,000–20,000 B.Th.U./hr. input, and a thermal efficiency of 55 to 60 per cent. should be attained.



[BY COURTESY OF ASCOT GAS WATER HEATERS LTD

Figure 87.—Gas water heater

Instantaneous Heaters. Instantaneous Single-point Heaters are fixed closely adjacent to the point of use—generally the kitchen sink. They also carry a control tap on the water inlet and are open at the outlet, so that they are not subject to any appreciable water pressure. In addition to the normal gas tap, automatic valves operated by water pressure are incorporated, which turn on the gas when the water tap is opened and turn it off when the tap is closed. An automatically controlled pilot light remains permanently burning to effect ignition of the gas. The water passage-ways are fairly long and pass through specially designed heat interchangers, so that the water flowing out has been adequately heated. The hot water output is usually about ⅔ gallon per minute raised 80° F. above the inlet temperature.

Instantaneous Multipoint Heaters are, in effect, an enlarged version of the Single-point appliances but capable of withstanding mains water pressure, and have water taps on the outlet pipes from the heater at the various points of use. They are intended to provide a complete hot water service to all taps in the house. Pilot ignition, automatic valves operated by the water flow and, in some cases, a water flow governor are incorporated. The gas rating is usually of the order of 100,000 B.Th.U./hr. input and the hot water output 1⅔ gallons per minute raised 80° F. On both types of instantaneous heater thermo-cut-off valves are standard fittings.

The Single-point Bath Instantaneous Heater, more commonly known as the Geyser, is the oldest type of Instantaneous Heater. In this, interlocking gas and water taps, manually operated, provide the controls, and construction is not so complex as in the Multipoint appliance, although the hot water output and the gas consumption are of the same order. It provides hot water only at one or, at most, two adjacent points.

In all the foregoing appliances connexion to a flue is required where the gas rating is 30,000 B.Th.U./hr. or more, except in the case of Single-point Instantaneous Heaters intermittently used. Luminous flames, either of the Bray jet or pinhole burner types, are universal, and for most gas governors are standardised. British Codes of Practice for gas appliances have now been issued and give full details of all types.(10) Thermal efficiency of all water heating units should be 75 per cent. minimum under steady state conditions. B.S.S. 1250 gives a survey of the various types and of the tests and performance standards covering them.

Lighting

As already indicated, lighting was the first use of town gas. Until the 1890's, the luminous flame burner, either in the form of the flat flame or Argand burner, or varieties of these, were the customary types. The commercial exploitation of electricity in the late 1870's seemed to sound the death knell of gas for lighting, but with the discovery by Von Welsbach, in 1886, of the properties of rare earth mixtures, and the invention of the ceria-thoria impregnated gas mantle, combined with the use of the aerated flame, a fresh lease of life was given to gas lighting. Domestic lighting appeared to hold its own until about 1920 but the rapid improvements in electric lighting devices, coupled with the convenience of the electric switch, have combined almost to cause the exclusion of gas as a means of domestic illumination. Nevertheless, in the older and smaller working class home, the amount of heat given off by a lighting burner was a substantial contribution to the comfort in the home during colder weather, and the cost of lighting was fairly low.

In recent years the general introduction of vacuum cleaners and radio has meant that electric power will be introduced into many houses irrespective of any other consideration and, in consequence, electric lighting has become almost a foregone conclusion.

Miscellaneous Appliances

The great utility and convenience of gas pokers for lighting solid-fuel boilers and fires should be noted. For laundry use, gas irons, either of the type with permanently burning burner or of the type independently heated over special gas burners, are frequently preferred to others on account of rapidity of heating and control of temperature. Thermostatically-controlled irons are also available in the former category.

Passing reference only can be made to gas refrigerators. These appliances are silent in operation and work on the absorption principle, at a rated

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(10) British Standard Codes of Practice. (1947), C.P. 331 101, 331.102, 331 103, 331 104, 332.101, 332.201, 332.301, 332.401, 332.501, 332 601,

consumption of 2,500 B.Th.U./hr. input. Various sizes of cabinet are made to meet all domestic requirements. A complete refrigeration service can be obtained for a consumption of approximately 15,000 B.Th.U./day in the average home.

A use for gas which has grown with the drive for planning all post-war houses is the heating of drying and airing cupboards. Special units, rated at approximately 12,000 B.Th.U./hr. input and completely isolated from the cupboard itself, are installed as heaters in the base of the cabinets, etc., and arrangements made for hanging clothes on appropriately-distributed racks inside. When it is a question of drying washing, arrangements need to be made for good ventilation of the cabinet in order to remove the moisture adequately from the clothes and the cabinet.

Chapter XV

THE DOMESTIC UTILISATION OF ELECTRICITY

by D. A. WINTER*

THE annual consumption of coal for the generation of electricity has steadily risen in the last 15 years from 10 to 24 million tons in 1944. Much of this is of a form or quality not readily acceptable by other industries, e.g., slack. Water power supplies are so small as to be negligible in this country and practically all the power is generated from coal. This coal is burned to raise steam which in turn drives turbo-alternators, and in the period 1943/44 resulted in a total quantity of electricity for sale of nearly 32,000 million kWh., of which 9,721 million kWh. were used for domestic lighting and power. Modern power stations average about 20 per cent. thermal efficiency, although some of the largest rise to over 30 per cent. With the completion of the Central Electricity Board's Grid System of distribution—a fine example of scientific planning—supplies of electricity, generated at a series of selected stations, are made available over a nation-wide network of transmission lines, thus bringing electricity more within the possible reach of everyone.

Public supplies of electricity were made available early in 1880 and were regulated by the Electric Lighting Act of 1882. Electricity was mainly used then for lighting purposes and was generally supplied as direct current. Electrical engineering, however, grew apace, and the economies of generating and transmitting power at high voltages over long distances, no less than the technical advantages of alternating current, have led to the virtual elimination of direct current in electrical distribution. The voltage for domestic use has hitherto been standardised at 230 but it has recently been resettled at 240.

The introduction of the two-part tariff system of charge has stimulated increasing use of electricity for domestic purposes other than lighting. The details of such systems are well known, and are based upon the accounting foundation of providing a fixed charge to cover the fixed charges associated with the making and distributing of current, and adding a running cost to cover the variable costs associated with the particular load. Many of these tariffs are definitely promotional in character with the intention of offering inducements to users to increase their domestic electricity load.

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* *Assistant to Technical Director, Radiation, Ltd.*

Intensive research and ingenuity by the electrical industry has evolved not only efficient and practical designs for the main domestic needs of lighting, cooking, space heating and water heating, but also for many small power units in everyday use in the home, as for instance vacuum cleaners, radio and radio-gramophones, laundry irons, refrigerators, washing machines, hair driers, clocks, fans and home cinemas. Electricity is the supreme motive power for many of the accepted domestic accessories which serve to ease the drudgery in modern life.

Lighting

Electric lighting is the accepted standard in modern housing. Not only is it extremely convenient, but it is simple to control at the touch of a switch, and is so flexible that by means of auxiliary plug-in points and flexible leads, desk or standard lamps or multiple lighting fittings can be arranged at will. A good standard of lighting in all rooms, offices and shops is readily possible and there can be no excuse for eye-strain because of lack of illumination. The cost of running is infinitesimal in comparison with the value of the service given.

Lighting fittings themselves are many and varied. The standard form depends upon the use of an electric lamp carrying a tungsten wire filament immersed in an inert gas, the filament being heated to white heat by the passage of the current, but latest developments make use of an electric glow discharge through an evacuated tube carrying traces of mercury or sodium vapour, and having, on the surface of the tube, a coating of material capable of fluorescing under the particular radiations emitted by the glow discharge, and so producing an intense light. Two-way switching and several other devices add yet further conveniences to a service which is already in a class by itself.

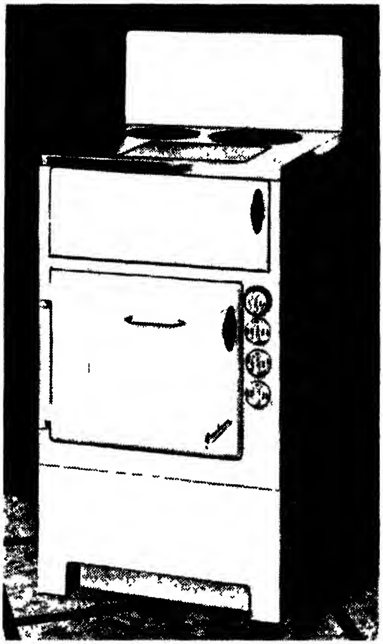
Cookers

The growth of the use of electricity for cooking has been steady over the last 10 years and, although final figures are not available, it is probable that there are at present in use in this country between 1¾ and 2 million cookers.

In cookers, as in many electric appliances where generation of heat is the main object, the heating effect is achieved by passing the current through resistance wires wound appropriately on formers, whereby temperatures even to the extent of bright red heat are attained.

The cooker usually consists of an oven, a grill-boiler and one or more boiling plates, assembled into a single structure with the oven either below the grill and boiling plates, or, in range models, alongside them with cupboard space under. Latest models have a cabinet-like outline with drop-down doors covering the grill and cupboard chambers and a drop-down covertop over the hotplate. Vitreous enamelled interiors and exteriors in various combinations of colours provide decorative appliances which are very readily kept clean.

Oven. The oven generally takes the form of a welded box-like structure closed by the door, vitreous-enamelled inside, and with the heating elements fitted in the side walls and sometimes additionally at the bottom or top. These elements are frequently covered by loose louvred internal lining panels, thus supplying radiant heat and hot-air circulation inside the oven. The oven is surrounded by a thick layer of heat-insulating material and is mounted in a rigid framework, usually of vitreous-enamelled cast iron strengthening members with vitreous-enamelled sheet iron panels as outer casing.* The oven door also is well insulated and when no thermostat is provided it carries a thermometer. A steam vent is usually provided in the oven door, sometimes having a "hit and miss" damper.



[BY COURTESY OF JACKSON ELECTRIC STOVE CO., LTD

Figure 88.—Electric cooker

Thermostatic control is provided on the latest models of electric cookers by means of a thermostatic switch fitted in the supply line to the oven and operated by the different expansion of a bi-metallic couple or strip or by an expanding liquid-in-bellows thermostat.

When a thermostat is fitted, the usual four-position switch is, of course, not required. Otherwise each individual part of the cooker, oven and hotplate alike, is customarily controlled by a four-position rotary switch with the four positions "Off," "Low," "Medium" and "High" corresponding with internal connexions which, in the case of the last three provide series, single-element or parallel running for the two circuits which make up any element.

Hotplate. The hotplate may include two or three boiling plates, one of which usually is open on the underside for use as a grill when a polished reflector plate has been removed. This latter is the grill-boiler. The hotplate itself is usually a casting, hinged at the back so that it may be lifted like a lid, with openings in it to fit the boiling plates. These latter are complete units with plug-in connectors, and are fitted with levelling screws resting on cross braces to enable the level of the plates to be adjusted so that the surface is just proud of the hotplate level.

The boiling plates may be in one of two forms, either a heating element

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* *J.I.E E., Vol. 82, No. 498, pp 565 and 583.*

covered by a cast plate machined flat in direct contact with the vessel to be heated, or an open type of heating element which becomes visibly red. Again, two types of open plate are possible, either a resistance heating element embedded in magnesia and the whole enclosed in a heat-resisting alloy sheath (usually nickel-chromium), or a thick resistance element working off a low voltage transformer and directly " live." The rating of boiling plates ranges between 1,000 and 2,000 watts. The covered plate gives a very smooth appearance and a surface which is readily kept clean, but it suffers in speed of operation by comparison with the open element, both as regards initial heating up and residual heat when boiling has been achieved. The open type element approaches nearer the flexibility of a gas flame burner. It might be noted in passing that thin-base or machined-base vessels are to be preferred for effectiveness and efficiency.

Hotplate switch controls are customarily of the three- or four-heat type, giving various degrees of heat. This confers flexibility and permits of lower inputs for simmering when once boiling has been achieved. A recent modification has been the use of an instrument called the Simmerstat which, as the name implies, is used for maintaining a simmering heat through the use of an automatic switching arrangement. The Simmerstat enables heat to be graded to maintain a simmering temperature with whatever type of utensil is used.

Grill. The electric grill is probably the best domestic device of its kind for effective toasting and grilling. As indicated above, it is customarily made to combine the functions of boiling and grilling, and it may sometimes form the separately-controlled top element in an oven. The use of a polished reflector plate above the element for grilling, or below it for boiling, increases the effectiveness and efficiency for these respective purposes. The grill may also be fitted with the Simmerstat.

Heat Storage Cookers

While most domestic cookers are designed for intermittent use, being switched on or off as required, there have been proposals for electrically-operated heat storage cookers. In these, the oven and hotplate are very heavily insulated against heat loss (the latter by hinged insulated covers) and current is consumed continually to ensure that both the heavy hotplate casting and the oven are at a temperature suitable for instant use. A rating of 500 watts is adequate in such a construction to give satisfactory results. The principle seems, however, not to have become popular for domestic use.

Breakfast Cookers

Mention should be made of a typical appliance which shows well the versatility of electricity. The Breakfast Cooker is a form of cooker-in-miniature intended for toasting, grilling, boiling and warming plates for a particular meal. Forms vary, some being on the lines of a small oven-griller and boiling plate, others being in the nature of well-insulated boxes (thermally) with the elements around the walls for general cooking, and an alternative grilling element to fit in the "lid." With the second type, of course, boiling must be carried out separately.

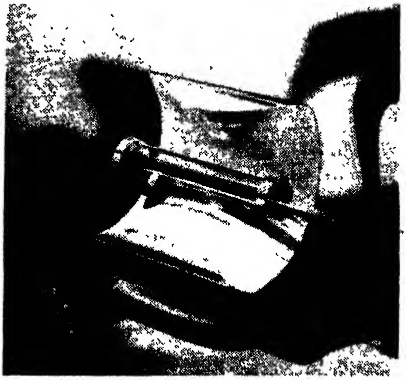
Miscellaneous Cooking Apparatus

There are many designs of one-purpose electrical appliances, intended for doing one specific culinary job, which may be plugged-in even on the sideboard or table. The electric kettle, with a rating of 1,500 watts, is perhaps the most frequently met of these, but there are also coffee percolators (500 watts), table toasters (500 watts) and plate warmers (300–400 watts), which assist in the preparation or serving of meals. Being special-purpose appliances designed specifically for the task in hand, they work very efficiently and give a welcome service. Toasters may embody mechanical devices for switching-off the current or ejecting the toast at the end of the predetermined toasting time.

Space Heating

The electric fire is a very versatile appliance with the great merit of being readily portable. The smaller sizes (up to 2 kW.) may be plugged into any convenient power socket. The larger fires (3 or 4 kW.) would normally be fixed at some focal point in the room, such as the hearth. Provided there is adequate ventilation in the room, the customary chimney from the fireplace may be entirely eliminated. For permanent fixing, built-in panel fires may find great use. Many and varied designs are available, usually with an incandescent helically-wound element on a former, supplemented in some cases by illuminated transparent mouldings simulating the coal or log fire. In other cases the element is placed at the focus of a curved reflector intended to give the appearance of a large heated surface and aimed at distributing the heat in desired directions.

For background heating purposes when it is required to take the chill off a room or to provide a continuous background of warmth, the tubular heater with a load of 60 watts per foot run is very effective. The low temperature attained by the surface (180° F. max.) is yet sufficient to give the necessary basis of warmth which may be supplemented by the higher-powered directional reflector heater. These appliances lend themselves readily to master-control by a room thermostat, whereby the back-



[BY COURTESY OF E.M.I. SALES & SERVICE, LTD

Figure 89. — SPACE HEATER. Electric reflector fire ground temperature may be regulated so as not to exceed a certain level.

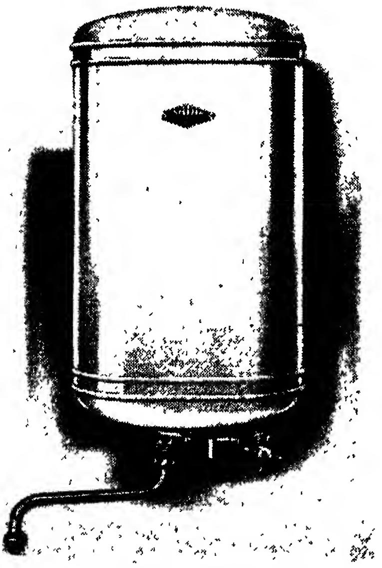
Warm air circulation is another method of room heating, readily possible by the use of electricity. In these appliances air is heated by passage over heating elements and then circulated around the room by slow-running fans. Many new artistic types are designed for the post-war market.

Whatever the form of heating appliance the thermal efficiency is substantially 100 per cent., which helps to off-set the low efficiency of electricity generation. With the use of the two-part tariff room heating by electricity can be very convenient and, for short period use, inexpensive

Water Heating

Electric water heating has the great advantage that there are no products of combustion to be disposed of. The only disadvantage is that bulk generation of hot water in very large quantities is limited on account of the probable overloading of domestic supply cables. The use of Instantaneous Heaters is therefore ruled out of consideration in normal circumstances for reasonable rates of hot water generation.

Three types of Storage Heater are in common use. Two of them embody a heating unit in a storage tank, one being a Single-point appliance with a storage capacity of approximately 1½ gallons, and the other a Multipoint appliance with a storage capacity of 15–20 gallons. Varieties of the latter are made for under-the-draining-board installation, and various makes differ in the position of the heating element or elements. In general the rated consumption of the Multipoint appliance may be anything up to 4kW., and of the Single-point appliance up to 2 kW. Both types are heavily insulated (thermally) and carry thermostatic controls, set to maintain the stored water at 160° F. The Single-point appliance, having a free outlet, is never subjected to mains water pressure, but the Multipoint appliance is designed to withstand the usual district water pressures up to 100 lb./sq. in.



[BY COURTESY OF AIDAS ELECTRIC, LTD

Figure 90.—Electric water heater

The third type is in essence *a* separate heating element which is customarily inserted inside an existing hot water storage cylinder. This is the well-known Immersion Heater and is an extremely adaptable appliance. The heating element is of the customary sheathed wire type with a coil of resistance wire embedded in magnesia and surrounded by a corrosion-resisting metal tube. It is made in various lengths according to the rating, the type of service offered and the size of tank into which the element is to be fitted. The unit screws into a standard 2¼ in. B.S.S. boss which is customarily provided in cylinders and tanks for this purpose (see B.S.S. 417 – 1944, 688 – 1944) if required. It can, therefore, be very readily fitted to any existing storage system when it can be used either as a sole source or an auxiliary supply of hot water. Thermostatic control is usually applied and the whole forms a very easily-installed and simply-operated source of hot water. It is used as an auxiliary to the solid-fuel-fired system adopted by the Ministry of Works in some of the temporary and permanent housing.

Refrigerators

Electric refrigerators may be either of the absorption type, where use is made of the heating element to create circulation of the refrigerant, or they may incorporate power-operated pumps to create mechanical circulation. The latter type is by far the most numerous since the power needed is very small and a variety of refrigerants is available. The details of working are beyond the scope of this chapter, but are well dealt with in the appropriate specialised reference books such as " Modern Electric and Gas Refrigeration " by Althouse and Turnquist (Chicago, 1939), and " The Refrigerating Data Book " (New York, 1939), to which attention is directed.

Miscellaneous Domestic Apparatus

Electricity is of use in the home as a source either of heat or of power. Cooking, space heating and water heating equipment are the most common instances of the former, but towel rails, irons, blankets and bed-warmers are equally serviceable. Of no less importance are those uses in which power is required. Electric motors, some of very small size, provide means of operating vacuum cleaners, fans, washing machines for home laundry (both for agitating the clothes to be washed and for removing excess water afterwards by centrifugal action), electric clocks, hair-driers, home cinematographs, dry-shavers. In country houses without main water supply, electrically-motivated pumps provide a valuable service.

An interesting point with regard to clocks is that by virtue of the periodicity of alternating current and the fact that the alternations can be, and are in normal circumstances, very closely controlled, small synchronous electric motors of uniformally constant period of revolution may be constructed and by suitable gearing be used for indicating the time with great accuracy.

Modern examples of electric irons are extremely interesting in external design as well as for the fact that many of them incorporate thermostatic control.

The unique physical properties of the radio valve in its various forms, the reception of radio waves and the transformation of their modulations back to audible sound waves or visible light waves (in television), the harnessing of the properties of electrical circuits with the interrelation of capacitance and inductance, and, in the radiogram, the translation of physical vibrations into sound, epitomise some of the marvels of electricity applied to everyday life.

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