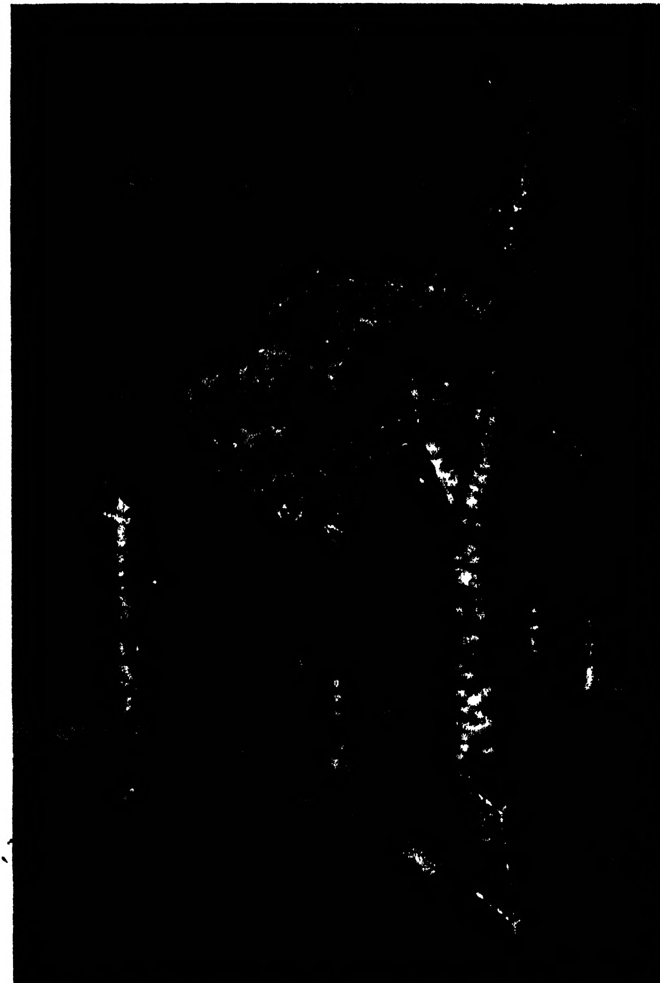
RUBBER



PLANTATION HEVEA TREES

(1466)

PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

RUBBER

PRODUCTION AND UTILIZATION OF THE RAW PRODUCT

BY

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FOURTH EDITION

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PREFACE
TO THE FOURTH EDITION

THE text has again been carefully revised throughout and expanded in certain parts, for example, the last chapter on the direct utilization of latex, which is an important recent development in the industry.

We desire to acknowledge with thanks the valuable assistance of Mr. G. E. Coombs, of the Rubber Growers' Association, in augmenting the botanical and planting side of the early chapters with reference to recent developments. We also tender our thanks to Mr. W. E. Duck and the Firestone Tyre and Rubber Co. Ltd., and to Mr. S. Gritton and Messrs. David Bridge & Co., Ltd., for providing us with many new illustrations.

THE AUTHORS.

LABORATORIES,
15 BOROUGH HIGH STREET,
LONDON BRIDGE, S.E.1.
1934.

PREFACE
TO THE FIRST EDITION

THIS little book is intended to serve as an introduction to the study of Rubber, and deals both with the production of the raw material and the subsequent manufacturing processes.

A good deal of interest is now taken in Rubber from different points of view. During the last few years we have seen the successful development of the Plantation industry with which we have been closely associated. Our consulting practice also brings us into contact with the rubber manufacturing industry to which the attention of the public has been drawn owing to the popularity of the motor-car.

It is hoped that this book will be found suitable to the requirements of the average reader who is desirous of obtaining general information on the subject. In a narrower circle the book should prove useful to planters who wish to get some idea of the methods employed by manufacturers for the utilization of their raw material, while those interested in manufactured goods will, we believe, be more particularly interested in noting the methods employed for treating the latex and curing the rubber on the plantations.

We are much indebted to Mr. J. K. Burbridge for reading through the proofs, and to Mr. P. M. Matthew, Mr. Herbert Wright, and various firms of rubber

machinery manufacturers for some of the photographs and illustrations.

The space at our disposal has necessitated a very brief treatment of all the matters dealt with, but it has been our aim to make the book as comprehensive as possible.

THE AUTHORS.

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LONDON BRIDGE, S.E.1.

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CHAPTER I

INTRODUCTORY

RUBBER, or india-rubber, was the name originally given to a material of West Indian origin used for removing pencil marks. To the English chemist, Priestley, in the eighteenth century is given the credit of this discovery. Rubber in a modified form is still used for this purpose, although at the present day other commercial applications of far greater importance have to be considered.

Central and South America may be taken as the home of the more important rubber-producing trees, and, consequently, we turn to Spanish sources for the earliest historical mention of rubber. We have early reports of games played by Indians with elastic balls made from the gum of certain trees, and Christopher Columbus is said to have seen the natives playing with rubber balls in the Island of Haiti.

For a long time india-rubber was nothing more than a chemical curiosity. One of its first applications was that of waterproofing cloth. India-rubber dissolves easily in many organic fluids, such as naphtha, benzene, and carbon tetrachloride, and on evaporation of the solvent the rubber is left again in the form of a film. This film may be said to be impervious to water—water-resisting would be a better word, for as a matter of fact, when immersed in water, it slowly swells and absorbs a small quantity. However, by spreading a layer of rubber solution on cloth it is easy to render it waterproof, and garments made of this cloth have been known as mackintoshes ever since the early days when they were made by a firm of that name.

Raw rubber, however, is not an ideal substance with which to treat a wearing material. Even the best qualities of raw rubber get soft and sticky in hot weather, and it is safe to say that, had it not been for the discovery of a radical nature by which these difficulties were overcome, rubber could never have been adapted to the numerous commercial uses to which it is now put.

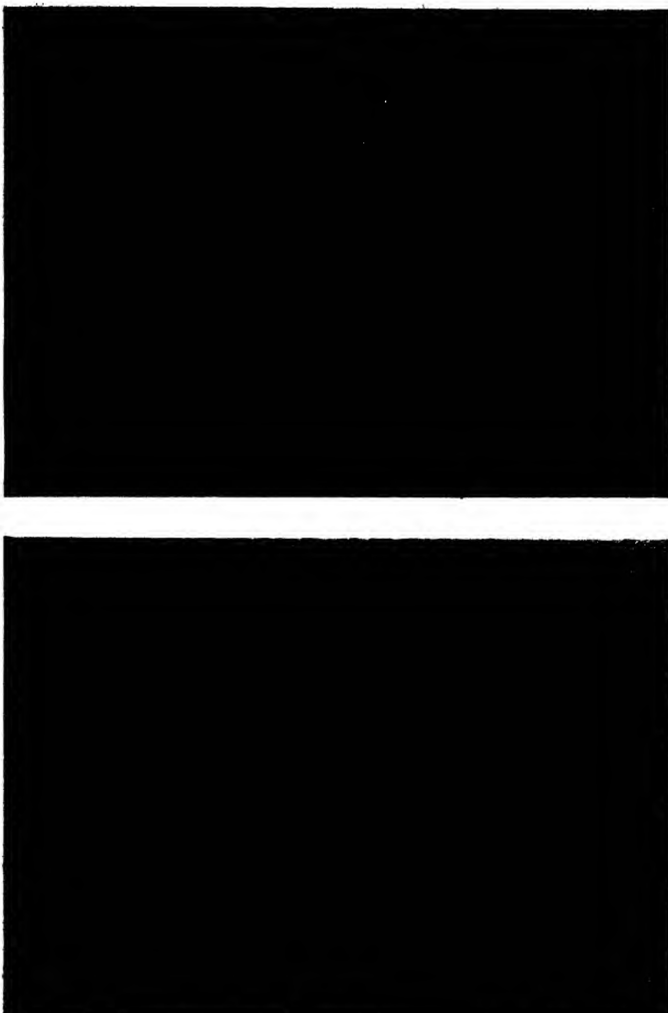
This discovery, which was made in the year 1839 by the American, Charles Goodyear, consists in heating the rubber with sulphur under carefully regulated conditions, when a chemical reaction takes place and the resulting product is no longer sensitive to the ordinary seasonal changes of temperature, and in addition to this, its strength and elasticity are actually improved. This process, known generally as vulcanization, was discovered independently by Hancock in London, who, later on, came to an arrangement with the Mackintosh firm by which the process was applied to the manufacture of waterproofs. The original firm of Hancock's in the Goswell Road, London, are still manufacturers of rubber goods. Hancock also found the means of uniting pieces of india-rubber into one mass by the process of mastication or kneading, a discovery of prime importance for the manufacture of rubber goods. Nowadays nearly all commercial rubber goods go through the vulcanizing process, the only exceptions of importance being the crêpe rubber soles for footwear and the tape used for the first layer surrounding the copper conductors of electric cab'es, for although the cable may be heated to a vulcanizing temperature for the purpose of vulcanizing the outer layers which contain sulphur, the first layer of pure rubber tape next to the conductor remains unaffected.

CHAPTER II

THE RUBBER TREE (*Hevea Braziliensis*) AND RUBBER LATEX

EVERYONE is familiar with common milk weeds or spurges: when the stem is broken a milky juice exudes; but whereas such milk or *latex* yielding plants of any size are comparatively rare in temperate climates, they are exceedingly common in the tropics. Many of the largest trees in the tropical jungles of South and Central America, the Continent of Africa, India, Ceylon and the Malay Archipelago, exude a milky juice when the bark is cut or damaged, and the leaves or twigs torn or snapped across. This milky juice has its origin in a system of capillary vessels, which are found both in the primary, that is to say, first formed, tissue of the stems and leaves, and also in the secondary tissue, generally in the under layers of the bark, and sometimes also in the sap-wood of the tree trunk and branches.

Under the microscope the milky juice, or, as we will now call it, latex, consists of innumerable minute particles suspended in a watery liquid or serum (see Fig. 1). The particles may vary in shape and size according to the botanical origin. Thus, the particles of Rambong latex resemble drops of oil, those of Ceara latex rods, and those of Hevea latex take a rounded form, seldom wholly spherical but generally ovoid though sometimes cone-shaped, varying in size from 0·5 to 3 micromillimetres. The analogy with animal milk, which consists of a liquor containing tiny globules of butter fat, is at once apparent. The latex globules, however, are much smaller and do not consist of fat, but of rubber



By courtesy of *The Rubber Growers' Association*

FIG. 1. PHOTOMICROGRAPH OF RUBBER PARTICLES IN LATEX

(*caoutchouc*) and resins. Very many trees yield a latex from which only resins or resin-like substances are obtained. These are practically valueless. Others yield some caoutchouc with a larger or smaller proportion of resin, and their commercial value may be taken as roughly proportional to the percentage of the former. The latex of the *Hevea Braziliensis*, or Para rubber, contains only 2 to 4 per cent of resin, and yields the finest commercial rubber.

The term "resin" is used in a general sense, as there are innumerable resins obtained from different trees, each of which, if considered from a chemical standpoint, consists of complex mixtures of different individuals. The so-called "resin" of Para rubber (*Hevea Braziliensis*) contains in addition to resins an inert substance (inosite derivative) and fatty acids, e.g. oleic acid, lipins, etc.

Terminology

The native Indian word for rubber is "cahuchu," and this was first adapted in the form "caoutchouc" (German, *Kautschuk*) as a synonym for rubber. The word in English is now generally used to signify the chemical substance or hydrocarbon (compound of carbon and hydrogen), which is the essential ingredient of raw rubber. It forms the main portion of commercial raw rubber. Raw rubber is the natural product as obtained direct from the trees, and consists of caoutchouc in intimate mixture with small proportions of protein, resin, and other substances. At one time the bulk of raw rubber available was obtained from the Amazon district and some of it is known as fine Para from the name of the port of shipment. Nowadays native Brazilian Para rubber forms only a very small part of the raw rubber available—the great bulk of it (98·6 per cent last year) is derived from plantations in the East, although it is necessary to bear in mind that a large number of the latter are small-holdings which are responsible for "native rubber" (see p. 27). Such rubber is also known as Para rubber, because it is derived from the same tree as that found in the valley of the Amazon and its tributaries.

Para Rubber

Hevea Braziliensis. This tree, as its name implies, is a native of Brazil. It is found in the extensive forests drained by the Amazon and Orinoco rivers and their tributaries. It occurs, however, not only in Brazil, but in Bolivia, Peru and other parts of tropical South America. The raw rubber is found in commerce under various names according to the method of preparation and source of supply. The brands known as fine hard Para, hard and soft cures, are the best. The inferior grades are partly derived from other species of genus *Hevea* and are not smoke-cured. *Hevea Braziliensis* thrives in the forests of the Amazon valley, in what are known as the "islands" in the delta of the river, and also in the higher lands lying back from the valley of the river. The climate of this region is extraordinarily uniform, the annual mean temperature being about 80° F., and the daily range usually between 75° and 90°. The annual rainfall is from 80 to 120 inches.

The general habit of the Para rubber tree will readily be seen from the various illustrations. It attains a height of over 60 feet and a girth of 8 to 10 feet. The leaves are characteristically three-lobed. The flowers are individually small and inconspicuous, but are borne in little sprays, and are succeeded by dry fruits, each containing three seeds about the size of large Kentish cob nuts, and with the curious brown and black mottling so characteristic of seeds of many plants of this family, *e.g.*, the castor-oil bean. The seeds are very oily and soon lose their vitality, so that special precautions have to be taken to transport them successfully over long distances when required for propagation. When ripe the hot sun causes the capsule to burst with a sharp report, and the seeds come rattling down in all directions.

Collection of Wild Rubber

In Brazil the trees are tapped during the dry season, which varies in different districts. The rubber collectors, or *seringueiros*, search the forests for suitable trees, which should not be less than about two feet in girth. An incision is made in the bark with a small axe, and a receptacle fastened immediately beneath. The latex begins to run at once and is caught. A number of cuts are made in each tree, a cup fastened under each, and allowed to remain for a few hours. At the end of this time the flow of latex has ceased and the contents of all the little cups are transferred to a larger vessel. The next step is to convert the still liquid latex into solid rubber. A fire is lighted and nuts of various species of palms placed on it. These produce a dense smoke. A kind of paddle is dipped in the latex and held in the smoke. The rubber coagulates or dries down, forming a thin layer on the paddle. This is then dipped into the latex and again smoked. Another layer is deposited on the first, and the process is continued until a sufficiently large mass of solid rubber has been collected on the paddle. It is then removed and is ready for export.

The smoke-cured fine Para comes into commerce in the form of " loaves " or large, rounded masses, brown to black on the outside but white or greyish in the interior, with a peculiar smell of smoked fish. The other brands are also produced in rounded, irregular masses of various sizes, dark on the outside where the rubber has dried, and whitish in the interior where it is still wet. In some of the inferior grades putrefaction has set in and the rubber when cut open smells very unpleasant. This is particularly marked in the African rubbers. These latter are of very little importance to-day, as the cost of collecting an inferior quality of the rubber makes competition with the plantation product very difficult. Low-grade rubbers are usually soft and plastic. For this reason they act as softeners in rubber manufacture. This fact probably explains why small amounts still find their way to the market.

Plantation Rubber

The introduction of the Para rubber tree (*Hevea Braziliensis*) into the East was no easy matter, on account of the difficulty of securing the seeds in the face of opposition from Brazil, and of preserving the vitality of the seeds after collection. In spite, however, of these hindrances, the late Sir Henry Wickham succeeded in bringing a considerable quantity of seeds to Kew, where they were planted and a fair proportion germinated. The young plants were dispatched to Ceylon in 1876 in Wardian cases. As early as 1877–8, young plants raised from cuttings were dispatched to Burma and the Straits Settlements. After the first flowering and consequent seed crop in Singapore in 1881, seedlings became available for dispatch to other countries. The illustration on page 10 is of some of the original trees in the Singapore Botanical Gardens.

As already stated, over 98 per cent of the world's present rubber supply, amounting in all to about 850,000 tons per annum, is derived from plantations of *H. Braziliensis* trees in the Malay Peninsula, Ceylon and the

FIG 2. HEVEA RUBBER TREES

Malay Archipelago generally. This output could be largely increased were the price to rise appreciably through increased consumption.

On the average trees do not yield rubber until they are four or five years old, even under the most favourable conditions. It should be understood, however, that maturity in this respect is rather a question of development than age of the tree. The various brands of plantation rubber differ broadly from the old-type wild rubbers in the greater care taken in their preparation, and the fact that they are marketed dry instead of wet, that is, with seldom more than 1 per cent of moisture; whereas wild rubbers may contain anything up to 15 or 20 per cent. Plantation rubber is sold principally in the form of smoked sheets, or crêpe. Various "off grades," i.e. slightly discoloured or dirty rubber, which are produced from time to time, fetch lower prices than standard smoked sheet.

Methods of Cultivation

It used to be thought that the plant would only grow on moist, preferably periodically inundated, ground and near the sea level. This, however, has proved not to be the case, and good results have been attained in Ceylon up to an elevation of 2,000 feet, and in some cases even higher, but the growth is then much slower, and the trees are much older before they can be tapped. This slowness of growth is probably entirely determined by the lower temperatures and greater relative scarcity of soil water which obtain.

The other requirements are practically those indicated as existing in the Amazon valley, i.e. a rainfall of about 100 inches per annum, and a mean annual temperature of about 80° F. The plant grows very rapidly from seeds, the seedlings being raised in nurseries.

By courtesy of *The Rubber Growers' Association*

FIG. 3. CLEARING LAND FOR RUBBER PLANTING IN THE FEDERATED MALAY STATES

The trees have been felled and burned, and the ground cleared, ready for planting

These usually consist merely of patches of land, where the soil has been prepared and fenced in if necessary. After one or two years' growth, the tops of the young plants are cut off, the plant pulled out of the ground, and the root trimmed. The young plants, known in this state as "stumps," are then planted out in the open and generally throw out fresh shoots after remaining dormant for two or three months. The distance apart the plants are set depends on circumstances. If eighteen feet by eighteen feet we get 135 trees to the acre, whereas twenty feet by twenty feet reduces the number to 109. In the early days it was considered advisable to plant comparatively closely, and to tap the trees until they become crowded, and then by removing the worst give the others room for further development. In this way a large yield would be obtained during the first two or three years after the trees came into bearing. It has been found, however, that it is not easy to remove trees closely planted without damaging their neighbours, and the roots and stumps left in the soil are always a source of danger, as encouraging white ants and fungus pests. Nevertheless it has been found imperative to thin planted areas, even when wide planting has been adopted.

The Yielding Power of the Trees

From early days it was observed that the power to produce rubber in both quality and quantity varied with individual trees, and that this power was something apart from conditions of nutrition. Individual yield of trees forming the populations of average blocks of rubber showed that some 70 per cent of the rubber came from 30 per cent of the trees, and that the range in individual yield varied from 1 lb. to 25 lb. of rubber annually.

The pendulum thus swung towards a very dense initial planting of seeds from high yielders, up to 400 per acre, with very heavy thinning in the young stages and subsequent gradual thinning to a stand of 70 to 80 trees per acre. By this means the yield per acre was increased up to 50 per cent, but the index of increase was a matter of hazard since so little was known of the factors which controlled the transference of the increased yielding power in the seeds themselves.

Scientific investigation has been, and still is, going on concerning the variability of seedling stock and the analysis of the factors which determine the transference of "high-yield," but side by side with this and, for the time being beating it in the race, has come the operation of budding as a means to yield increase.

Budding simply entails the transplantation of a live bud into the healthy tissue of a seedling. It is part of the stock-in-trade of all horticulturists. The application of the technique to rubber was, however, a baffling and slow process, but so well known now are the factors which make for success that the budding of rubber has become a matter of mere estate routine. As a rule, green buds are taken from a high-yielding tree, known to be inherently high yielding, and transplanted under the bark of a seedling about 1 in. above the ground. The successful fusion with the seedling tissue is shown by its tendency to swell, at which stage all food from the seedling root is diverted to it by cutting off the seedling stem just above the transplanted bud. The new crown develops from the bud itself and carries its characters.

It is interesting to speculate what might be procured from growing the highest-yielding buds on the most vigorous stock. There are untold possibilities. At all events present scientific advice is to plant rubber as large blocks of buddings of the same parentage. This system is known as monoclone planting. Yields up to 1,500 lb. of rubber per acre are likely to be procured by it. When this is compared with the present seedling planting average of 500 lb. its importance can be appreciated.

Catch Crops and Clean Weeding

During the first four years, catch crops, such as groundnuts, cassava, bananas, cotton, etc., can be grown. Sometimes the rubber plants are set amongst matured coffee or tea, with the idea of removing the coffee or tea altogether later on, i.e. gradually transforming a tea or coffee estate into a rubber estate.

Rubber planted among tea or coffee does not grow so rapidly in the early stages as on newly cleared land. Much rubber in the Malay Peninsula has been planted on land from which one or more crops of cassava have been taken. This latter is an exhausting crop and the land is usually abandoned after the third crop. It is only to be expected that the growth of rubber trees on such land will be somewhat retarded, at any rate during the early stages. The same applies to old coffee land. As regards clean weeding, it is now recognized that it is a mistake to leave the land between the young trees bare and exposed at one time to the heat of the tropical sun, and at another to the wash of tropical rains, although it has been found in practice that if the weeds are to be kept from choking up the young trees the simplest course is to keep them out altogether; early attempts to cultivate plants such as the wild passion flower or crotalaria to cover up the soil were not successful, but more recently " vigna " and other plants have been used with great advantages. In the Malay Peninsula cleared land is choked up with a miscellaneous growth in a very short time; a few heavy showers followed by a few days of sunshine, and land which was bare soil will be covered with a thick growth of weeds, which in two or three months may reach a height of five or six feet. Prominent among these is the *Lallang*, a very coarse grass growing to a great height, which is exceedingly difficult to eradicate. Rubber planted on sloping ground requires special precautions to prevent excessive wash and loss of surface soil. For this it is customary to dig ditches in the form of terraces which follow the contour of the land, and also catch pits have been found effective.

The recent economic depression which has had such a disastrous effect on rubber production has dictated a policy of upkeep on the estates, and theories as to the benefits or otherwise of clean weeding have had to go by the board. It seems not improbable that herbaceous undergrowth, persistently cleaned or better still kept free from lallang, will be allowed as ground cover in the future. Carpet growths of *Centrosema* and *Calapogonium* are recent developments in this problem in that they create humus and prevent erosion.

Pests and Diseases

It used to be the general custom to leave the stumps and half-burnt tree trunks on the land to be planted after the jungle trees had been felled and burnt off. The ground was thickly strewn with them and they took years to rot away and disappear. An example of this method of clearing and preparation for planting is shown in the illustration on page 12. The more progressive estates have now cleared the timber off the land in spite of the considerable expense involved, as the rotting wood harbours a dangerous fungus pest, *fomes lignosus*, which attacks the roots of the *Hevea* tree with fatal results. This fungus has been found on trees of all ages, and if allowed to spread would destroy acres of rubber in two or three years. It is very common all over the Malay Peninsula, although not difficult to cope with if detected and dealt with in the early stages; the affected tree is dug up, burnt, and the pit limed, while its immediate neighbours are surrounded by a shallow trench, so that if the fungus has spread to these as well they are isolated from the rest of the plantation.

Fomes lignosus forms white thread-like filaments on the roots of the tree and spreads from one tree to those adjoining where the rootlets interlace. On dead wood it forms fructifications, and the spores may be spread by natural agencies to distant parts of the plantations. There are other fungoid growths, such as *nectria* (canker), and other diseases which attack the bark; also a leaf fungus which causes the leaves to fall prematurely. For details the reader is referred to *The Physiology and Diseases of Hevea Braziliensis*, by T. Petch. White ants (*termes gestroi*) give a little trouble on some estates, and when the trees are young damage is often done by wild deer and even by monkeys. A recent disease is the *corticium Javanicum* from the Island of Java, which has been detected in both the Malay Peninsula and Ceylon. It forms a pink growth on the branches.

Oidium is a leaf disease which is giving very considerable trouble throughout the Middle East. It is a leaf disease which causes secondary defoliation, not to be confused with the similar symptoms caused by *Phytopthera*, and necessitates power spraying with colloidal sulphur.

Systems of Tapping

As is pretty obvious, some trees will be lost by one means or another and the vacancies are filled in with fresh supplies. At a certain stage in their growth, seldom less than four years after planting out, the trees are ready for tapping. The time when tapping can begin depends on the trees attaining a sufficient size, which is judged by measuring the girth three feet from the ground; eighteen or twenty inches is usually considered sufficient. Of course, trees planted at the same time do not all reach this stage together. It is usual to go out into the field where the trees are "coming into tapping" and "mark out" those that have attained the required size by scoring them with a V-shaped gouge along the lines where the cuts are to be made.

A great many arrangements of cuts have been tried, most of which have been abandoned. One system, now abandoned, was the "herring-bone" or a modification of this, the "half herring-bone." Cuts were made on the bark, branching at an angle of about 35° on either side of a shallow vertical groove four or five feet long which served to guide the latex oozing from the side cuts. In this way there might be as many as ten or twelve sloping cuts on one side of the tree, covering half the "tappable" area (Fig. 4). The tree was furnished with a little tin spout at the bottom of the vertical cut, from which the latex dripped into a cup placed at the base of the tree. In the half herring-bone (Fig. 5) there were still half this number of cuts. It was found that some cuts yielded more than others, and almost, if not as much latex was obtained with only two cuts if the results were taken over a long period. This led to the introduction of the basal V (Fig. 6). To-day even this system has been found too drastic, and at the present day most tapping is restricted to a single cut. The main reason for restricting the number of cuts was the necessity which gradually became apparent of conserving the bark or more properly the cortex.

The process of tapping, which may be done every day, or at less frequent intervals, consists in paring away a thin shaving of bark from the lower surface of the branch cuts. This opens the latex vessels, the ends of which become eventually plugged when the flow ceases and are opened again at the next tapping. In this way the bark of the tree is gradually pared away from above until the whole of the bark on one side of the tree is

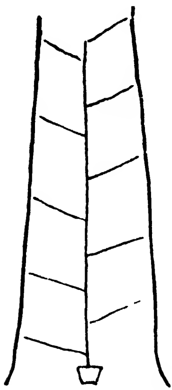


Fig. 4
Whole Herring-bone

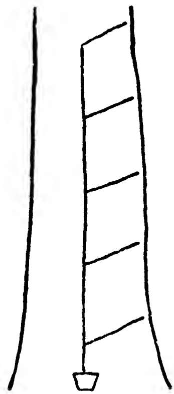


Fig. 5
Half Herring-bone

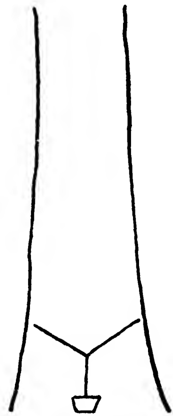


Fig. 6
Basal V

removed. All the while, however, fresh bark is re-forming. Each day, or every other day, a thin shaving is pared away so that the cut descends at the rate of an inch in sixteen to twenty-five days, tapping being carried out every day. When all the bark is pared away from one side of the tree, a start is made on the opposite side. In this way the whole of the bark of the lower four or five feet of the tree is removed.

It used to be thought that four or five years would suffice for the complete renewal of the bark, so that at the end of this period tapping on the renewed surface could begin again. It has, however, been found that this estimate was unduly optimistic, and that eight or

By courtesy of *The Rubber Growers' Association*

FIG. 7. THE MODERN METHOD OF TAPPING

ten years are required, although a great deal depends on the vigour of the trees, distance of planting, situation, and a number of other factors. To economize in bark surface, tapping every day has been generally replaced by tapping on alternate days or even every third day. Another method is to rest the tree half the time, that is, tap regularly, say, for three months, and then rest for three months before tapping again.

Wound Response and Collection of Latex

The latex flow is very irregular, individual trees yielding a varying quantity. Sometimes one tree out of several hundreds will yield ten or twenty times the average quantity and sometimes trees run dry altogether and yield nothing. When a tree is tapped for the first time the flow is almost negligible and only a few milky drops issue from the freshly pared surface, but each day the quantity increases until the full flow is obtained. This susceptibility of the bark to repeated wounding is known as the " wound response," and is the reason why much larger yields of rubber are obtained than the early planters originally anticipated.

Rubber estates are usually partitioned off into divisions of a few hundred trees, to each of which is apportioned one or more tapping coolies whose business it is to tap the trees. A start is made at sunrise, as the flow of latex is better early in the morning. The bark shavings may be kept as rubber adheres to them. A little latex, too, remains in the branch cuts which dries down and can be stripped off. These form two of the varieties of plantation " scrap " rubber. A coolie goes round with a pail an hour or two after tapping when the latex has ceased to flow and empties the cups, and the pails of latex are taken to some central station for coagulation and further treatment When the cups are emptied a little latex will remain round the sides. This should not be left indefinitely in the cup or it would putrefy and contaminate the latex the next time the cup was used. Two methods may be employed for "scraping" the cup, that is, removing this latex which eventually goes to yield what is known as "cup-washings scrap." The latex-collecting coolie may carry round with him two pails, an empty one in which the latex is collected, and the other half-full of water in which each cup is washed. Alternatively the latex may be allowed to dry down in the cup and then removed in a thin film when dry. The latter method is now generally adopted.

Latex often begins to coagulate before it arrives at the coagulating station. This is almost entirely due to shavings of bark which fall into the latex cups and form centres for coagulation, and results in the latex containing a number of lumps of various sizes of semi-coagulated rubber which must be removed before the latex is strained. These lumps are separately treated and form another variety of scrap. In addition, therefore, to the rubber (sheet, crêpe, etc.) prepared from the liquid latex, or first latex, which amounts to about 75 per cent of the total yield, there are the following varieties of scrap which are usually worked up and marketed in the form of crêpe rubber—

(1) Lump rubber }
(2) Cup washings } 10 per cent.

(3) Rubber stripped off the cuts, or tree scrap, 9 per cent.

(4) Bark rubber, 4 per cent.

(5) Mud, or earth rubber, 2 per cent. This last, the most inferior quality, is obtained from latex which has been spilt from the cups or flowed down the bark of the tree in wet weather and coagulated in the soil beneath.

Latex Coagulation and Rubber Drying

The treatment of latex in the rubber factory depends on whether or not it is intended to wash the coagulated rubber in the ordinary two-roll rubber-washing machine. The latex always contains bits of bark, shavings, leaves, twigs and other impurities, besides lumps of coagulated rubber. The latex must be freed from these impurities by being strained through a fine mesh sieve. The strained latex is poured into tanks fitted with movable partitions and there is added a small quantity of diluted acetic acid by stirring. When the tanks are full, the partitions are put in place. Standing a few hours is sufficient to cause the whole mass to set after the addition of about one part of acetic acid to 500 or more of latex, and the whole forms a solid mass like a junket, but much tougher and harder. The next day the slabs of "coagulum" are taken out and most of the liquor is squeezed out by passing them through steel rollers with diamond-shaped markings. The name of the estate is usually engraved on the rollers so that all sheets are marked and can be identified as the produce of the estate. The first plantation rubber was made in the biscuit form, as the planters used soup plates, the first things that came handy, in which to coagulate their rubber. Both biscuits and sheets must be dried before they can be packed for export, and for this purpose were laid out on wire gauze shelves, or else hung up in a loft out of the sunlight, but with as good a ventilation as possible. Drying rubber is a long and tiresome process, particularly in a climate where the air, although hot, is at times practically saturated with moisture. The drying may take several weeks. The white surface turns dark like the surface of a cut apple, and the mass gradually shrinks until it eventually gets translucent, the last traces of moisture showing through as white patches where the sheet is thicker, and therefore slower in drying. The sheet is not properly dried until the rubber is everywhere translucent. Sheet rubber is now seldom marketed in the air-dried state for these reasons, and also because such rubber always goes mouldy, but is smoked by hanging in the upper part of a "smoke-house." On the earth below fires are lit, which are kept smouldering so as to produce plenty of smoke but no flame. The rubber dries more quickly thus than in air. It is impregnated with smoke and consequently it does not so easily get mouldy. This is sold as "plantation smoked sheet."

The process for the production of sheet rubber is carried out on a large scale, although on many estates a different method is frequently adopted; only part of the rubber may be worked up in the form of sheet. If crêpe is being made the latex is coagulated and the coagulated rubber washed in a stream of water while being passed repeatedly between the rollers of an ordinary rubber-washing machine. The machine flattens out the rubber into long strips usually 8 in., or 10 in., wide with an irregular uneven surface due to the tearing action of the rollers. This, when dried, comes on the market as crêpe.

For some purposes the colour of the rubber is of importance and a premium is put on very pale rubber. This effect is easily obtained by heating the rubber, which destroys the *enzymes* or ferments which produce the darkening in colour. This treatment, however, damages the rubber, and pale crêpe is now produced by adding a small quantity of sodium bisulphite to the latex before coagulation. A very small quantity, such as one to two parts per thousand parts of latex, is all that is required. This improved treatment has resulted from the investigations carried out by the scientific staff of the Rubber Growers' Association.

The scrap rubber from various sources, being dirty, is generally washed and sold in crêpe form. It may usually be distinguished by its dark colour from the best grades, which are pale. Plantation rubber is almost always marketed in the form of either crêpe or sheet.

The best plantation rubber, whether it be dark or pale, is always translucent, except after exposure to winter cold, when it becomes opaque. The " frozen " rubber is easily thawed, when it regains its transparency. Owing to the fact that plantation rubber is thoroughly dried before exporting, cases of putrefaction are rare, but some trouble is occasionally experienced with air-dried or insufficiently smoked sheets, owing to the growth of mildew on the surface. A good deal has been written about " tacky " rubber, or rubber which on arrival in Europe is found to be soft and sticky, or partially decomposed. This is not uncommon with some of the lower grades of wild rubber, but is comparatively seldom met with in the plantation product.

It is, of course, impossible to prevent a certain amount of stickiness in the case of the lowest grades such as earth rubber. Where, however, the better grades, particularly first quality crêpe and sheet, show any tackiness, it is almost entirely due to carelessness in preparation. While sheet is almost invariably satisfactory, crêpe occasionally shows signs of tackiness due to contamination with oil containing ground particles of copper alloy from the bearings of the crêping machines. Cases have also occurred where rubber has become tacky through being exposed to bright sunlight.

Some years ago rubber manufacturers were almost unanimous in declaring plantation rubber inferior to fine Para, and various theories were put forward to explain the supposed inferiority of plantation rubber. Among others it was stated that the seeds from which the Eastern rubber trees have sprung were collected from a district (Tapajos) in Brazil which does not yield the best-class rubber. This has been denied by Wickham, who collected the seeds. Attempts have been made to distinguish between the different varieties or sub-species of *Hevea* and the quality of rubber yielded, but authorities differ, some stating that the *preta* or black tree, which gives such fine yields, cannot be distinguished from the *branca*, which is supposed to yield only a weak-quality rubber. Now, however, that manufacturers have had more opportunity of gaining experience with plantation rubbers, many of them admit that much plantation rubber is equal to or even better than the fine, hard Para, formerly regarded as the best rubber on the market. However this may be, the frequently repeated statements as to the superiority of fine, hard Para rubber have led to attempts to prepare rubber in this form in the East. The labour entailed is considerable, and the method is generally recognized to be inapplicable to the conditions on rubber estates. Moreover, rubber so prepared in the East has not been favourably received by the manufacturers. Several machines have been devised for the more rapid preparation of this form of smoked rubber. Most of these machines are on the drum principle, that is to say, a drum is revolved in a smoky atmosphere and the latex applied in a thin film to the internal or external surface of the drum. When a sufficient number of layers have been applied in this manner, the band of rubber is slit with a knife and removed. Various difficulties arose in working these machines, particularly in applying the latex in an even continuous layer. Further, the output is relatively small and the process is expensive owing to the heavy consumption of fuel, nor is the quality of the rubber any better than that of smoked sheet properly prepared—indeed, we should prefer the latter. Mention may also be made of sprayed rubber, prepared by spraying the latex into hot air. The fine droplets dry and collect on the bottom of the chamber as a " snow " which is swept up and pressed into blocks. The use of such rubber has some disadvantages from the manufacturer's standpoint.

As very little rubber produced to-day is derived from wild sources, it follows that manufacturers are now mainly dependent on plantation supplies, which formed 98·6 per cent of the total world's output in 1933. Of plantation rubber about 62 per cent was produced in British colonies, 33·5 per cent was produced in the Dutch East Indies, and the remaining 4·5 per cent in Siam, Sarawak, and French Indo-China. Of the British and Dutch output approximately 44 per cent was derived from small-holdings, that is, native rubber.

Packing of Rubber

The normal packing adopted for plantation rubber is plywood casing. The cases are square and hold about 160 lb. of rubber. They have the great advantage of keeping the rubber clean during transit, and, being rigid, they prevent the pressure resulting from packing in a ship's hold from causing the rubber to "mass," that is, the sheets sticking together. On arrival at the factory the cases are smashed and the rubber removed. The method is obviously not ideal; it is expensive, as the plywood cannot be used a second time, and the breaking of the case is liable to contaminate the rubber with wood splinters. A bale of rubber as extracted from a plywood case can be seen in the illustration on page 46.

Experiments have been made on packing rubber in various types of bags, e.g. jute sacking, paper bags, etc. These have the advantage of being cheaper than plywood, but usually keep the rubber less clean. Also, if it is desired to separate the sheets of rubber at the factory it is necessary to dust them with a lubricant powder before packing, e.g. with French chalk, in order to prevent the massing of the rubber during storage.

CHAPTER III

OTHER RUBBER-YIELDING TREES

THESE are to-day of very little importance, as they yield only a fraction of the rubber supplies available. As the total American (South and Central) production is only 1·4 per cent, and the bulk of this is from the *Hevea Braziliensis*, that is, the Para rubber tree, a very short mention of other rubber-yielding trees is all that is necessary, and that only as a matter of interest.

Castilloa (or *Castilla*) *Elastica*, the Spanish name of which is Ule, is a native of Central and some parts of South America. It has been extensively planted in Mexico and other parts of Central America. The plant has been known to science longer than any of the other rubber-yielding plants, and was first described by Cervantes at a meeting of the Royal Botanic Garden of Mexico, in July, 1794. The rubber passes commercially under a great variety of names, mainly denoting the country from which it has been obtained.

The trees cannot be tapped in the same way as Hevea, as the latex starts clotting and the rubber globules begin to separate as soon as the latex exudes from the cuts in the trees. This interferes with the flow and makes it difficult to collect in a cleanly manner. The bark of the Castilloa, too, is harder and it does not show the "wound response." The trees are therefore tapped at intervals of a few months only, but then yield many times what would be obtained from a single tapping of Hevea trees of the same age. On standing, the rubber globules rise to the surface of the latex like cream, and they may be conveniently washed by stirring up repeatedly with fresh quantities of water and then drawing off the wash waters from the bottom, or by centrifuging in the same way as cream is separated in a cream separator. It is not easy to get the globules to unite to a cake of rubber; heating is usually necessary, or alcohol in some form may be added. Much of the rubber is obtained from latex which is allowed to dry down on leaves or on the trunk of the tree itself.

A characteristic of the rubber is the very dark colour of the dried outer surface, the latex from this tree containing a dark colouring matter.

Ceara or maniçoba rubber is obtained from the *Manihot glaziovii*, a tree of the Spurge order (Euphorbiaceae). This tree grows only to a medium height, but is remarkable on account of the rapidity of its growth and the early age at which it begins to yield rubber, which may be put at three to four years. The rubber comes chiefly from the province of Ceara in the Brazils; it is translucent and of a yellow to brown colour. The yields of rubber from planted trees have been disappointing.

As stated, the Ceara rubber tree grows with great rapidity, plants raised from seed often reaching to ten or more feet in height within one year and thirty feet by the end of the second year. Once seen the trees are easily recognized by their spreading habit and their five-lobed, curiously bluish-grey leaves. The bark is thin and very hard; it peels off in thin sheets or strips. The plant will thrive in places absolutely unsuited to most cultivated plants. Rocky and stony soils of poor quality and arid districts present no obstacles to it. Trees raised from seed can be tapped when about four to six years old. The thin outer layers of bark are usually removed, and either the whole surface scraped sufficiently deep to allow the latex to escape, or incisions

FIG 8. ROAD ON A RUBBER PLANTATION, SHOWING YOUNG HEVEA TREES

FIG. 9. FACTORY ON A RUBBER PLANTATION

made here and there with a knife. The latex is very liquid and flows readily.

Rambong and Assam Rubbers

These are derived from the *Ficus elastica*, a tree growing to enormous size in Assam and various parts of Malaysia. Like the well-known Banyan tree it throws out aerial rootlets which fix in the soil and rapidly increase in thickness so that the fully-grown tree is supported on a tangle of trunks instead of one central one. These frequently have exactly the appearance of props fixed as if to bear up the branches. The leaves are fleshy and of a rich dark green colour, while the new shoots are enveloped in a bright red sheath. The plant is familiar to most people as the India-rubber plant, to be seen in houses and conservatories in this country. It is extremely hardy and has been largely planted in the East, particularly in Assam and Java, where it is also indigenous. The latex, which is very white in colour, flows rapidly on cutting the bark, but the wounds must be made deep to obtain a good yield. Fresh cuts require to be made at each tapping and the tree has an inconvenient habit of throwing out aerial rootlets from old wounds. The latex remains liquid for almost any length of time, but can be coagulated by heating and stirring, or by adding an alcoholic liquid. It may also be coagulated by mixing with a small proportion of Para latex. When acid is added to the mixture the coagulation of the Para carries the Rambong latex with it, although the latter is by itself not coagulated by acids. The rubber may also be obtained by allowing the latex to dry down, as often happens, on the branches and trunk of the tree. Sometimes mats or leaves are placed on the ground underneath the trees on to which the latex is allowed to drip.

By courtesy of *"The India Rubber Journal"*

The freshly coagulated rubber is often pink in shade, as also is the wood of the tree. This is probably due to a ferment in the latex, and it is difficult to prepare the rubber in such a way as to keep it pale in colour.

Funtumia Rubber

Lagos silk rubber is the product of the *Funtumia elastica*, a native of tropical Africa. It will often be found referred to as *Kickxia elastica*, but the true Kickxias are all Malayan, whilst the Funtumias are African plants. The tree occurs in Liberia, the Gold Coast, Lagos, and Southern Nigeria, the Cameroons, the Congo and Uganda. Until quite recently it was thought to be entirely confined to the West Coast of Africa, but Mr. M. T. Dawe, in the course of his botanical exploration of the Mabira Forest, Uganda, found it there also, an important discovery materially altering our ideas of its geographical range. Funtumia belongs to the same natural order as the Landolphias, and, like them, is related to our common garden Periwinkle. Its flowers are white or yellow and the seeds are very characteristic, each bearing a beautiful silky plume about two inches long, by means of which they can float through the air like thistledown, and may often be found travelling about through "West Coast" forests.

Quite a number of companies were formed to cultivate the tree, but their experience has been disappointing and the yields low. The latex, like that from the Castilloa and Ficus trees, is not easily coagulated, and to effect this, similar means have to be adopted, that is, heating, etc.

Landolphia Rubbers

These rubbers are obtained from various species of the genus Landolphia, popularly known as vine rubbers,

FIG. 11. FACTORY SHOWING HEVEA RUBBER TREES IN THE FOREGROUND

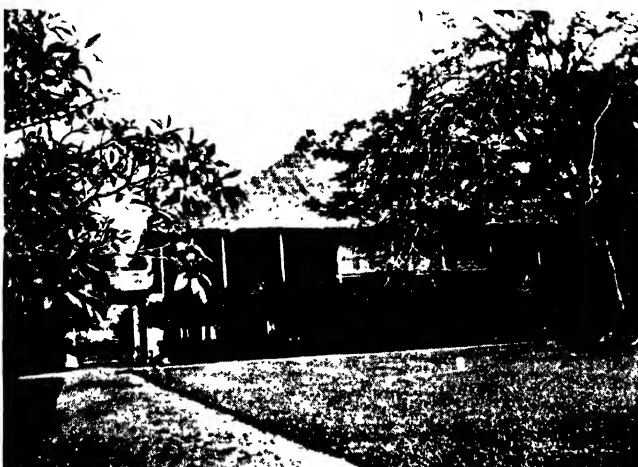


FIG. 12. BUNGALOW ON A RUBBER PLANTATION

as they are climbers. They correspond to the British "periwinkles" (*Vinca*), whose stems also exude a milky juice or latex, although this is not rubber-yielding. The Landolphias are found mostly in Africa and Madagascar. They grow to a great size, climbing to the tops of the highest trees and developing heavy, twisted, rope-like stems of hard wood. Many species bear sweetly scented flowers in profusion, often succeeded by large brightly coloured and sometimes edible fruits.

Collection of the rubber is in the hands of natives. The methods are naturally very primitive. The thick woody stems are hacked with knives and the latex which exudes is caught in earthenware vessels and coagulated with acid juices, or allowed to drip on to leaves and there dry down. It is also recorded that in some parts the native smears the latex over his body and strips it off when it is coagulated. One can well understand that the native is not too particular in his methods, and the African rubbers are among the dirtiest on the market. The stench emitted on washing in the factory has in some cases been so repulsive that their use has been restricted. To-day they are hardly met with, and some rubber manufacturers could not use them at any price, having dispensed with their washing plant.

The so-called root rubber is also obtained from a species of Landolphia, viz., *L. Henriquesiana*, but is not really obtained from the roots but from the rhizomes or underground stems. There is also a rubber obtained from the tuber of the Ecanda. Samples examined by the authors were clean and the rubber was of fair quality.

Inferior Grades and Pontianac

We have now learnt something about the more important rubber-yielding trees and the methods by which the rubber is extracted. There are, however, other natural products which may be classed as rubbers, although of inferior quality, however carefully they may be prepared. As already explained, there are numerous tropical trees which yield a latex consisting of caoutchouc or caoutchouc-like substances with a large proportion of resinous constituents. In this group must be classed some of the species of castilloa, ficus, etc., which yield a rubber of low commercial value, but there are a large number of others not previously mentioned which may be grouped in this class. We have examined such products collected in both Africa and the East. Of these the most important is Gutta Jelutong, also known as Pontianac or Dead Borneo, a soft white or grey mass containing a large percentage of moisture and coarse impurities which are difficult to remove. It is derived from different species of *Dyera*, in particular *Dyera Costulata*, and may be prepared for manufacturing purposes by heating with a quarter to half its weight of linseed oil. The thick, semi-liquid mass is then strained through fine mesh gauze under pressure, or the straining may be carried out without the addition of oil by using sufficient pressure and keeping the mass hot enough. In this form it was largely used, especially on the Continent, for compounding with other rubbers in the manufacture of certain classes of cheap rubber goods. To-day it is hardly used by rubber manufacturers and the main outlet for the material is manufacture of chewing gum.

Guayule Rubber

This account of the commercial raw rubbers would not be complete without a reference to Guayule rubber, which is obtained from a shrub growing wild over large tracts of country known as " bush prairies " in Mexico. The rubber is not obtained by tapping, but the shrubs are gathered whole, or we may say harvested, and taken to large factories where the material is worked up on scientific lines. Considering the unpromising character of the raw material, the rubber obtained is surprisingly good, and by suitable purification and deresinification yields a product from which tyres can be manufactured.

The shrub belongs to the natural order Compositae, and is known botanically as *Parthenium Argentatum*. It usually grows to a height of two to three feet, the wood is hard, yellow in colour and heavy. It contains 90 % of the rubber in the plant. The leaves are of a silvery green, and the flowers small and whitish in colour. The shrub grows best on a shallow, rocky soil at a considerable altitude with small annual rainfall and a wide variation in temperature.

The shrubs are cut down and delivered to the factory, where they should be worked up as quickly as possible. The plants are cut up and ground so that when mixed with water the rubber floats to the surface, leaving the heavy wood and debris at the bottom. It is, however, better to grind with weak caustic soda solutions which dissolve part of the resins and most of the dark gummy colouring matters, so that a pale amber-like product results. This is capable of further purification by suitable solvents. In spite, however, of this treatment samples analysed by the authors seldom showed less than 15 % of resinous matter, while dark cruder products contained over 20 %, besides much moisture.

Tau Sagyiz

Another rubber-yielding shrub is the Tau Sagyiz, which is cultivated in Russia. The yield of rubber from the shrub is said to be comparatively high, and the rubber itself of good quality and fast-vulcanizing. However, it is not considered to be economically competitive with plantation Hevea.

PART II

MANUFACTURING PROCESSES

CHAPTER IV

Preliminary Treatment

In previous chapters we have described the production of raw rubber from the latex and we shall now proceed to show how this rubber is made up into manufactured goods.

The raw rubber is stored in vaults at the wharves in the ports as it is received. Of these London and Liverpool are of first importance. Here it is sampled, that is to say, a few pieces are removed as nearly as possible representative of the whole consignment. On these samples the rubber is subsequently sold.

Rubber Washing

Arrived at the factory, the first process consists in washing and drying the raw rubber. Most plantation rubber is clean and dry and hardly requires any further treatment. The reverse, however, is the case with other rubbers, and so accustomed are manufacturers to washing and drying all their raw material that when plantation rubber first came on the market they insisted on putting this, too, through the machines, and for some purposes still continue to do so. For instance, in factories making inner tubes or electrical goods such as cables or ebonite, rubber washing may be still carried on. In the former case all extraneous particles must be eliminated, and in the latter the electrical properties are improved by the reduction of protein and naturally occurring water soluble substances in the rubber. Many plantations have justly acquired a reputation for rubber free from all dirt and moisture, and as we pointed out many years ago, manufacturers are now satisfied in many instances to take these brands as they are, without further treatment.

Now that plantation rubber forms so large a proportion of the world's total production, the washing and drying departments of the rubber factory are utilized to a less extent than previously.

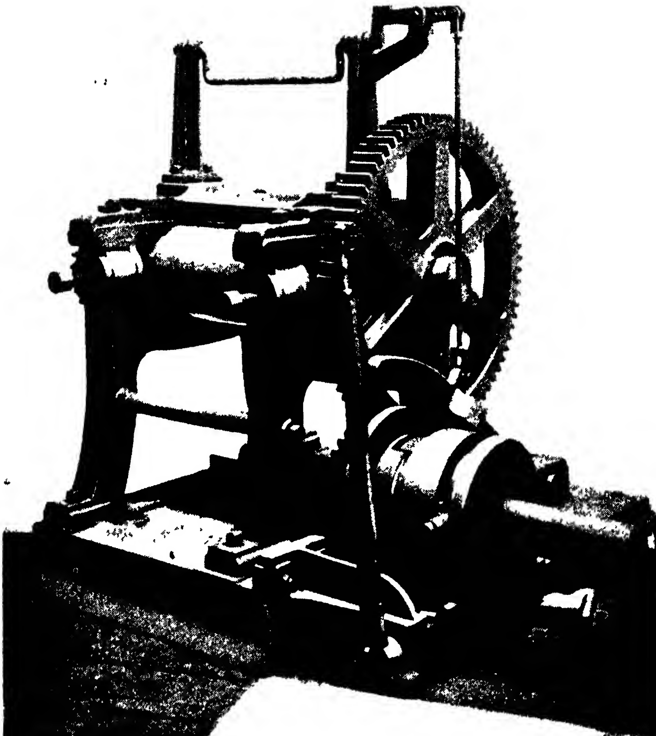
While on this topic mention should be made of a tendency at one time noticeable, both in this country and on the Continent, to erect factories solely for the purpose of washing, drying, and preparing rubber. This is now confined to the washing and drying of native rubber in the East which is exported as "amber crêpe."

The process of washing rubber in the rubber factory is carried out in exactly the same manner as on the plantation, but the rubber requires some preliminary treatment before it is ready for the rollers. The raw rubber, if in large lumps, e.g. Brazilian Para, is cut into smaller pieces, usually by hand. These pieces are thrown into a tank containing water kept warm by a pipe carrying live steam. The dry rubber gradually absorbs moisture and swells and the lumps get softer and can be better treated between the rollers. The length of treatment in hot water varies with the nature of the raw material, which is removed as soon as it is sufficiently soft.

It is difficult to describe the action of washing rollers to those who are not familiar with this type of machinery. As one roller moves faster than the other, there is a sort of grinding or tearing action on the rubber which is held back on one side by the slower moving roller and dragged forward by the other ; at the same time it is submitted to considerable pressure. The net result of passing once or twice between the rollers is to reduce the rubber to the form of sheet with a very torn and irregular surface. To give the rollers a better grip they are grooved on the surface with spiral or diamond-shaped markings. Under the combined influence of the squeezing and tearing action, particles of dirt, bark, etc., are forced out, in some cases thrown out by the elastic rubber and carried away in the current of water which is kept playing on the rubber all the time. From the grooved rollers the sheets are taken to the smooth rollers which have a similar action to the former, but reduce the rubber to a much thinner and more even sheet. This facilitates the next process, the drying.

Washing rollers (Fig. 13) are very strongly constructed and are usually driven direct from the main shafting by spur wheels and pinion, with a suitable clutch, although belt driving is sometimes preferred. The rollers are provided with safety appliances, so that they are readily thrown out of gear in a moment by pulling a hinged rod or cord, as their crushing power is tremendous, and there is a possibility of a careless operator getting his hand drawn in. The driving-shaft and clutch are seen in the lower part of the machine. The safety rod is immediately above the rollers. Pulling this releases a lever which allows a heavy arm to drop and throws the clutch out of gear. The two screws seen in front of the machine are for the purpose of adjusting the distance between the rollers.

There are two other types of washing machines used to a limited extent. The first of these, an internal washing machine, has been found the most effective for washing dirty rubbers with the minimum amount of mechanical effect. It consists of a pair of rollers in a deep trough; the rollers move at the same speed, and are much more deeply grooved than the ordinary washing rollers and work under water. The rollers are made with



By courtesy of *Messrs. Joseph Robinson & Co.*

FIG. 13. RUBBER-WASHING MILL WITH CLUTCH

peculiar wavy grooves and are placed at the bottom of the trough. The impurities are carried away through gratings in the sides of the vessel. It requires little attention, being more or less automatic ; the charge of rubber is put in and the machine left for half-an-hour or longer till the washing is complete.

The other type is also partly automatic, and is now little used except for washing balata and gutta-percha. It is similar in build to the papermaker's hollander, and consists of an oval trough with centre partition, between which and one side a heavy roller revolves carrying bars or knives. The trough is filled with hot water and the gutta is opened up between the bars of the roller and similar bars fixed on the bottom underneath the roller, and washed clean.

Rubber Drying

The drying is carried into effect by hanging up the strips from the washing machine in festoons in dark or darkened chambers provided with a good natural draught. It used to be said that the more gradually rubber is dried, the better the results obtained when it is made up into vulcanized goods, but no satisfactory explanation has, so far, been forthcoming, and the statement requires some modification. There is no doubt that the mechanical treatment to which the rubber is subjected in the process of washing impairs the physical qualities, or, as it is usually expressed, tends to destroy the " nerve "; but this only to a slight extent if the treatment is not carried too far.[1] The same thing applies to an even greater extent to rubber in the process of mastication.

[1] Nobody seems to be able to give a satisfactory definition of the meaning of the word "nerve" as applied to raw rubber, but the term is in constant use. The word "nerve" may be taken as summing up those characteristic physical qualities peculiar to india-rubber.

Loss on Washing

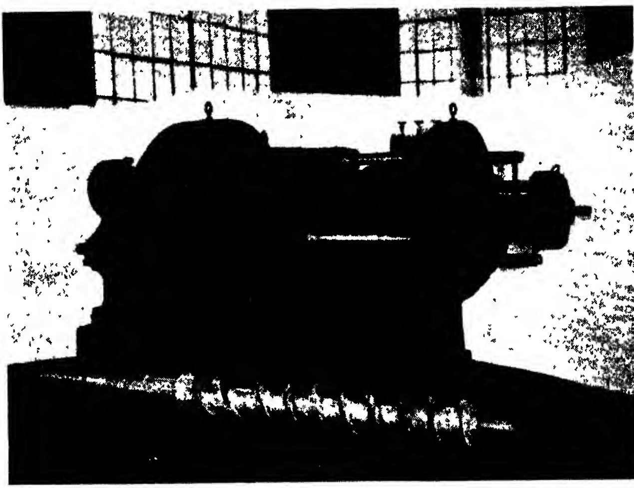
In the course of washing and drying, native wild rubbers lose considerably in weight, as might be expected, partly through removal of grit, bark and other impurities, conveniently classed as dirt, and secondly, through loss of water. As already explained, plantation rubbers, being almost always clean and dry, lose practically nothing; the only exception in this class is some of the scrap rubbers, but even these are nearly, if not quite, dry and have generally been washed before shipment. On the other hand, the very best grades of wild rubber suffer considerable loss on washing; even the standard fine hard Para loses about 20 per cent, chiefly due to removal of moisture. Low grades of wild rubber might lose 50 or 60 per cent.

Refining

An alternative process to washing, which is much cheaper and yet at the same time an adequate treatment for plantation rubber, consists of refining the plasticized material after milling (see next chapter) by "forcing" or extruding it through a nozzle fitted with a fine sieve (40 mesh) which is supported by a perforated plate. Any impurity such as grit, dirt, etc., is left behind on the sieve and the extruded rubber is cut off into convenient lengths and stacked ready for use. An illustration of a refining extruder is shown in Fig. 14. (Compare with forcing machine, page 82.)

Rubber Blending

One effect of washing rubber is to blend it; that is to say, if rubber from different sources is being washed the effect is not only to cleanse it but also to mix it. This is a valuable result owing to the fact that raw rubbers, even from the same source, vary very slightly in composition from time to time, and in order to obtain uniform properties, particularly as regards vulcanization, it is advantageous to blend the different supplies together.



By courtesy of *The Bridge-National Machinery Co.*

FIG. 14 TEN-INCH STRAINER OR REFINER
Forcing screw removed and illustrated separately

However, the blending of supplies of rubber from different sources is usually carried out in large factories by either or both of the following systematic procedures—

1. On arrival at the factory the plywood case is stripped from the bale of rubber, which is then placed on the table of a mechanical cutter (see Fig. 15). The bale is cut into six or more equal segments, one piece from each bale being placed in each of six or more bins as it is cut up until the requisite charges of raw

By courtesy of *The Bridge-Farrel Birmingham Machinery Co.*

FIG. 15. RUBBER BALE CUTTER: CUTS INTO TEN PIECES

rubber are obtained. These are then put aside for the next stage of the process, milling (see later).

2. Further blending is obtained at a later stage by mixing the masticated rubber according to the following scheme—

1A	B	C	D
2A			
3A			
4A			

where 1A–4A, 1B–4B, etc., represent the positions in which batches of masticated rubber are placed as they come off the mill. 1A–1D, 2A–2D, etc., represent the order in which they are removed for the further mixing process (see later). Thus, if rubber from different sources is being masticated, the method of removal for mixing ensures a blend of each mastication.

CHAPTER V

COMPOUNDING AND MIXING

Vulcanization

This term is applied to the process or change by which rubber is made to combine[1] with sulphur, the result being the formation of vulcanized rubber. This differs in certain important respects from the original raw rubber in possessing greater strength and being less influenced by changes of temperature.

The process of vulcanization may be brought about in several ways. The rubber may be immersed in a bath of molten sulphur. On raising the temperature, combination sets in, spreading gradually from the outer surface of the rubber to the interior. The method is of historical interest, being one of the first discovered, and adapted to a time when the means of mixing and compounding rubber goods was unknown.

The method employed in the great majority of cases consists of bringing the rubber into intimate admixture with finely powdered sulphur and heating the mass (1) in moulds, or (2) between steam-heated plates in a press, or (3) between layers of cloth, or (4) simply unconfined and resting in a layer of chalk. The vulcanization process is commonly termed "curing," and the last-named method is known as the "open cure."

For the sake of completeness we may here mention another system of vulcanization, termed "cold cure," which is carried out on a considerable scale for high-class goods made up from thin sheets. It consists of

[1] The combination is undoubtedly chemical, but some consider that the cause of the change is physical, or mainly physical.

dipping the articles into a solution of sulphur chloride in a solvent, such as carbon bisulphide, or otherwise applying the solution to the surface of the rubber. With the help of the solvent the sulphur chloride penetrates into the rubber and both the sulphur and the chlorine combine with the rubber to vulcanize it.

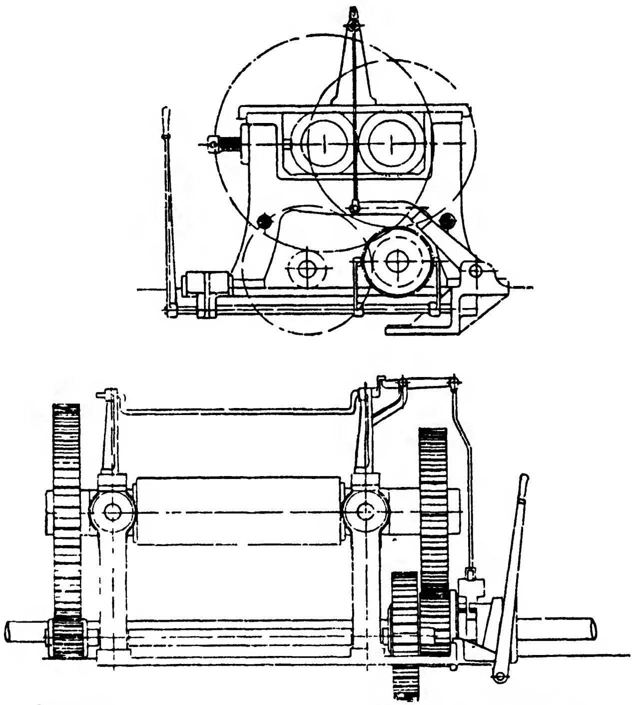
Mention should also be made of the Peachey process, in which the articles are submitted to the action of hydrogen sulphide and sulphur dioxide gases.

Mastication or Milling

In order to bring the washed and dried rubber into such a condition that it can be mixed with sulphur and other ingredients it is masticated, that is to say, worked or ground between rollers till it is soft and dough-like in consistency. The plant usually employed consists of two steel or chilled iron rollers with smooth faces and so geared that one roller moves faster than the other. Except for details in build these rollers resemble the ordinary washing machine, but in addition they are hollow and bored for the purpose of steam-heating, and are so arranged that the workman can turn on steam for heating or cold water for cooling as desired.

A pair of mixing-rollers are shown diagrammatically in Fig. 16, geared direct to the main shaft. In front are screws for adjusting the distance between the rollers, and on the top are adjustable cheeks on either side for confining the compound and preventing it spreading over the ends of the rollers. In the figure the same machine is shown in section and elevation.

The operator from long experience judges the temperature with his hand, and varies it according to the degree of softness desired. When the rubber is soft and of poor quality the temperature can be kept low; indeed, if raised too high the rubber would stick to the rollers and become unworkable. By correctly adjusting the temperature the sheet of rubber follows the slower moving roller, which is immediately in front of the



By courtesy of *Messrs Joseph Robinson & Co.*

FIG. 16. DOUBLE-GEARED MIXING MILL

operator, and forms a continuous band round this roller on gradually bringing the rollers up to one another. One roller has the bearing blocks fixed, while those of the other are adjusted by screws on either side of the operator. The temperature of the rollers with a good-class rubber is such that the hand can just be kept upon them. The friction produced during mastication soon raises the temperature, and hence the necessity for a cold water supply to keep the rollers from getting too hot. Great care is needed when cold rubber is first put into the machine, and it is not until it gets warm that it begins to flow and work easily. It is, therefore, common to provide a hot plate or steam chest, that is, a flat, steam-heated box on which the rubber intended for mastication can be warmed before putting into the machine. Large mixers may be rollers eight feet long and a foot and a half in diameter, although, perhaps, the commoner sizes are of rather smaller dimensions. The general tendency is to use larger rollers.

When sufficiently milled or masticated, an operation which may take up to half-an-hour or so, the rubber should be soft enough to " take up " the mineral powders, sulphur, and other ingredients, but it is usual to put the rubber aside for a time after masticating before proceeding further with the mixing. For some purposes another form of masticator is employed, but more recently internal mixers of different types have been introduced which are more efficient than the ordinary roller mill.

Mixing

The mixing is carried out on the same machines as the mastication. These are, as a matter of fact, usually known as mixing-mills, or perhaps more shortly as "rollers." The operator has given to him on a tray all the necessary ingredients which have been carefully weighed out ready for the batch of mixing. He starts with the rubber on the rollers, and as soon as this is soft enough he adjusts the distance between them, so that the layer of rubber carried round on the near roller is just too thick to pass round it without being carried against the farther roller, and thus the plastic mass heaps itself a little between them as shown in the illustration (Fig. 17), in which A is the slower moving of the two rollers.

The operator then shovels the " drugs " or minerals on to the top of the rollers, so that what is not at once caught up and buried in the rubber remains in the space between the rollers and is gradually absorbed instead of at once falling between them. When all the minerals have been

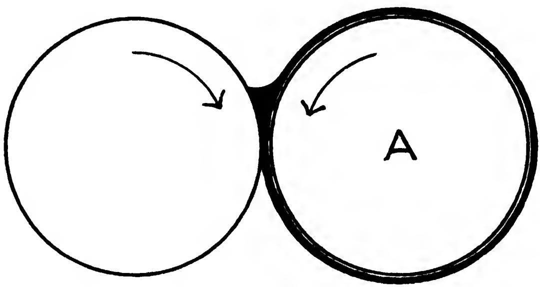


FIG. 17. ILLUSTRATING POSITION OF RUBBER AND ROLLERS DURING MIXING

emptied on to the rubber, probably some of them will have fallen between the rollers and have been caught on a tray immediately underneath. The operator sweeps the powders out of the tray with a small hand-broom and shovels them on to the rubber again, repeating the process until the whole of the minerals are absorbed. To help the mixing it is a good thing to slit the rubber at an angle half-way across with a knife pressed against the roller as it moves in front of the operator, and then fold the flap over on to itself. This helps to get the mixing uniform and prevents the layer of rubber merely passing round and round on the roller without drawing the minerals in with it. The rollers are next brought up close to the "grind," and the whole of the batch passed through once or twice with the purpose of producing a complete admixture and breaking down any lumps of mineral imbedded in the rubber. After opening the rollers a little and passing through a few more times, the mixing is finished and the mass can be sheeted to any desired thickness or otherwise moulded as required.

The great art in mixing consists in distributing the minerals uniformly and regularly throughout the entire mass of rubber without overworking it.

As previously mentioned, both the operations of masticating and mixing can be carried out on the same machine, but in large works separate machines are used at the different stages of treating the rubber. Thus, one machine may be kept running simply for the purpose of warming up the cold rubber, which has got hard on standing, and getting it into the plastic condition ready for mixing in the next machine.

Internal Mixers

More recently the internal mixer has been adopted to an increasing extent for milling and mixing rubber. An illustration of a well-known make of this type of machine is given (page 54). Its mechanism is similar to that of the mixing mill, but the rotors are totally enclosed and work in a trough. In addition, the rotors are not completely cylindrical, but are partially knife-shaped so as to have a tearing as well as a compressing (rolling) action on the rubber. This facilitates the mixing process and enables it to be completed in a much shorter time than is the case with ordinary rollers. In addition, owing to the mixing chamber being totally enclosed, this machine has the important advantage that it makes less dust than the open rollers. Considerable power is required to operate a Banbury mixer, and the work done on the

By courtesy of *Messrs. David Bridge & Co., Ltd.*

FIG. 18. INTERNAL MIXER

No. 9 spray-cooled Bridge-Banbury

rubber generates a great deal of heat. This has caused the normal mixing process to be split up into a mixing stage in the internal mixer, when all the ingredients except the sulphur are incorporated, followed by a "sulphuring" stage on ordinary rollers when the sulphur is added to the mixed rubber after it has cooled. This procedure is necessary to avoid prevulcanization (scorching). Attempts are being made to modify the internal mixer, by adopting such devices as internal spray cooling in the rotors so as to make it suitable for the preparation of complete mixings without "scorching."

For large factories making tyres or other articles containing carbon black or other light powders such as magnesium carbonate, the internal mixer is a great asset, for it economizes in floor space and labour (operative) charges, and gives a greatly increased output with less generation of dust. The following comparison indicates the economic advantages obtained by the use of internal mixers, always assuming that the full output of the machines can be utilized. This is based on an American survey of a plant in operation—

	6 *Roll Mills* (60 *in.*)	1 *Banbury* (*No.* 3)	
Daily production (7 hours)	10,000 lb.	10,000 lb.	
Average batch	100 lb.	120 lb.	
Mixing time per batch	25 min.	5 min.	
Output per hour	1,440 lb.	1,440 lb.	
Costs per 100 lb.—			*Reduction*
Fixed charges	$ 2820	$.1000	64·5%
Power	$.2556	$.0544	78·7%
Operating labour	$.3150	$.1041	67·0%
Compounding labour	$.0400	$.0333	16·7%
Totals	$.8926	$.2918	

Savings—	
Per 100 lb.	$ .6008
Per day	$ 60.08
Per year	$18,024.00

Calendering

For most purposes the rubber-mixing is next taken to the calendering rollers. The simplest possible form of calender consists of two perfectly true and smooth rollers,

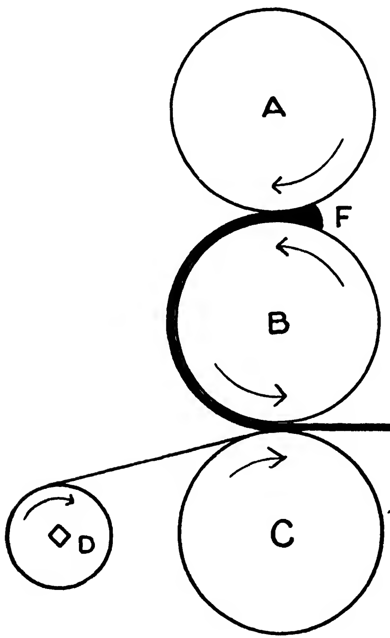


Fig. 19. Illustrating Position of Rubber, Cloth, and Rollers during Calendering

one superimposed upon the other, the mass of mixed rubber being fed in between the rollers on one side and passing out in the form of a sheet on the other. The sheet so produced is led to a wooden roller on to which it is wound between a layer of cloth as fast as it is formed. Most calenders consist of three or more rollers, and the

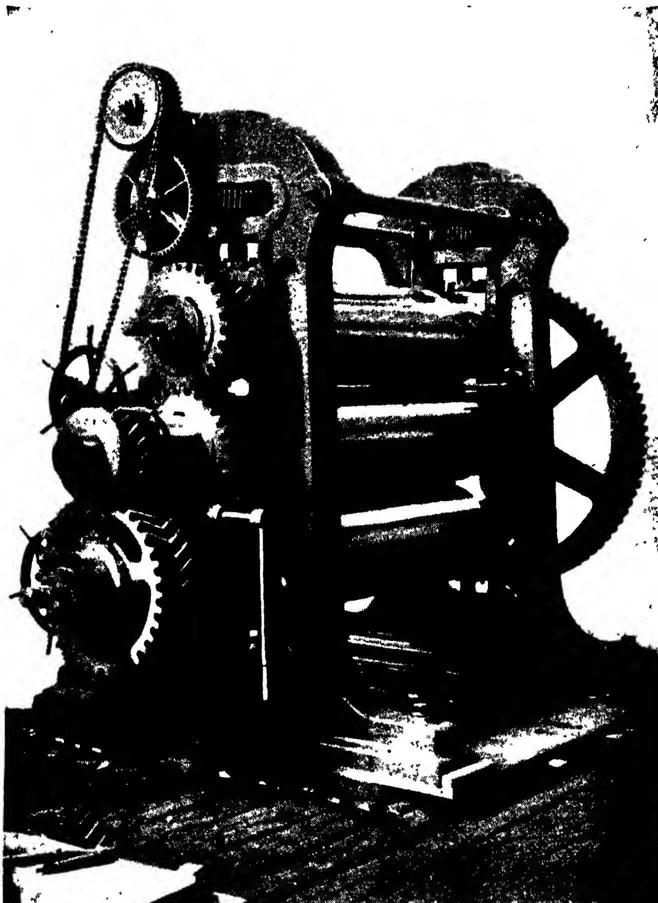


Fig. 20. Three-bowl Calender with Differential Gear for Friction Calendering

By courtesy of *The Firestone Tyre and Rubber Co., Ltd.*

FIG. 21. CALENDER IN OPERATION

Calendering—or spreading fabric with a thin coating of rubber sheet formed between the first two is led round the lower and then between this and the one below it, and so on. The sheet obtained is, of course, more even and regular than would be produced by one pair of rollers only. The calender rollers are bored for steam-heating, as when warm the rubber is, of course, softer and more plastic.

A three-bowl calender, as shown (Fig. 20), is the type most commonly met with. In this machine the two bottom rollers are doubly geared so that by means of a clutch, the lever for which is seen in the foreground on the left of the illustration, they move either at the same speed or the lower one moves more slowly. The latter combination is used for friction calendering. This will be better understood by reference to the accompanying diagram (Fig. 19), which shows the disposition of rollers, rubber, and cloth when the process of calendering is being carried out.

A, B and C are the three rollers in section. The rubber compound is applied at F and is compressed to a sheet between the rollers A and B. It passes round the roller B and then between the rollers B and C, where it is rubbed on to the upper surface of a layer of cloth from the wooden roller D. The two pass on together and are wound on the wooden roller E, the layers of cloth preventing the layers of rubber from adhering to one another. With very adhesive compounds an additional separating cloth is used. If now the roller C move slower than A and B, the friction of the roller B on the surface of the rubber will force it into the cloth so that it adheres firmly. This arrangement is frequently used for permanently coating a cloth with a layer of compound, as in the manufacture of heavy waterproof sheeting and tyre canvas (Fig. 21).

CHAPTER VI

INGREDIENTS OF MIXINGS

WE have referred to sulphur and minerals as ingredients of rubber-mixings in addition to the rubber itself. It must not be supposed that the minerals are only used for the purposes of adulteration, or even what may be termed the legitimate cheapening of the rubber goods. The sulphur, of course, is necessary for vulcanization, but some of the minerals confer valuable qualities on the vulcanized rubber. Others must, however, be described as "fillers"; they do not add appreciably to the strength or durability of the rubber goods, but only load or harden them. Mineral matters employed in compounding rubber include such substances as clay, chalk, magnesia, asbestos, zinc oxide and other metallic oxides and carbonates.

Besides sulphur and minerals, a large number of other substances are used in compounding rubber and included in the term "compounding ingredients." Of these we may mention carbon black (or gas black), ground rubber waste, reclaimed rubber, rubber substitutes, glue and softeners such as pine tar and mineral rubber, and certain oils and waxes, such as rosin oil and ceresine wax. In addition there is the important group of complex organic materials: accelerators and antioxidants, which are only added in small quantities, such as half or one per cent on the rubber. Colours, in the form of mineral pigments or organic dyes, are also frequently required.

The specific gravity or density of the minerals used in the manufacture of rubber goods is a matter of great importance. When buying goods the purchaser is careful to take the specific gravity into consideration; a pound, say, of solid tyre of low gravity will go much further than one of higher gravity, as in reality a certain bulk, not weight, of the tyre is required to go round the wheel. In the early days of the rubber industry, the gravity was also a measure of the quality of the goods, as the larger the proportion of rubber the lower the gravity. The gravity of clean washed and dried raw rubber is well under unity, and the rubber floats on water, while the minerals with which it is compounded have mostly a gravity of over two or three, chalk and clay being two of the lightest in common use. The trade speaks of floating qualities, meaning thereby a rubber compounded with so little mineral that when vulcanized it still floats on water. The rubber manufacturer has to keep down the gravity of his goods to within certain limits, and as the gravity of the goods depends chiefly on the gravity of the components, the use of much mineral, or mineral of high gravity, necessitates the use of a large proportion of a low gravity constituent to counteract its effect. At one time this could only be obtained by the addition of genuine new rubber; nowadays, however, there are a great many substances, such as the rubber substitutes, oils, and waxes, and some of the reclaimed rubbers, and bodies like lamp black and gas black, all of which tend to lower the gravity of the average rubber goods. If, however, the gravity is of little or no value as a test of quality, it will remain of considerable commercial importance so long as goods are sold by weight and not by bulk. Some account of rubber compounding ingredients will now be given. It may be pointed out that, though for convenience they are divided into sections, any one ingredient may actually fall into more than one section.

Sulphur and Vulcanization

This element is almost always employed in the form of the ground mineral or of "flowers of sulphur," obtained by allowing the vapours to condense in cold brick chambers. Precipitated sulphur is another form which finds application for special purposes. This is made by treating solutions of alkaline sulphides with acids, and then washing and drying the precipitate formed. We have already explained that the vulcanization of rubber, considered from a purely chemical standpoint, consists in the combination of rubber with sulphur. The extent to which this takes place depends, firstly, on the temperature to which the mass is heated and, secondly, on the time during which the heating takes place. The higher the temperature and the longer the time, the further the chemical reaction proceeds, and the larger the proportion of sulphur which enters into combination with the rubber. There is, however, a limit beyond which it is not safe to go, as the vulcanized rubber, when over-cured, goes rotten and perishes either at once or after keeping for a time, according to the extent to which the safe limit has been overstepped. Regarded in a chemical light and from another point of view, vulcanization is a sluggish reaction; it proceeds slowly, and to produce the effect required in a reasonable time it is necessary to add a good deal more sulphur than will actually enter into combination with the rubber. In a vulcanized article, therefore, we have part of the rubber "combined" and part uncombined or "free."

Compounding

We may interpose a word here with regard to the fineness of division of rubber compounding ingredients. Generally speaking, the smaller the particle size, that is, the greater the state of subdivision, the more valuable the material as a compounding ingredient for rubber. The finely divided material is said to have a reinforcing effect on the rubber which is quite different from the mere filling effect of large-particled materials. Two ingredients now to be described are used in large proportions in goods like tyre treads where it is desired to make a hard and very tough compound.

Gas Black

This material results from the incomplete combustion of natural gas which comes to the surface of the earth in parts of the United States of America. The flame is allowed to impinge on a cooled moving metal surface, from which the deposited carbon is removed by a scraper. "Gas" or carbon black is perhaps the reinforcing ingredient *par excellence*, and is known to have the smallest particle size of all rubber compounding ingredients. A tyre tread may contain 40 to 50 per cent of gas black on the rubber, which greatly toughens it and improves its wearing qualities. Other types of black are acetylene black, lampblack, and thermatomic black. The specific gravities vary from 1·5 to 1·8.

Zinc Oxide

This is one of the most expensive but at the same time most serviceable of minerals for rubber mixings. It is a good toughener, like carbon black, but it also imparts strong resistance to tearing in the rubber compound containing it. It is usually necessary also to add zinc oxide in small quantities to all rubber compounds vulcanized by the aid of organic accelerators, in order to bring out the full activity of the latter. The specific gravity is high—about 5·5.

Fillers

In the opposite category to gas black and zinc oxide, we have the mineral fillers which have relatively coarse particles. These are entirely inert towards the rubber, and tend to increase the " tearability " of the vulcanized product. A good example is barytes (or barium sulphate). This mineral has a specific gravity of 4·4 and therefore adds considerably to the weight of goods containing it. Its chief application lies in the manufacture of floor tiling, where it is often desired to impart a heavy and " dead " feeling to the rubber. By precipitating 25 to 30 per cent of zinc sulphide on to barytes a pigment termed lithophone (specific gravity 4·2) is obtained which, owing to its high barytes content, is to be regarded as a filler but which is also used as a white pigment.

There is a large intermediate class of mineral and inorganic substances which are used as compounding ingredients and which, although used often primarily as filling and cheapening agents, have also some reinforcing action. Such materials are clay (specific gravity 2·6), chalk or whiting (specific gravity 2·7), French chalk or talc, a magnesium silicate (specific gravity 2·8), asbestos, kieselguhr, fossil flour (specific gravity 2·4), calcined magnesia or magnesium oxide (specific gravity 3·4) and magnesium carbonate (specific gravity 2·2). In addition to filling and reinforcing action, some of the above have special applications. Asbestos finds employment in goods which are subjected to heat during use, and is often employed when a toughening effect is required. Light magnesium carbonate behaves similarly, and is used for tough compounds. Magnesia is used in two grades, heavy and light, the latter having much smaller particles, and whilst both act as accelerators, the latter is the more effective. Clay is to be had in various grades, the finest colloidal clay being the best for compounding rubber. Too great a proportion of clay in rubber goods leads to the tendency for tearing easily, and should therefore be avoided.

Another class of fillers are wholly or partly organic in nature, such as the rubber " substitutes," ground rubber waste, and reclaimed rubber. Ground rubber wastes are made by simply grinding waste vulcanized rubber, mainly tyres, to as fine a degree as possible. The more mineral the waste contains the more easily the scrap will grind up, but, generally speaking, any fully compounded rubber which may be termed vulcanized in the technical sense will go to a powder or " crumb," and not a homogeneous mass, as will raw rubber when passed through the rollers of a mill.

Rubber substitutes are of two classes—brown and white. Brown substitutes are vulcanized oils made by heating rape, cottonseed, or other oil with sulphur. If the oil is vulcanized by treatment with sulphur chloride and heat is not applied, white substitute results. The use of these materials has decreased in late years, and they are not used in the manufacture of tyres where hard wear and high physical qualities are requisites.

Reclaim

The manufacture and use of reclaimed rubber, or "reclaim," as it is usually called, have at times assumed enormous proportions, only to fall off again when the price of raw rubber fell. Reclaim is made by subjecting scrap vulcanized rubber to certain mechanical and chemical processes, the object being to remove any free sulphur and render the material plastic. The combined sulphur is not removed, so that the rubber is not devulcanized in the true sense.

Reclaim may be made in several ways. As a preliminary operation (in the case of ground tyre casings), it is generally necessary to remove the cotton fibre. This can be done by a mechanical draught, but more usually the ground rubber is heated at high temperatures, say 180° C., in an autoclave, with a dilute caustic soda solution. This has the combined effect of swelling and softening any cellulose fabric and dissolving the free sulphur and some of the oils. It also renders the material plastic. The resulting mass is washed and can then be milled like raw rubber in the ordinary way, with or without the addition of further softeners. It is then sheeted out ready for use. Other processes employ dilute acid solution in place of caustic soda to attack and rot the fibre, and in some cases plastification is effected by heating the ground waste with oils, etc. Since rubber itself is very inert and resistant to chemical reagents, it is unaffected by the chemicals employed in the processes described above, and these latter therefore act only on the ingredients in the rubber, while the heat and steam, together with oils or other softeners, facilitate the milling of the final product and convert it to a smooth plastic mass which is readily mixed with raw rubber and compounding ingredients.

The specific gravity of reclaim varies with the proportion of mineral matter or other ingredients retained from the original waste of which it was made. A "whole tyre" reclaim may have a specific gravity of 1·1 to 1·2, and as it retains the bulk of the carbon black in the original tyre it can in part take the place not only of raw rubber but also of the carbon black in the mix. Of course, one cannot go on replacing raw rubber by reclaim indefinitely, even if one replaces one part of raw rubber by two of reclaim to allow for the compounding ingredients in the latter.

Softeners

In order to help the mixing of the numerous powders, etc., into the rubber, and also to render the resulting " dough " moderately soft, so that subsequent manufacturing operations, such as calendering and tubing, do not lead to too great a consumption of power, certain softeners may be added to the mix. While reclaim and substitutes have a helpful action in this respect, certain oils and waxes are even more effective. As softeners may be mentioned mineral rubber, pine tar, palm oil, stearic acid, oleic acid, rosin oil, paraffin and ceresine waxes, carnauba wax and vaseline. All these are used in small quantities up to 5 to 10 per cent at the most on the rubber, and aid not only in plasticizing but prolonging the life of the vulcanized rubber containing them, and in helping the uniform distribution of accelerators and fillers throughout the compound.

Accelerators

The period since the end of the War to the present time has seen a tremendous expansion in the development and use of rubber accelerators. These substances are complex organic chemicals, which, when added to the raw rubber mixture in quite small proportions, i.e. ½ or 1 per cent on the rubber, very greatly reduce the time and temperature necessary for vulcanization, that is, they accelerate the " cure."

In the early days of the industry certain metallic oxides were observed to act in this way, though their activity is not comparable with that of the modern organic accelerators, which are much more effective. These inorganic or mineral accelerators are zinc oxide, litharge (lead monoxide), magnesia and lime. The former two still find application as accelerators; zinc oxide, which has a scarcely perceptible action of itself, is largely used in conjunction with organic accelerators. Of the latter, diphenylguanidine is very popular for general work. Just as inorganic accelerators differ in activity, so organic accelerators differ among themselves, and diphenylguanidine (or D.P.G., as it is commonly called) is classed as an accelerator of medium activity. As a rough example of its activity, it may be noted that whereas a " pure " rubber mix containing 10 per cent of sulphur requires 2 to 3 hours at 140° C., to vulcanize, the same mixing with a half part of D.P.G. and 5 parts of zinc oxide would be vulcanized to the same extent, as judged by the physical properties of the vulcanizate, in about 20 minutes.

It has been found that most organic accelerators are more active when a metallic oxide is included in the mix, and, as already stated, zinc oxide is usually added for this purpose.

As examples of more powerful organic accelerators we may cite: mercaptobenzothiazole, which is highly active; zinc diethyldithiocarbamate, a " super " accelerator of very great activity; also tetramethylthiuram disulphide and zinc isopropyl xanthate, also of this class. Many accelerators are sold under trade names such as "Vulcafor," "Accelerene," "Robac," "Captax," etc., the chemical names being too complex for commercial use. Organic accelerators are now used in the great bulk of rubber mixings.

Colours

As with accelerators, colouring materials for rubber fall naturally into two groups, namely, the mineral or inorganic pigments and the organic dyestuffs.

The mineral pigments were those first introduced for the purpose of colouring rubber. They are the more permanent. Of organic dyestuffs, only those are used which survive the rather drastic and prolonged heat treatment with sulphur necessary for vulcanization. The introduction of accelerators, however, has allowed both the temperature and the time of heating, necessary for vulcanization, to be reduced, so that there are now many organic colours which previously could not be used but which find employment in accelerated cures.

Among inorganic and mineral pigments may be mentioned: *White:* Lithophone, titanium oxide, zinc oxide and carbonate. *Red:* Iron oxide (rouge), crimson antimony (antimony sulphide), and vermilion (mercuric sulphide). *Green:* Chromium oxide *Blue:* ultramarine. *Yellow:* Golden antimony sulphide, arsenic sulphide and cadmium sulphide. *Black:* Gas black, lamp black, and litharge. The last cannot be used as a yellow pigment, as it reacts with sulphur during vulcanization to give lead sulphide, which is black. It thus finds application in black goods, such as goloshes and Wellingtons.

Dyestuffs for rubber are complex organic substances, often admixed with or precipitated on a base material such as alumina, which can then be mixed directly into the rubber. All colours and varieties of shades are available, and it is only necessary to add them in small quantities; as with accelerators, a ½ or 1 per cent often suffices. They are usually added in the form of lakes, that is, in conjunction with mineral matter. It is often advantageous to add zinc carbonate to mixes coloured with organic dyes, as this material is said to bring out the full shade.

Anti-oxidants

This class of compounding ingredients is of recent introduction but of increasing importance. As the name implies, they are added (in very small quantities) to prolong the life of rubber goods which ordinarily are subject to " perishing " and oxidation. " Nonox " is a trade name of one of the best known.

Artificial or Synthetic Rubber Substitutes

An immense amount of research work has been carried out on the preparation of artificial rubber, and a reference to the files in the Patent Office will give an adequate idea of the extraordinary combination and manipulation of materials that have been brought forward to this end.

Before the research chemist can synthesize, he must study the decomposition products of the substance he is aiming to produce. A man must first discover the sort of materials of which a house is built and the manner in which they are superimposed, that is, their relative position to one another, before he is able to produce a replica of the building. In a similar way the chemist, by breaking down stage by stage the molecules of which rubber is composed, obtains, as it were, a plan of the composition of the substance; he is then able to set to work to reconstruct on well-ascertained lines. Considerable progress has been made, and we have plans of the rubber molecule, some of which seem to answer pretty well to the way it behaves.

From the chemical standpoint the whole subject is too complex to be summarized, and the reader with sufficient chemical knowledge is referred to the numerous publications in the scientific press. However, the following is a brief account of the present position.

The numerous attempts to produce synthetic rubber have not yet been successful, that is to say, a material exactly resembling natural rubber has never been synthesized. The research work directed to this end has, however, produced a number of rubber-like substances which may be correctly described as synthetic rubber substitutes.

Taking these in a chronological order, the first material of importance was the "methyl rubber" and allied substances produced in Germany during the War. These materials were obtained by the polymerization (chemical building up) of isoprene, butadiene, methyl butadiene, etc., all of which substances are known to be formed by the decomposition of natural rubber; hence their use as a starting point for the synthesis. The "rubbers" thus produced, however, had very poor physical properties, aged (perished) badly, and were principally of service in the manufacture of hard rubber (ebonite) for use in electrical components, switches, etc.

Little further progress was made until comparatively recent years, which have witnessed the introduction of two more important synthetic rubber substitutes. The first of these is rubber-like only to the extent of being flexible and capable of manipulation on rubber-mixing machinery. This is described as an ethylene-polysulphide reaction product, and is made by reacting ethylene chloride (or other halide) with calcium polysulphide (or other polysulphide). The product is yellow, tough, flexible, and evil-smelling, and its principal applications appear to be complementary rather than competitive with natural rubber, for it requires some natural rubber as an addition to facilitate processing; thus it is specially suited for making flexible petrol and oil-resistant products, being insoluble in practically all the usual solvents except carbon bisulphide. Two commercial forms of this material (called Ethanite and Thiokol respectively) are available, and are finding numerous uses on the lines mentioned.

The final and perhaps the most interesting substitute is of American origin, and is synthesized in the first place from acetylene. The ultimate product is a chloro substance, that is, its molecule contains a chlorine atom, and the position of this chlorine atom corresponds to that of a methyl group in natural rubber. Duprene, as this material is called, thus bears a strong chemical resemblance to natural rubber, but differs from it in containing chlorine. In physical properties Duprene in some ways lies between natural rubber and Ethanite; it is susceptible to the action of some solvents, but resists others better than natural rubber. It is, however, superior to Ethanite in its ultimate tensile strength and similar properties, closely resembling natural rubber in this respect. It appears to be a promising material, but its use is limited by its high price.

CHAPTER VII

THE VULCANIZATION PROCESS

VULCANIZATION

IN the last chapter we outlined the vulcanization process and the matter has also been referred to when speaking of rubber-reclaiming methods. We shall now consider vulcanization in more detail and, in the first place, vulcanization by heat with a short description of the plant employed.

The conditions under which rubber goods are vulcanized depend, among other things, on the proportion of sulphur taken. As the sulphur reacts with the rubber and not with the minerals—with certain exceptions—the proportion of sulphur should always be reckoned on the raw rubber and not on the whole mixing. Allowances must be made for ingredients which react with sulphur, such as reclaimed rubbers, and also in those cases where accelerators and litharge are used. The proportion of sulphur to rubber when reckoned as a percentage on the latter varies in practice from one to forty per cent. The larger proportions of sulphur are used in the manufacture of hard rubber, commonly termed vulcanite or ebonite.

In order that rubber may combine with sulphur it must be heated above the melting point of the latter unless accelerators are used. At this temperature the rubber itself becomes soft or semi-fluid according to quality, and this has to be taken into consideration in mixings for goods intended to be " open cured," such as solid tyres, rubber tubing, and the like, as they are liable to sag during the cure. Where moulds are used the thickness of metal of which they are made and the conductivity of the metal and the rubber compound itself have all to be taken into consideration when fixing the time for vulcanization. The moulds used in rubber works are usually of steel or aluminium, and substantially constructed in two or more parts held together by bolts screwed up so as to confine the rubber to the space between them. The rubber compound as it comes from the rollers is fairly soft and plastic so that it takes the shape of the mould. The temperature and time of heating are interdependent. If the time is prolonged the temperature can be kept lower and, vice versa, by raising the temperature the time can be shortened. From the manufacturers' standpoint, and for economy in working, the time of heating is shortened as much as possible. By the use of suitable accelerators the time is cut down to five to fifteen minutes, by which means a very large output is obtained with the minimum number of moulds and vulcanizing capacity.

The length of time and temperature—or put shortly, the cure—required depend on the quality of the rubber used for the mixing. Of all varieties Para rubber cures faster than any other, whether from the West or from the East. The method of preparation has but little influence on the rate of cure. On the other hand, the rate of cure is somewhat variable, even with plantation rubber prepared in the same way.

The rubber-mixing before vulcanization is soft and plastic. The lower grades of rubber and those containing much resin of low melting point are, of course, much softer than better-class rubbers, but even the best rubber is relatively soft and weak when fresh from the rollers as compared with untreated rubber, owing to the "working" it has undergone. If, for instance, a corner of a freshly-calendered sheet be stretched out between fingers and thumb it remains extended or only very slowly and incompletely returns to its original shape. When fully cured it returns almost completely, and at once, but if under-cured, that is to say, if the temperature has been too low or the time of heating too short, it shows an intermediate behaviour, it returns pretty completely, but it takes a long time to do so.

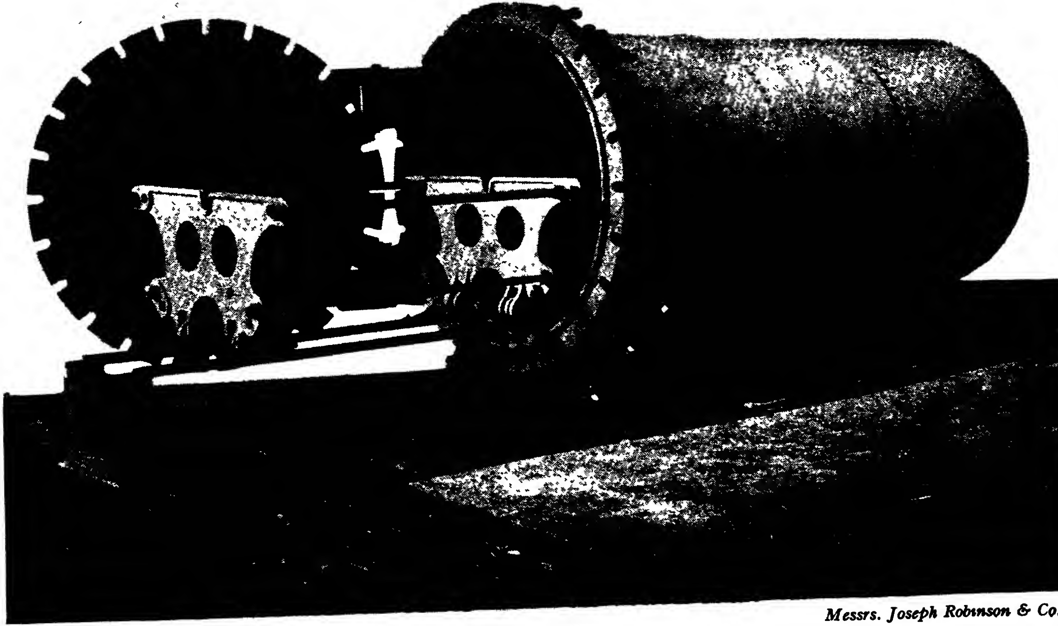
Before vulcanization two rubber surfaces pressed gently together unite firmly and cannot afterwards be separated. When partially cured the surfaces are still adhesive and stick together, but may separate again when pulled apart. A fully-cured sample is still adhesive on the freshly-cut surfaces, but these are easily pulled apart. When we speak of adhesion between surfaces we refer to clean or freshly-cut ones. Dust tends to destroy the tendency to adhesion and this plays a very important part in the manufacture of rubber goods. Where it is desired to destroy the adhesiveness of the surface so as to facilitate handling before vulcanization, liberal use is made of French chalk, which is dusted over the articles. On the other hand, dust must be avoided where two surfaces have to be joined up as, for instance, in building up an india-rubber tobacco pouch from pieces cut from a sheet or in the manufacture of india-rubber shoes.

If the temperature during vulcanization be too high, or the heating be continued too long, the rubber becomes as it is termed "over-cured." This may not be at once noticeable when the article is examined, but after keeping for a time it loses its strength and may eventually become hard, friable, and "perished." Great care is therefore required not to exceed the safe limits. If the quantity of sulphur be large and the heating be very prolonged, the product becomes tough and hard by conversion to vulcanite. Raw rubber of good quality is pale in colour and very translucent, or almost transparent, especially in the case of the best plantation brands. When cured it tends to darken in colour, and if over-cured the best pale plantation Para turns orange to brown. If the cure be further prolonged and more sulphur added, the colour turns almost black and the rubber becomes opaque.

Vulcanizing Pans and Presses

Whether mould-cured or open-cured, the heating is generally carried out in vulcanizers. These consist as a rule of long cylindrical boilers (Fig. 22) connected with a supply pipe for live steam obtained from a steam-generating boiler, and also with a waste pipe for blowing off. The steam supply pipe runs along on the bottom inside the vulcanizer and has several outlets, and in addition to which there is a stage or platform immediately over the supply pipe and running the whole length of the vulcanizer, so that the steam is well distributed on entering and uniform heating is obtained. One end of the vulcanizer is detachable and is arranged to swing open on a hinge, and the articles to be vulcanized are wheeled in on a cage which runs on a pair of rails right along inside the vulcanizer on the platform already mentioned. The door is then shut to and made fast with a number of swing bolts. The vulcanizer is also provided with a safety-valve and pressure-gauge. The progress of the cure is followed by means of a thermometer, the bulb of which lies inside the vulcanizer and is protected by a metal tube. In many factories self-recording instruments are installed which register the steam pressure or the temperature during the cure on a sheet of squared paper round a cylinder driven by clock-work, such as is used for self-recording barometers and similar instruments.

The works manager has therefore an unalterable

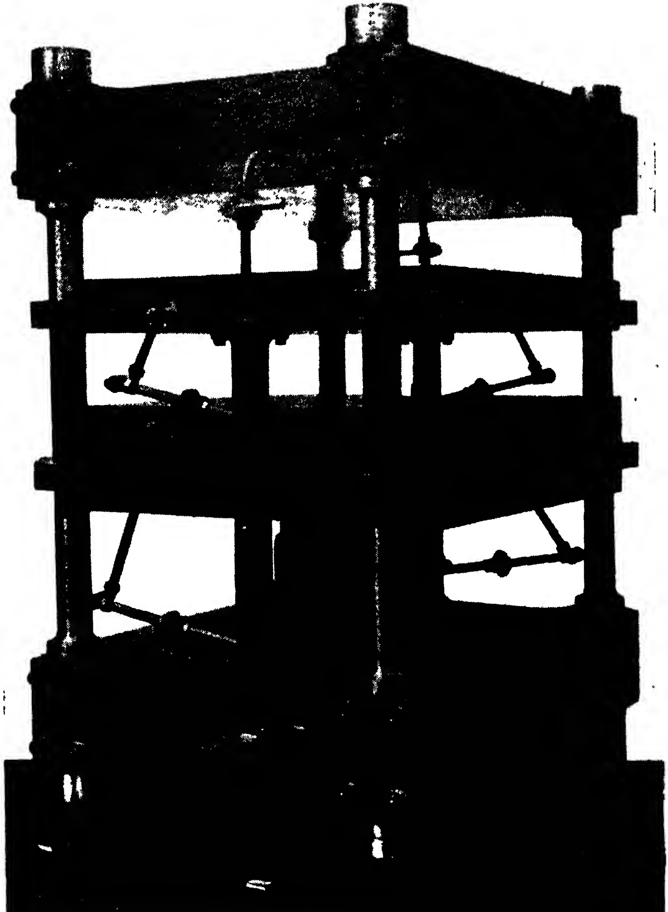


By courtesy of *Messrs. Joseph Robinson & Co.*

FIG. 22. VULCANIZER

record of each cure, which can be filed and referred to in case anything goes wrong and the goods are subsequently found to be under- or over-cured. Vulcanizers are built in a variety of sizes to suit the type of goods, and may be three to twelve feet in diameter, and anything from three to sixty feet in length or even longer for vulcanizing hose. Some vulcanizers are built with a steam jacket where the steam is kept permanently at a pressure and let into the interior only when the articles to be vulcanized are in place and the lid screwed down. This has the advantage of more rapid working, as the vulcanizer is not allowed to cool down and has not therefore to be heated up again with the fresh charge. The heating is also more uniform, a great essential in successful working. It can easily be understood that with condensation on the walls taking place all the time there is a liability to currents, and, therefore, uneven heating in the interior. Steam-jacketed vulcanizers are not suitable for working with hot air, for the same reason. In the case, say, of a number of layers of rubber being cured between cloth, the outer and inner layers get heated but the hot air cannot penetrate between them, and the middle layers get only gradually heated by conduction from the outer ones and are consequently under-cured. In some vulcanizers there is a contrivance to keep the articles to be vulcanized in motion so as to secure even heating.

In addition to the ordinary pan vulcanizers there is the vulcanizing press (Fig. 23), which functions not only as a means of heating but at the same time as a mould. The simplest form of press consists of two steel boxes with smooth, even surfaces facing one another. The boxes are heated by steam, the pressure or temperature being controlled exactly as in the vulcanizers above described. The sheet to be vulcanized is placed between the surfaces



By courtesy of *Messrs Joseph Robinson & Co.*

FIG. 23. VULCANIZING PRESS

and pressed down while steam is let in and the rubber cured. Presses are often built up of several of these steam boxes superimposed and worked by a hydraulic ram so that several articles can be cured at the same time. They are also made in very large sizes for curing such articles as belting or heavy waterproof sheeting.

Reference must also be made to hot-air vulcanizing, suitable for waterproofing materials where moisture and heat combined would spoil the colours in the fabric. The proofed material is hung in festoons and the hot air blast driven through so as to secure uniform heating throughout.

This process was at one time limited to articles such as goloshes which were compounded with much litharge, but it is now possible to cure in hot air at moderate temperatures with almost any rubber composition with the aid of suitable accelerators and antioxidants.

There are also " autoclave " presses, in which the press is heated by steam of a surrounding pan. This type is preferred for motor tyres. In other cases the platens of the press are shaped to take the article, as in the " watch case " vulcanizer—also for tyres.

Blooming

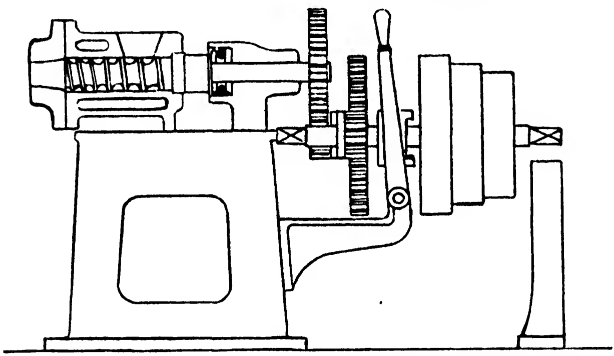
We have explained that it is necessary to take more sulphur for vulcanization than actually enters into combination with the rubber, so that there is always some free sulphur in the vulcanized product. When the percentage of free sulphur exceeds a certain figure the sulphur crystallizes out on the surface of the vulcanized article as a white dust or powder. This is also largely dependent on the ingredients of the mixing and the method of curing. This phenomenon is termed blooming, and is common with all types of rubber goods, where a large percentage of sulphur has been used. In some cases it gives a finish to the appearance of the rubber, which is desired, but in other cases the blooming is regarded by the manufacturer as an unwelcome feature. Especially is this the case where the rubber is compounded without fillers. The matter is, however, of a sentimental rather than practical nature, as blooming does not affect the quality of the goods in a real sense, that is, it does not detract from the strength or resistance to wear and tear. The formation of the powdery sulphur layer is gradual, and no traces are to be found on the freshly-cured goods. On standing, the sulphur begins to appear either in the course of a few minutes or after a few hours or days. Where not required, it can be removed by washing in a bath of weak soda which dissolves the sulphur.

CHAPTER VIII

MECHANICALS

Solid Tyres and Rubber Tubing

Having now explained the process of vulcanization by heat, we will pass on to a short description of the methods employed in the manufacture of some of the commoner rubber goods. There is a large class known in the trade as "mechanicals," which include such rubber goods as are



By courtesy of *Messrs. Joseph Robinson & Co.*

Fig. 24. Forcing Machine

used for mechanical purposes, such as buffers, hose, tyres, etc. We will take, to begin with, the manufacture of solid rubber tyres and rubber tubing, both of which articles are open-cured.

As moulds are not used, the goods are shaped to the required form by other means. In this case, a spewing or forcing machine is employed, constructed on the same lines as machines for making lead tubing, or to take a homelier parallel, it bears some resemblance to a sausage machine. (Compare also the refining machine already referred to, page 45.) The machine, shown in outline in Fig. 24, consists essentially of a very strongly-constructed cylinder in horizontal position, within which a powerful screw or worm revolves. This is driven by a belt and pulley at one end, while the other end of the cylinder tapers and is fitted with a die of the required shape, that is, corresponding to the section of the tyre to be made. The nozzle is arranged so that the dies are interchangeable. In the illustration the dies have been removed. At the other end, at the top of the cylinder is a rectangular opening through which the rubber compound is fed into the cylinder. In some machines a pair of small rollers are fixed over the openings with axes parallel with the axis of the cylinder for forcing the rubber compound into the cylinder. These are not shown in the illustration. The rubber, as required, is cut off from a batch kept hot on a pair of smooth rollers close by, or fed by a continuous band conveyor, and the cylinder of the forcing machine is also heated by means of a steam jacket. The shape of the die does not correspond exactly with the cross section of the tyre, but is made rather different in outline and somewhat smaller, as the rubber compound expands as it leaves the nozzle owing to the enormous compression exerted on it in the interior of the cylinder. The expansion is not, of course, a true expansion of the material in the ordinary sense of the term, as rubber compound is not appreciably compressible. The expansion in this case is rather of the nature of a flow due to the irregular strains and stresses than to the compression of the material.

When making rubber tubing, the principle is the same, except that the die has a projecting piece in the centre which forms the cavity in the tubing. The spewing machine was at one time used for small-sized tubing only, large-sized hose being built up from calendered sheet in quite a different manner, but a modified machine is now frequently used for large hose. As the tyre or tubing comes away from the nozzle, it is led on to a large circular tray on which a thick layer of French chalk has been spread. This tray is pivoted so that it turns easily, and the continuous length of tyre is wound in a flat spiral on the surface of the tray. When full, the end is broken off and another tray started on. Further quantities of French chalk are dusted over the rubber and the trays taken to the vulcanizer for curing. As we have explained, care must be taken to so compound the rubber that it does not sag appreciably at the temperature of the cure. In cases where this has not been sufficiently taken into consideration, tubing is found to come out of the vulcanizer with an oval instead of a circular section. Curing in the open is cheaper than the use of moulds. There is the saving in the capital expenditure on the moulds and in the time and labour taken for filling the moulds and emptying them. Heavy solid tyres are cured in moulds in one piece after being shaped roughly in a forcing machine. They are vulcanized on to a steel rim which is then fixed direct to the wheel. In order to get the rubber to adhere firmly, it is necessary to insert between it and the steel rim a layer of rubber compound termed a "junction." This consists really of a vulcanite mixing with the addition of such materials and other ingredients as may be necessary to make it cure hard in the same time as is required for curing the body of the tyre. The production of a vulcanite layer entails the use of a large proportion of sulphur in the compound, and when the composition is correctly adjusted a very firm joint results. Cab tyres, for horse vehicles, of course, are either wired on or held by being gripped by flanges on either side.

Even when the compound is intended for curing in moulds, the forcing machine comes in useful for roughly shaping the rubber which is subsequently cut up into compact blocks, and the method can be adapted to the manufacture of a number of other articles.

Washers, Valves and Railway Buffers

Many goods are built up out of the calendered rubber sheet. It would take too long to explain the exact method of procedure in each case, but rubber washers and valves may be taken as examples. Calendered and unvulcanized sheet of the required thickness is taken, or a sheet of the required thickness is built up in plies by rolling two or more sheets together. The article is then cut out or stamped out to the required shape, or perhaps a trifle on the large side. It is then vulcanized in the press, a flat ring of the correct shape being used to confine the rubber. The cuttings go back to the machine and are worked up again. In a machine for cutting washers the sheet is laid on a table and cut by knives attached to a revolving arm. Railway buffers consist of thick cylindrical pads. They are vulcanized in moulds. Sometimes metal plates or rings are vulcanized on to them in the same manner as in the case of the solid tyres with steel rims already referred to. The surface of the metal must be clean, and to ensure good adhesion it is usually painted with some of the "junction" compound dissolved in coal-tar naphtha. When the latter evaporates it leaves a thin layer of the compound in close contact with the metal.

Rubber Hose

Large-size rubber hose is built up from long strips of compound in sheet form; these are wrapped round a mandrel with special forms of support on a bench stretching the whole length of a large room. The hose is built up with alternate layers of rubber and canvas. The canvas used is sometimes subjected to a previous treatment by which it is coated with a thin layer of rubber which penetrates the interstices between the cotton fibres. The rubber compound adheres more firmly to canvas that has been treated in this manner. The method of coating the canvas will be explained later. The hose can be built of one strip with a central join along its whole length or it can be spirally wrapped. The latter method is, of course, preferred. The mandrel is of iron and must be well rubbed over with chalk to prevent the rubber sheet from adhering to it. The sheet itself has, of course, to be well chalked to enable it to be handled, and it is necessary to get rid of this chalk where the join has to be made, which is done by washing with naphtha. The clean, washed surfaces are then pressed together to cause them to unite. It is here that defects may arise and the method of spewing has the advantage, the tube being formed whole without a seam. The Americans were the first to design spewing machines for the manufacture of hose of large size with canvas between. The machine is built on the lines of that already described for the manufacture of solid tyres or small tubing, except that the forcing screw has a hole through its axis through which the iron mandrel passes and the rubber compound is squirted on to the mandrel as it passes along, forming an even layer over it. A mechanical contrivance pushes the mandrel forward at a speed corresponding to the rate at which the rubber is forced out. When the mandrel is coated from end to end, it is removed and wrapped with one or more layers of canvas as required. It is then taken back to the spewing machine and a layer of rubber is spread on to the surface of the canvas just as in the previous case when it was spread on to the mandrel itself. To bring the various layers of which the hose is built up into thorough contact it is wrapped spirally with cotton cloth before vulcanizing. The cloth is taken in strips and must be tightly and evenly bound along the whole length. If this is not done, the hose will not be uniform and air may be retained between the several layers. What we have said with regard to wrapping applies equally to hose that is not spewed but lapped and joined. After vulcanizing, the cotton cloth is stripped off and leaves an impress in the form of fine cross markings on the rubber. Instead of wrapping a layer of cloth or fabric between the layers of rubber, the fabric can be woven on to the first layer of rubber in the form of a seamless sleeve, which is then coated with a solution of rubber in naphtha. In this way, if required, several layers of fibrous material can be woven on to the rubber. Hose made in this manner will stand much greater pressures than that made by lapping cloth in the ordinary manner. For some purposes hose has to stand not only a considerable pressure, but also a high temperature, as, for instance, for coupling the steam-heating appliances in railway carriages. The steam may be at several pounds pressure which means a temperature considerably above the boiling point of water; in addition to this there is a good deal of ordinary wear on the hose in the coupling and uncoupling of the carriages. As might be expected, the life of such hose is short, but nothing more economical has been found to replace it satisfactorily. Armoured hose may be employed for purposes of withstanding a high pressure, as in connection with vacuum brakes or for water under pressure. In this a spiral steel wire is wound either inside or outside the rubber and canvas layers, according as to whether it has to withstand a pressure from the outside or inside.

The wire may also be actually imbedded between layers of canvas in the walls of the hose.

Deodorization of Rubber Goods

Plantation crêpe rubber is odourless, or at the most has a faintly sweet smell, noticeable when the rubber is being milled on hot rollers. No objection can be taken to the smoky odour of hard-cure Para or the very faint odour of sheet plantation rubber, although even good-class plantation rubbers may have a very unpleasant smell if produced by spontaneous coagulation, or where fermentation has set in before the rubber has been washed and dried. Such rubber, however, is very seldom met with. Some of the lower grade African brands are notoriously evil-smelling, but the use of these is almost a thing of the past. Nevertheless, vulcanized rubber has a slight odour, even when made from the best raw material, particularly if solvents have been used in the manufacture. In fact, it is the residues left in the rubber by these solvents when they evaporate which are mainly responsible for the bad odour of such articles as waterproofs and canvas-lined hot-water bottles. The odour is a serious drawback in certain classes of goods, particularly some sorts of hose, such as brewers' hose. Here the rubber comes in contact with the beer, which may become tainted. Various means have been tried for deodorizing the vulcanized rubber. These may consist of washing with solutions of oxidizing agents or stoving, that is, heating for some time to a temperature which, of course, must not be too high. In the latter case, the use of charcoal is recommended as helping to absorb the evil-smelling substances driven out on heating the rubber. It is difficult to effect a permanent deodorization, as these methods remove the noxious substances from the surface layers only of the rubber, so that after a time contamination sets in again from the inner layers.

It is known that by considerably diluting the latex before coagulation when preparing the rubber in the East, it is possible to reduce the content of non-rubber substances, particularly protein, which are responsible for many of the odours which arise on vulcanization. Further, by careful choice of accelerator and other ingredients of the mix (diorthotolyguanidine with zinc carbonate has been found very suitable) it is possible to produce substantially odourless rubbers. These latter also readily lend themselves to "reodorization" by means of perfumes, essential oils, etc. The reader interested in this aspect of rubber manufacture is particularly referred to the Bulletin of the Rubber Growers' Association for May, 1933, and August, 1934.

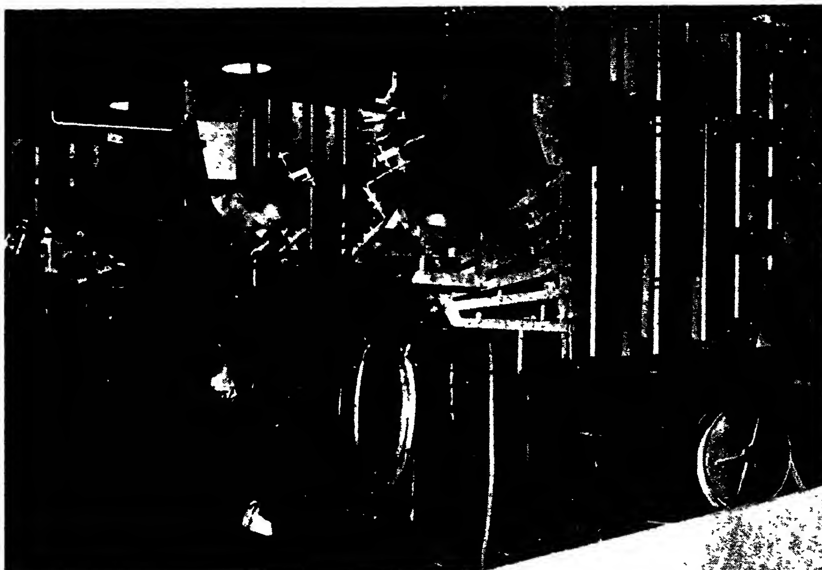
CHAPTER IX

MECHANICALS—(*contd.*)

Motor Tyres

Of all types of rubber goods, the motor tyre, perhaps, comes more often before the notice of the general public than any other class of rubber article, and absorbs three-quarters of the total raw rubber consumed. It has not, however, proved capable of absorbing the whole of the vast quantities of rubber that the East is now producing, so that we look to-day for new outlets, such as rubber paving blocks, to absorb the surplus quantities produced. It must not be forgotten that the pneumatic tyre is not wholly built up of rubber, but that cotton cord plays an important part in its construction and that the rubber used is compounded.

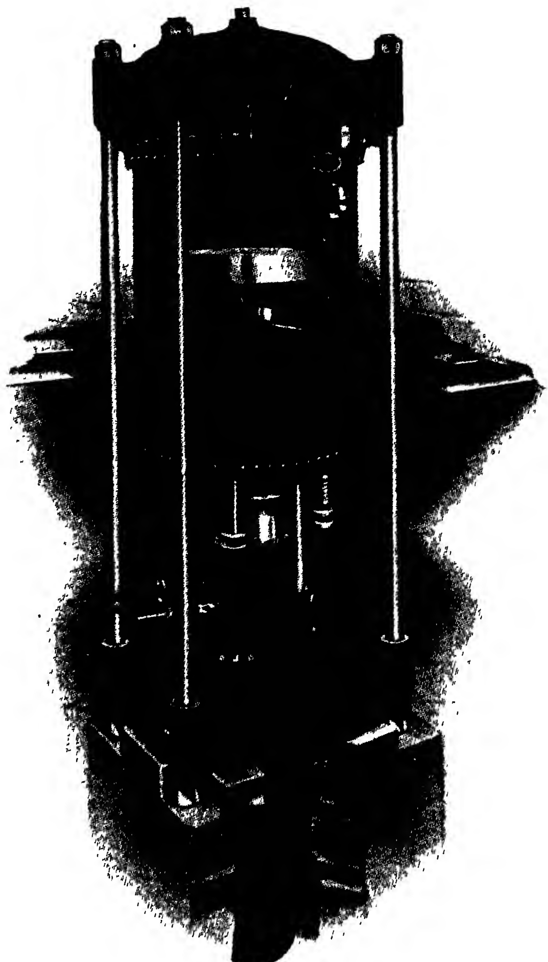
The manufacture of a motor tyre is a difficult and expensive operation. Great care and skill are required in building up the different layers of rubber and cord or canvas. This latter itself is an expensive material. It has been much improved of late, the tightly-woven canvas being replaced by a loosely-woven "cord"; hence the term "cord" tyres, as compared with the original canvas tyres. The layers of rubber and cord are laid over a core or drum (see Fig. 25) and built up in the same way as rubber hose with canvas insertion. The tyres are then vulcanized in moulds and the capital expenditure on these is a heavy item in the cost of the tyre. Every variation in size and form of tread necessitates a new mould. Fig. 26 represents an autoclave press, showing clearly the method of operation. The tyre



By courtesy of *The Firestone Tyre and Rubber Co., Ltd.*

FIG. 25. ASSEMBLING A "DRUM-BUILT" TYRE

The fabric is fed in a continuous strip through "trays" over the drum



By courtesy of *Messrs. John Shaw & Sons*

FIG. 26. HYDRAULIC TYRE VULCANIZING PRESS

moulds are seen in section in the upper part of the pan and are held in position by hydraulic arms, obviating the necessity of screwing up each mould separately. Of the four tyre moulds shown in section the second from the top is a pneumatic, the others being solid tyres. Considered as an outlet for rubber a solid tyre is better than a pneumatic one.

Curing (vulcanizing) may also be done in "watch-case" vulcanizers (see Fig. 27). These have certain advantages over autoclave presses; they are of lighter construction and thus cheaper to install and are more easily operated. In the autoclave press the moulds are separate, and, being heavy, require considerable physical strength for handling even with the help of hoists, for example, when filling the vulcanizer. In the watch-case vulcanizer the mould is fixed to the steam chambers, from which it is heated by conduction and the operator handles only the tyres and not the mould.

The following formulae are representative of modern tyre tread and side-wall compositions; the other compounds used in the under construction ("under tread," "breaker strips," etc.) vary somewhat from these, usually containing less carbon black and being, therefore, somewhat softer and more adhesive—

	1	2	
Rubber (smoked sheets) .	100	100	parts by weight
Sulphur	3	4	,, ,, ,,
Stearic acid . . .	5	10	,, ,, ,,
Zinc oxide . . .	10	5	,, ,, ,,
Carbon black . . .	43	45	,, ,, ,,
Litharge . . .	—	5	,, ,, ,,
Mercaptobenzothiazole .	1	—	,, ,, ,,
Antioxidant . . .	1	—	,, ,, ,,

The time of vulcanization depends on the accelerator employed and the size of tyre being made; a medium car tyre would be cured in a "watch-case" vulcanizer in,

By courtesy of *The Firestone Tyre and Rubber Co., Ltd.*

FIG. 27. WATCH-CASE VULCANIZER

Removing a "cured" giant tyre

say, 40 minutes at a steam pressure of 80 lb. per square inch.

Tyre Repairs

While on the subject of tyres reference may be made to the repair by vulcanization. With the inner tube of a bicycle tyre a thin patch on the outer side of the tube cemented with a little solution of rubber in naphtha makes a satisfactory joint, the pressure of the inner tube against the inner lining of the outer cover helping to hold the patch in place. At one time this method did not produce a satisfactory repair with a motor tyre, possibly on account of the heat developed which caused the rubber solution to flow so that the patch did not hold in place, but such patches have been so improved that a similar method is applicable to motor tyres and universally employed. Consequently, the older method of vulcanizing a repair has almost ceased to be used except for outer covers and then only in special cases.

Rubber Rings and Bands

India-rubber rings and elastic bands are made in a similar manner to rubber tubing, that is, either by means of a spewing machine or by wrapping layers of calendered unvulcanized rubber sheet round an iron or aluminium mandrel, until the required thickness is obtained. The rubber is then vulcanized, after being wrapped in cloth, as with rubber hose. It is then slipped on to a mandrel and taken to a lathe where the length of tubing is cut up into rings. The rubber compound used must be of good quality, containing but little mineral matter, so that the ring can be stretched to many times its original diameter without breaking, and great care is needed to see that it is neither under nor over vulcanized. Besides elastic bands large numbers of rubber rings are made, the so-called Codd's rings, which are used for closing aerated water bottles with an airtight joint. These are made usually of red rubber, and antimony sulphide is a constituent of the mixing, if not replaced to a large extent by cheaper colouring matters.

Dental Rubbers

These materials are vulcanite or ebonite mixings, that is, raw rubber with a large excess of sulphur to which has been added sulphide of mercury to give the desired shades of red and pink. The mineral colours may also be replaced by the more permanent vegetable lakes.

The ordinary black vulcanite serves equally well and is even preferable, as it can be compounded of rubber and sulphur without the addition of minerals, which results in a lighter and stronger product. People, however, seem to prefer any shade of red or orange rather than black; at any rate black is seldom used. The pink colour of some plates which is a really good match to the colour of the gums is obtained by a veneer of material on the front of the plate which is heavily compounded to give the desired shade.

For those who are not familiar with mechanical dental work it may be explained that the dental plate is prepared by moulding the soft rubber against a plaster of Paris mould of the palate, confining this with a metal plate to form a box or mould and vulcanizing in a small boiler under pressure. Dental rubber compounds are made of the very best materials procurable and the prices paid for them are relatively high.

Elastic Thread

Elastic webbing and braid consist of elastic threads running parallel and woven in with cotton or silk. In recent years mercerized cotton and artificial silk have been largely used when a good appearance is required at a price which would not justify the use of real silk.

The elastic thread itself represents one of the highest classes of rubber goods, and only the best Para rubber is capable of giving the particular physical properties termed " tension " demanded by the manufacturers of webbing. The mixing is compounded of rubber and sulphur only, softened with naphtha, and is calendered to a thin and very regular sheet on to cloth. This is then tightly wrapped in layers of cloth and vulcanized in steam in the form of a roll. When cured the sheet is unrolled from the cloth and re-rolled on a drum. Some shellac or similar substance dissolved in spirit is spread between the layers of rubber, so that when dry the whole mass is stuck together to a firm cylindrical block. It is then taken to a lathe and accurately cut, so that the sheet is reduced to long strips of rubber of square section and of the original length of the sheet. The shellac is then dissolved out in a bath and the thread boiled in a weak solution of caustic soda which removes the excess of sulphur that has come to the surface in the form of bloom. The thread is made in a variety of sizes or counts reckoned by the number of threads required to be laid side by side to measure one inch. They must be free from mineral matter and translucent, or almost transparent. They must stretch neither too much nor too little under a given weight. All these requirements necessitate the greatest care in vulcanizing; if under-cured the thread is soft and stretches too easily, and if the right cure be overstepped ever so little the thread will gradually lose strength and go rotten. This is not apparent when first made and the thread may keep all right for months, when suddenly the rubber begins to get weak, and is easily broken, finally becoming thoroughly brittle and perished.

Rubber thread is also made direct from latex by a novel process which is described in the last chapter.

CHAPTER X

RUBBER SOLUTION AND ITS APPLICATIONS

Rubber Solvent

Many goods are manufactured with the aid of a rubber solvent. The solvent most commonly used in this country is coal-tar naphtha, a volatile, inflammable liquid obtained from the first portions which pass over when coal-tar is distilled. Mineral naphthas find employment to some extent mainly in America, although they are less suitable for the purpose, disadvantages attaching to their use being counterbalanced to some extent by a lower price. Chemically considered, they differ entirely from coal-tar naphtha, but have the same qualities of volatility and inflammability. They are obtained from the lower boiling constituents of petroleum or from shale oils and are known respectively as benzine and shale naphtha. There are many other liquids which dissolve unvulcanized rubber, such as ether, chloroform and carbon disûlphide, but the only other solvents of technical importance are carbon tetrachloride, and some similarly constituted bodies which have been introduced to manufacturers in recent years. They have the advantage that they are not inflammable, but they are too costly for many purposes, at any rate wherever the solvent is not recovered in the manufacturing processes, and they are all more poisonous than the ordinary naphthas.

India-rubber Solution

Speaking broadly, rubber when vulcanized does not dissolve in the ordinary rubber solvents, although it swells and takes up some of the liquid, especially if the rubber be under-vulcanized. It can, however, in some cases, be got into solution if subjected to sufficient mechanical treatment, or if heated with the solvent. In the latter case the rubber is partly decomposed. By long grinding of some kinds of vulcanized or semi-vulcanized rubber with a solvent a strongly adhesive but slow-drying solution is obtained.

If a piece of raw rubber be placed in a bottle of naphtha the rubber gradually swells, absorbing the solvent, and eventually loses its tenacity. If the mass be vigorously stirred or the bottle shaken at a certain stage and this treatment repeated from time to time, an apparently homogeneous solution is finally obtained. The solution is very sticky and tenacious. If poured on to a glass plate or other smooth surface and allowed to dry down it forms a skin of rubber which can be peeled off. If spread on cloth it forms a thin coating, and, the solution having penetrated more or less between the fibres of the cloth, the skin of rubber adheres firmly and cannot be torn off. A test often applied to rubber solutions consists in spreading an even layer on a strip of cotton canvas to within a few inches of either end, and then folding the canvas in the middle so that the coated surfaces are brought in contact and pressed firmly together with a roller. The force required to tear the two surfaces apart after they have had time to dry thoroughly is a measure of the tensile quality of the solution. There is a great difference in the appearance and properties of solutions made from dried raw rubber and similar rubber which has been masticated. It would appear that when rubber latex coagulates and the globules coalesce the other constituents of the latex are also precipitated, in particular, certain substances containing nitrogen and termed "protein." These substances form the so-called insoluble constituent of india-rubber. It was for a long time supposed that this insoluble substance consisted of the elements of carbon and hydrogen with perhaps some oxygen, the carbon and hydrogen in the same proportion as in the remainder of the rubber, until Spence discovered that the insoluble constituent contained nitrogen and consisted wholly, or at any rate to a large extent, of "protein." The source of the "protein" is the original latex in which it is present in soluble form.

The protein is distributed throughout the rubber in the form of strings or films and is probably impermeable or with difficulty permeable to naphtha. As the particles of rubber are enclosed in the protein films as in a mesh, the solution takes place with difficulty unless well stirred. The solution is also very viscous on account of these protein films, and we have found that the difference in viscosity of solutions of raw rubbers of the same strength is largely accounted for by the mode of distribution and amount of protein present in the rubber.

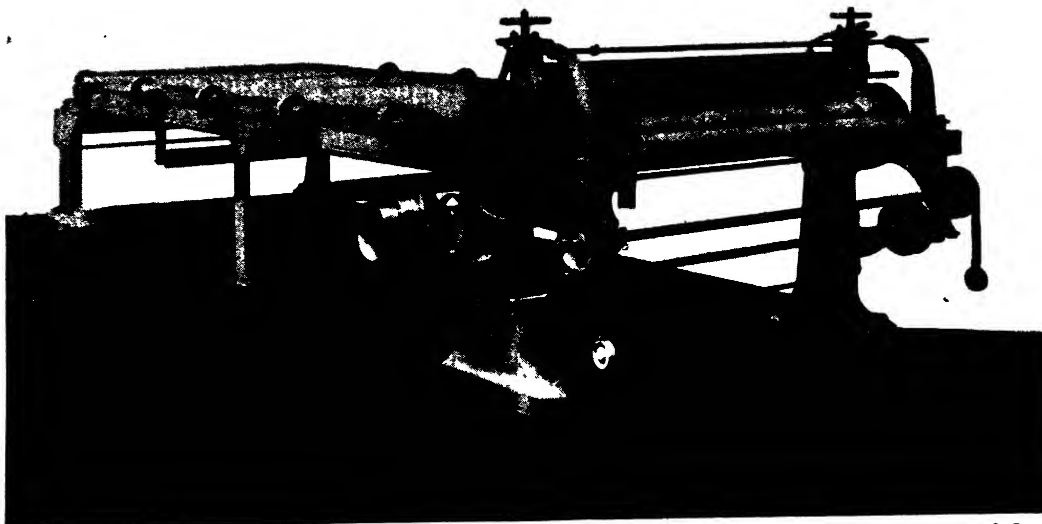
On masticating the raw rubber these films are broken up, and consequently the masticated rubber dissolves more readily in naphtha and the solution is less viscous than that from the untreated rubber. But, apart from this, it is found that the viscosity, i.e. the resistance to flow, is mainly dependent on the conditions and period of mastication. On the solution being allowed to stand the protein films separate and form a deposit at the bottom. For purposes of clarification on a manufacturing scale the solution is forced through fine gauze filters.

There is a great difference in the way various raw rubbers are dissolved by naphtha. Strips cut from a loaf of fine Para and dried are only slowly dissolved, and some of the plantation sheet and biscuit is even more difficult to get into solution, while the solution is more viscous. On the other hand, well washed plantation crêpe is easier to dissolve, particularly after it has been masticated. These considerations would appear to prove the futility of attempting to judge the quality of rubbers by the viscosity of a fresh solution, as has been suggested.

Owing to the inflammable nature of rubber solutions, brought about, of course, by the naphtha used as the solvent, great restrictions are placed on the carriage and storage of the material, and users as a rule purchase the rubber and make their own solutions in small quantities at a time as required, or purchase from a local maker.

Spread Sheet

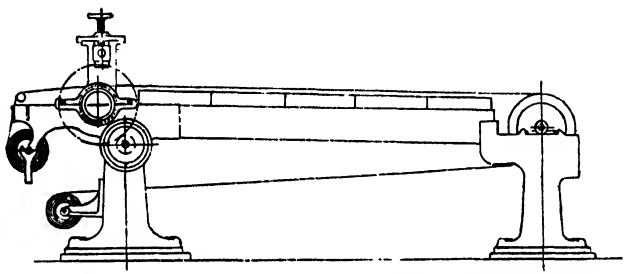
Rubber solution is used in some quantity by the cycle and motor tyre repairer, and also in various trades as a waterproof varnish. The original mackintosh was prepared by treating cloth with a solution of rubber, but, owing to the inconvenience attaching to a surface which became sticky in hot weather, the manufacture would have been abandoned had it not been for the discovery of the means of vulcanizing the layer of rubber attached to the cloth. The chief consumption of naphtha in the rubber trade is for the production of a rubber solution or "dough," so called as it is very stiff and pasty. This dough is further manipulated, and the naphtha is removed by evaporation. The fact that rubber can be dissolved and the rubber obtained again on evaporation of the solvent affords the rubber manufacturer an invaluable means of manipulation. This can be illustrated by reference to the production of "spread sheet." We have seen how raw rubber can be calendered to form a sheet and that for certain purposes the rubber is softened with naphtha before



By courtesy of *Messrs. Joseph Robinson & Co.*

FIG. 28. SPREADING MACHINE

calendering, and the naphtha subsequently removed by evaporation. Spread sheet is made by dissolving the rubber in naphtha and spreading the thick, viscid dough on to the surface of specially prepared cloth. Heavy calender rollers are not required, the rubber dough being soft. The cloth carrying the layer of rubber solution or " dough " passes over a large shallow box or " chest " which is steam-heated to evaporate the



By courtesy of *Messrs Joseph Robinson & Co.*

FIG. 29. WORKING ARRANGEMENT OF THE SPREADING MACHINE

naphtha. When one layer has been deposited and dried another can be deposited on the first, and so on till a sufficiently thick sheet has been built up. This is then well chalked and separated from the cloth.

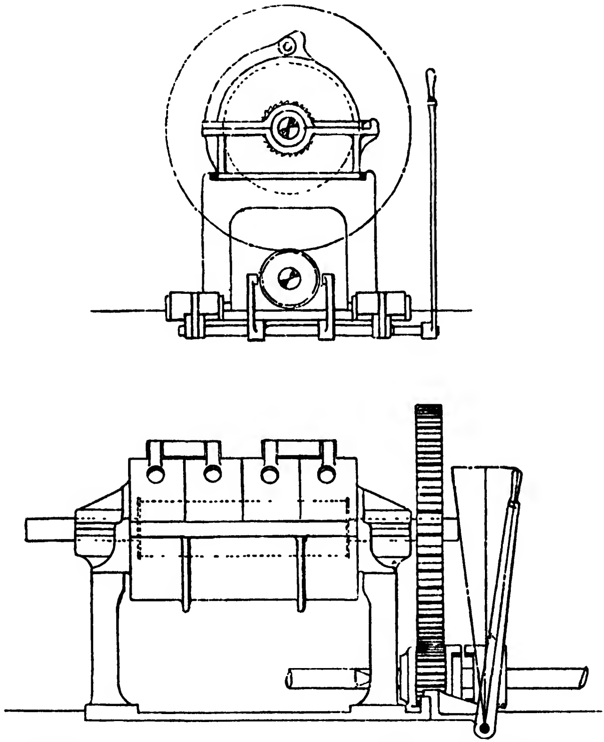
The spreading machine or spreader (Figs. 28 and 29) consists of a roller fixed at one end of a large steam chest or table. Over the roller is an adjustable knife, " doctor," or " gauge " with a blunt edge, and the cloth to be coated passes from an auxiliary roller over the first-mentioned roller and under the knife. The rubber compound, which has been milled with naphtha to suitable consistency in a pug mill, is spread on the surface of the cloth on the top of the roller and the knife edge is adjusted at such a distance from the surface of the cloth that a layer of the required thickness passes along on the cloth, the remainder being held back by the knife. The two wheels on the top of the machine on either side are for the purpose of adjusting the height of the knife, and there are two cheeks, also adjustable, which confine the dough and prevent it wandering over the ends of the roller on to the bearings. The cloth with the coated surface passes over a roller at the end of the chest, and almost hidden from view in the illustration, and then back again underneath the chest where there are two guiding rollers, and is finally wound on to a roller slipped on to one of the square shafts in front of the machine.

It is curious to note that spreading machines are very little used in America. The American practice is to use friction calender wherever possible.

CHAPTER XI

Cut Sheet

There is a third method for the manufacture of sheet more costly than either of the two preceding ones. The rubber produced is known as "cut sheet," and had its origin in this country, although it is now made in many parts of the Continent as well. In principle the method consists in slicing thin layers of rubber from a block with a knife having a rapid to-and-fro motion. The rubber is frozen to a hard block to give it the necessary rigidity. It must be absolutely homogeneous and free from air-bells, or flaws of any kind, or corresponding defects will occur in the sheet. For some of the purposes for which it is used, in particular electric insulation, flaws or pinholes would be fatal defects. The raw rubber, which at one time consisted exclusively of fine hard Para, is carefully and thoroughly washed. Special pale cut sheet is also made from plantation rubber. For this purpose it is generally washed before using, in spite of the fact that it has already been carefully washed on the plantation. The washed and dried rubber is next masticated in a special machine (Fig. 30) which is intended to reduce it to the necessary degree of plasticity. This machine consists of a hollow iron cylinder with openings in the top and a roller with a ribbed surface which revolves on the rubber. The illustration shows the machine in section and the general external view when the casing is closed. The machine is arranged for steam heating. The rubber is taken out of this machine after mastication in a bolster-shaped block, which is then placed in a steel cylinder and subjected to hydraulic pressure by means of a plunger. The rubber is then frozen, which at one time used to take many months,



By courtesy of *Messrs. Joseph Robinson & Co.*

FIG. 30 RUBBER MASTICATOR

but with modern refrigerating machinery this is accomplished in a few weeks. Time, however, must be given for the block to freeze right through to the centre, which is always a slow process owing to the fact that rubber is a bad conductor of heat. In the older process the sheet was sliced off the end of the block, that is to say, in a plane at right angles to the direction in which the pressure was applied, and it is stated that the best results were obtained in this way. For the production of a continuous sheet the block, which is cylindrical in form, is in the first place compressed in the steel cylinder, and a steel spindle is then forced down along the centre line of the block. After freezing the spindle is forced out again, leaving a hole along the axis of the cylinder on which the block is mounted. It is then made to revolve against a very rapidly oscillating blade which slices the rubber in a continuous length, spiral fashion. The knife is kept well lubricated with water and leaves its mark on the sheet in the form of a number of very fine lines parallel with one another. This marking is so characteristic of cut sheet that it has been imitated abroad by the use of an engraved calender roller. The surface of machine-planed steel will mould a very similar appearance on a sheet of rubber.

Insulation Tape

Most of the pure rubber sheet is vulcanized at some stage or another, either by the cold-curing process or by immersion in a sulphur bath. Part of it, however, in an unvulcanized state finds employment as rubber tape for electrical purposes. Rubber tape consists of long strips about half-an-inch wide used for winding round the copper conductors of cables. Copper is a dangerous metal to bring in contact with vulcanized rubber, as after a time the copper would be liable to be corroded by the excess of sulphur in the rubber and this would cause the rubber itself to perish, and consequently the insulation of the cable to break down. It is usual, in the first place, to tin the surface of the copper and then to wrap a layer of unvulcanized rubber next to the metal, to be followed with vulcanized rubber outside this again. The best tape is, of course, that made from cut sheet, the strips being cut at right angles to the knife marks. Spread sheet is, however, very generally employed for insulating purposes and also gutta-percha compositions.

CHAPTER XII

COLD CURING OF INDIA-RUBBER

THIS process, discovered by Parkes in 1846, consists in treating the raw rubber with sulphur chloride (disulphur dichloride, S_2Cl_2), which reacts with it in the cold. The reaction is a vigorous one and a diluent is required, as otherwise the surface of the rubber would be attacked and over-cured while the centre of the sheet would be unaffected. For a diluent a liquid is required which will mix with the sulphur chloride without decomposing it and which will also have a solvent or swelling action on the rubber. The first effect of a solvent is to penetrate the sheet causing it to swell. Of numerous substances which have been tried for this purpose, nothing has been found to work so well as carbon disulphide. Consequently it is generally used for this purpose in spite of its inherent drawbacks which include inflammability, volatility and a poisonous nature. The solution of sulphur chloride required is a very weak one, containing somewhere about two or three per cent. of the chemical. This solution can be brushed or spread over the surface of the rubber by a suitable mechanical contrivance, or the article may be dipped in the solution. Another method by which the sulphur chloride may be applied consists in allowing the vapour to act on the surface of the rubber in a closed chamber. In this case, however, the rubber is not penetrated to the extent it would have been if a solvent had been used, and although the action of the vapour is under control, the surface primarily is acted upon, while the inner portions remain unvulcanized. Any excess of sulphur chloride may be removed after treatment by washing the vulcanized articles in a weak solution of soda which decomposes the residues of sulphur chloride and neutralizes the hydrochloric acid formed in the reaction. As an alternative, the article may be well dusted with magnesia. The cold cure is the usual method of vulcanizing waterproof textures but not the only means. The method is also used for articles such as tobacco pouches and some surgical goods. From what has been said as to the penetration of the rubber by the sulphur chloride with the aid of a rubber solvent, it can readily be understood that the cold cure is only applicable to rubber in the form of thin sheets and preferably containing little or no loading. Some of the minerals used in rubber-mixings are inert, but a great number of them, particularly those of basic character, as magnesia, litharge, etc., are inadmissible for compounding rubber intended for cold curing, as these minerals react with the sulphur chloride and decompose it.

Sulphur chloride is prepared by bringing the two elements together, dry chlorine being passed over heated sulphur. It is an amber-coloured liquid which fumes in the air and gives off vapours which irritate the eyes and nose. It is decomposed by water, and hence in working the cold cure process moisture must be carefully excluded. In the manufacture of tobacco pouches, india-rubber gloves and similar articles, the unvulcanized sheet rubber is cut to shape and the article built up therefrom on wooden moulds. The edges are joined up by making them overlap and gently pressing them together, or the edges may be brought up flush and the joint strengthened, if thought necessary, by laying a narrow strip over it.

Unvulcanized rubber can easily be made to adhere if the surfaces are clean, and an inspection of any rubber tobacco pouch will illustrate the way these articles are made. In this connection, mention should be made of some of the best black india-rubber tubing; the joint along the tube is easily detected, and if made from cut sheet the strip is taken at right angles to the marks of the knife cuts, the latter forming circles round the tube.

Cold curing is largely used for waterproof cloth. We refer to light cloth such as is used for the manufacture of the ordinary mackintosh, and which has been spread with a thin layer of rubber. The rubber is generally adulterated with substitutes, often with a large proportion of the latter, and the general low level of quality produced by competition and demand by the public for a low-priced article has considerably restricted the output of the industry in recent years.

Reference has been made to a suitable mechanical contrivance for cold-curing the cloth on which the rubber has been spread. This consists essentially of a wooden trough and roller dipping into it. The trough takes the solution of sulphur chloride in carbon disulphide and is built shallow, coming close up to the roller so as to expose as little surface of the solution to the air as possible, in order to minimize both evaporation of carbon disulphide and decomposition of sulphur chloride. The cloth is led with the rubber face downwards on to the surface of the wooden roller, which spreads an even layer on the rubber. The rubber is kept in contact with the wooden roller by guiding rollers and then passes over a heated table or drum to remove the remainder of the chemicals, and is finally re-rolled. Cold cure used to have the great advantage over vulcanization by heat in that the colours were better preserved, but to-day, owing to the low temperature at which rubber can be vulcanized by the use of accelerators, the reverse is the case. Many of the coal-tar dyes can be used when the cloth is cold cured. Some of the lustre effects on these cloths are got by the use of starch which is dusted on before treatment with the sulphur chloride solution.

India-rubber Teats

The use of rubber solution for the manufacture of spread sheet has been explained. There are other articles, such as teats for babies' bottles, which are made on the same principle. The reader may smile, but the number of these india-rubber teats manufactured in the course of a twelvemonth is enormous. The visitor to the rubber factory may find a big department devoted to this purpose. Rows of narrow benches are arranged down a long room on which are trays containing rubber solution. Over the trays are suspended square boards from the underside of which project a great number of moulds of glass or varnished wood. These are dipped into the rubber solution and the naphtha evaporating leaves a thin layer of rubber on the surface of the mould. On dipping a second time another layer is deposited on the first until a sufficient thickness of rubber is obtained. The board with the moulds now covered with a layer of rubber is next lowered over a tray containing a solution of sulphur chloride in carbon disulphide, so that the rubber is vulcanized, and, after being washed, the finished teats are slipped off the glass moulds, which are ready for making a fresh batch. With the introduction of plantation rubber teats may now be obtained pale yellow and almost transparent.

While on the subject of goods made from rubber solutions, a few remarks may be made on the question of recovery of solvent. It is obviously an undesirable thing to breathe in an atmosphere containing much naphtha vapour, quite apart from the waste of solvent when this evaporates and is lost in the air. Various suggestions have been made and plant erected for collecting the vapours given off from the spreading machine. A hood is provided over the table and a fan to draw the vapours up into the hood, which then pass into a condensing arrangement consisting of silica gel or a similar absorbent on which the naphtha vapours are condensed. The main difficulty is caused by the admixture of air with the naphtha vapours. This makes it much more difficult to condense the vapours, and it is found impossible in practice to fit a hood and construct the spreading machine in such a manner that air is not drawn into the hood along with the naphtha vapours.

Transparent Moulded Rubber

In recent years many goods previously cold cured have been largely replaced by hot-cured moulded goods, as by the use of suitable accelerators and restriction of the proportion of sulphur it is possible to manufacture pale transparent or translucent articles in this way. Much is also being done by replacing the solution of rubber in a solvent by means of rubber latex. The layer of rubber is either deposited by dipping in the latex or by a process of electro-deposition. Compounding ingredients can be mixed with the latex and deposited with the rubber. The articles are subsequently vulcanized at a moderate heat. Alternatively one may use vulcanized latex, that is, latex in which each particle of rubber has been previously vulcanized, so that the article when made is already vulcanized and requires no further treatment (see Chapter XV, also "Rubber Latex," published by the Rubber Growers' Association).

CHAPTER XIII

MISCELLANEOUS RUBBER GOODS

India-rubber Balls, Football Bladders, and Children's Toys, Etc.

The common method of making india-rubber balls, hollow rubber dolls, and similar toys, is a very ingenious one. It is obvious that they cannot be built round a mandrel or mould, as there would be no means of withdrawing the latter. They have also to be filled with air. To begin with, calendered sheet is provided of suitable composition and generally heavily mineralized. By cutting four segments out of the sheet of a suitable size and shape, and joining these along the edges a hollow article can be built up more or less resembling a ball. The shape of the segments will correspond to the four pieces of peel obtained by cutting up an orange into four quarters. Before joining up the edges two things must be done. Firstly, a small piece of rubber compound containing no sulphur, and which will not, therefore, vulcanize with the rest of the rubber, is stuck on the inside of one of the segments. A mark is made on the outside to correspond, so that when the ball is vulcanized the position inside of this piece of unvulcanized rubber may be easily found. And secondly, a pinch of carbonate of ammonia is placed inside before joining up the edges. The ball is then sealed up, placed in an iron mould and vulcanized in the ordinary manner. The moulds are simple in construction, consisting of two hollow plates with a large number of hemispherical depressions corresponding with one another in the two plates. When the mould gets hot it causes the carbonate of ammonia to vaporize and the pressure of this vapour inside the ball keeps the rubber pressed against the metal of the mould while the rubber is being vulcanized. When taken out the ball is found to be perfectly shaped on the outside. It is, however, quite soft and collapses as the carbonate of ammonia in the inside condenses to a solid again on cooling. To fill the ball with air, the operator takes a hollow needle, connected with a small bellows or air reservoir, and pushes the needle into the ball at the spot where the piece of unvulcanized rubber is fixed on the inner side. Air is then forced into the ball through the hollow needle and as the needle is withdrawn, the unvulcanized rubber closes over the hole so that the ball remains full of air under pressure. The same principles are applied in the manufacture of india-rubber dolls. Football bladders are put together out of sheet. Hot-water bottles are built up in a similar manner, but cloth insertion is used, as the function of the rubber in this case is to keep the bottle watertight and the walls are not required to expand, but merely to be flexible. Nevertheless, many hot water bottles are now moulded and vulcanized without insertion. This is a cheaper method of manufacture and gives a better finish, but the bottles are more liable to tear or split. Surgical goods, such as enemas and the like, are built of sheet and vulcanized in moulds in the same manner as india-rubber balls.

India-rubber Soles and Shoes

The manufacture of india-rubber overshoes or goloshes is a very large industry, particularly in the United States, Germany, Russia, and Scandinavia, where there is a considerable demand for these particular articles. In this country rubber shoes are used to a much smaller extent and are principally worn by women and children, who wear a lighter boot than men. Reference may also be made to the rubber " Wellington," which has become popular in the last year or two. Rubber shoes, like leather ones, are made on lasts, and we can also distinguish between the " soles " and the " uppers," which are made of different classes of compound. As in leather shoes, the soles must be made of a tough material to stand wear and tear, while the uppers require to be strong and elastic, but can be built much thinner. There is also the lining to consider, which is made of some sort of rubber-proofed cloth to suit requirements. The soles are made of calendered sheet. A special form of calender is employed, having an engraved roller which stamps or impresses on the rubber the common diamond pattern such as is usually seen on the underside of the sole. The roller in front at the top is engraved, for embossing in this case, for the uppers of shoes, a smaller calender being used for the soles. The sole piece is generally cut from the sheet by hand. The shoes are built up by hand on an iron or wooden last. The various pieces that go to form the shoe are supplied, already cut to shape, to the operator who joins them up on the last with the aid of a solution of rubber in naphtha. To vulcanize black the rubber must be compounded with litharge and lamp or gas black, but to give the shoes a bright gloss, presumably in imitation of polished shoe leather, the rubber is painted, before vulcanizing, with a special varnish, the main constituents of which are boiled oil, turpentine and lamp black. Much of the time and expense involved in the manufacture of rubber shoes is necessitated by the demand for an attractive-looking article. The shoes must be neatly put together with a good glossy surface and of good appearance generally if they are to sell readily. They are usually so neatly made that they look like mould-cured goods. A dozen or more pieces are required to build up a single shoe, and when the lasts are covered they are placed on a frame and cured in hot air chambers.

Besides goloshes there are various military boots and similar articles of rubber which are made in the same way.

Of recent years vulcanized rubber has largely replaced leather for the soling of boots and shoes with uppers made of leather in the ordinary way. This development started with the introduction of heel pads, or small pieces of hard-wearing rubber which could be attached to the heel and served to prolong the life of the latter. The next development consisted of soles in addition to the heels. The use of rubber soles was long delayed, owing to the difficulty of securing the latter to the leather. They could not be satisfactorily nailed or screwed on as in the case of the heel pads. The difficulty was solved by the discovery of improved rubber solutions or adhesives, which enabled the rubber sole to be attached without damaging the existing leather sole, so that "stick-on" soles and heels are now in common use. Further, it has been found that a preliminary treatment of the leather with latex and allowing this to dry before applying the rubber solution, greatly improves the bond. The latest development of the rubber sole is the manufacture of boots and shoes with rubber soles in the place of the usual leather soles. This development has been accelerated by the high price of leather, and the superior wearing qualities of the rubber. For this purpose new types of vulcanized rubber have been introduced, consisting of rubber very heavily compounded with carbon black, so that the rubber is not very resilient or springy, but still flexible and leather-like in quality. A reference in this place should also be made to the bright-coloured bathing shoes which have displaced to a large extent the older types of black rubber. These are made by various processes, some by vulcanizing in the heat with accelerators and the minimum quantity of sulphur. There is also the crêpe rubber sole, which consists of raw crêpe rubber specially prepared for the purpose. Shoes soled with crêpe are in great demand for sports purposes and country wear, although unsuitable for use on the muddy pavements of towns, owing to the danger of slipping.

Stationers' Rubber

Ink erasers and rubber for removing pencil marks as at present manufactured are much better adapted for the purposes for which they are required than the hard lump of raw rubber that was at one time used. For erasing purposes either the paper itself or the rubber must be worn away. For erasing pencil marks the rubber should be soft enough to crumble down without wearing the surface of the paper, and therefore for this class of article no harm is done in compounding with a liberal proportion of oil substitute. On the other hand, for erasing ink marks a hard rubber is required, into the composition of which some gritty mineral enters, such as ground pumice or glass, the object of the ink eraser being to wear away the surface of the paper to a depth to which the ink has penetrated, as ink does not lie on the surface of the paper like a pencil mark.

Rubber Sponges

There are a number of obvious means for producing air-bells in a mass of vulcanized rubber; for instance, one might apply the principle employed in the manufacture of rubber balls, incorporating ammonium carbonate in granular form with the rubber compound, so that at the temperature of vulcanization each particle of the chemical forms an air-hole. However this may be, it would appear to be a difficult matter to obtain an even and regular distribution of large air-bells throughout the mass.

The process consists in making a rubber mixing in the ordinary way but of very soft consistency. This is obtained by means of a liberal proportion of oils and other softeners. To this is then added the blowing agent such as carbonate of ammonia or bicarbonate of soda, and the mass is sheeted and vulcanized in rectangular moulds. The moulds are much deeper than the sheet is thick so as to allow for expansion. The rubber rises like a loaf of bread and fills the mould. The manufacture is more difficult than would appear from this description, particularly to ensure regular expansion and uniformity in size of pore. The rectangular blocks are then cut to shape and the skin or thin coating of rubber removed.

Another method consists in heating the dough without a blowing agent, but in the presence of nitrogen under considerable pressure, during which vulcanization takes place. On releasing the pressure the mass swells owing to the formation of large numbers of minute gas bells. This type of rubber is known as onozote. The cells or pores are much smaller than in the commoner types of sponge rubber, and as the walls are very thin the sponge is much lighter.

Moreover, each cell or pore is separate and enclosed with a rubber film or skin, whereas with the ordinary types the cells mostly communicate. It is obvious that such intercommunication is necessary if the sponge rubber is to take up water like an ordinary natural sponge.

Another new method of manufacture starts with rubber latex (see Chapters II and XV). The latex has added to it the necessary vulcanizing ingredients, and is then frothed up to a foam. In this condition it is set or coagulated and vulcanized by subsequent heating. The product is specifically lighter than the common types, although the cells or pores may be large and vary considerably in size. It is particularly suited for making large masses of sponge rubber, such as for upholstery purposes where lightness is desired. Thus a whole chair-seat cushion or squab can be cast from this froth in one piece, whereas with the ordinary type the rectangular sheets must be cut into strips and the cushion built up of these strips laid cross-ways with wide spaces between. Sponge rubber is being used not only for ordinary domestic upholstery, but for omnibuses and railway carriage seats. It is also used for kneeling mats, as an underlay for carpets, for toy balls and bouncers, and wherever a light elastic material is required.

Ebonite or hard rubber (see Chapter XIV) may also be obtained with a sponge or cellular structure. That produced by the onozote process is extraordinarily light and is the best heat insulator known. The latex process is particularly suitable for the production of a type with microscopic pore. This is merely a vulcanized latex coagulum which consists of a watery, spongy mass. When the latex coagulates it retains most or all of the moisture within itself as minute droplets. This water must be dried out when sheet rubber is made from latex. The mass of coagulum shrinks enormously in the process. If now we add to latex sufficient vulcanizing ingredients to enable the rubber to be subsequently converted to ebonite, coagulate it and vulcanize it without allowing the moisture to escape, there is obtained a water-filled ebonite. If made in the form of thin sheets this material serves as an excellent separator for accumulators as both electrolyte and current can pass through it.

Asbestos Washers

Rubber is often used as a binding material, as in the manufacture of asbestos washers. For making these, the rubber is softened with benzine so that the mixing can be carried out in a Werner-Pfleiderer machine instead of the ordinary mixing-rollers, which would break up the asbestos fibres too much. The aim is to keep these fibres as long as possible, consistent with a thorough mixture with the rubber and other ingredients, mostly fillers. The internal type of machine is used. Although modified in different ways for different purposes, the general type of this machine consists in principle of an oblong trough; two shafts parallel with one another and carrying curved arms pass through the sides of the trough, and these shafts are driven at different speeds by suitable gearing. The curve and shape of the arms have been carefully designed, and to this the success of the machine must be largely attributed. The mixture complete, the material is sheeted and after removal of the solvent forms a very tough sheet, especially where a good class of long-fibred asbestos has been used.

Washers made in this way, where the rubber is used merely as a binding material, will stand a much higher temperature and steam pressure than the older type of rubber washer in which both a larger proportion of rubber was used and a rubber of better quality. As "*ite*" compounds, and under other names, very large quantities have been put on the market, and have found a ready sale. This is especially owing to the greater demands put upon this class of article since the use of superheaters for steam raising has become general.

CHAPTER XIV

VULCANITE

VULCANITE, ebonite, or hard rubber (German *Hart-gummi*) is made, speaking broadly, in the same manner as the ordinary soft rubber goods, except that larger proportions of sulphur are employed and the vulcanization takes longer, while the temperature is generally higher. Reference to vulcanite has been made when speaking of dental rubbers. The best vulcanite is made from rubber and sulphur only in proportions somewhere in the neighbourhood of ten to three, or four; usually, however, a very small quantity of softeners is added.

The effect of increasing the proportion of sulphur and the time and temperature of vulcanization on the physical properties of vulcanite may be noted. When under-cured the tendency of the vulcanite is to be soft and leathery; it is tough, but easily bent and shows little inclination to return to its original position. These properties are less marked as the time of curing is lengthened, and at the right stage a thin sheet of vulcanite is no longer soft but full of "spring," and returns at once when bent out of shape, although it is so tough that it can be bent double without breaking. If the cure be carried further the vulcanite gets harder, and offers more resistance to bending, but tends towards brittleness.

Vulcanite is easily softened by heat, as, for instance, boiling water, when it can be shaped as required, or will take an impress, becoming hard and resistant again on cooling. If of good quality without mineral admixture it will take an excellent polish and has been used for ornaments. Perhaps the most familiar article for which it is now used is the fountain pen. Vulcanite can not only be moulded but cut and turned, and is also very resistant to strong acids and other chemicals, so that it is a most suitable material for making troughs, pipes, joints and cocks, for chemical manufacturing purposes; also photographic developing trays and electric accumulators. In the latter articles its high specific resistance as an electrical insulator is of great value.

The mixing of the compound intended for vulcanite is done in the same way as for soft rubber. When intended for polished articles care must be taken to exclude all grit, but for technical articles this does not matter so much. In place of ground waste, vulcanite waste is used which is finely ground, and this gives a better result than a mixture of rubber and sulphur alone. A tough substance like vulcanite takes a good deal of grinding, which is done in easy stages; one machine, like a stone breaker, breaks the waste down to large lumps; a second machine reduces this to coarse powder, which is reduced to fine dust on powerful rollers built like a mixing machine. The dust is sifted from coarser particles which go back to the rollers again. Besides vulcanite dust numerous fillers and reclaimed rubber can be used. As mentioned above, where the object is to produce an article which is to be finely polished, gritty substances must be avoided, and to get a fine, smooth surface in the case of sheets the calendered, unvulcanized compound is laid on a table and covered with a large sheet of tinfoil, which is made to adhere closely by the application of a heavy roller. The sheets thus coated are put in an iron frame and vulcanized in water with steam under pressure. When the sheets are cured properly the tinfoil comes away easily from the surface, but if they are under-cured it tends to stick as when curing soft rubber in cloth.

CHAPTER XV

Direct Utilization of Rubber Latex

During recent years rubber latex (see Chapter II) has been available commercially, and has become a raw material for the manufacture of rubber goods, thus displacing a certain amount of raw rubber. The latex as obtained from the tree is strained and a small quantity, about ½ per cent, of ammonia is added, either in the form of the gas from cylinders or as the ordinary aqueous solution. The latex after treatment is packed in kerosene tins, steel drums or barrels. It may even be stowed in tanks on ships like oil and pumped out into goods wagons at the wharf when it arrives. Slight changes take place during storage, but the latex remains perfectly fluid and uncoagulated. For some purposes it undergoes a further preliminary treatment, usually before shipment, whereby it is concentrated. This is effected either by centrifuging in a manner similar to the separation of milk, or by evaporation in specially designed machinery after being treated with soft soap or other suitable stabilizer. The former method yields a concentrate or cream of about 60 per cent dry rubber content, and the second method a thick liquid or paste of about 65 per cent. We have, therefore, latex available in three forms of a concentration of approximately 40, 60, and 65 per cent.

Concentrated latex is mostly used for rubber manufacture, because it means less water to be removed from the wet rubber. Also some dilution of the latex in the process of compounding is unavoidable. With dry rubber, when once it is plasticized on the hot rolls, any and every sort of powder can be worked into it, but the compounding operation with latex is more difficult, because fine powders including such essential ingredients as zinc oxide and many accelerators coagulate latex when mixed into it. This is not a chemical reaction but a physical phenomenon resulting from the withdrawal of the moisture from the latex to wet the powder. Consequently, to avoid coagulation in this way the compounding ingredients must be wetted first and the wet sludge of powders, etc., added to the latex. Even then coagulation difficulties sometimes arise from obscure causes so that stabilizers or "protective colloids" form a part of the mixture to be added to the latex. This wetting of the powders results in the latex being diluted and, therefore, the mixture usually requires further concentration before one of suitable consistency is obtained, although 60 per cent concentrated latex may have been used to start with.

In this way there is obtained a suitably compounded latex which will contain not only the required mineral and other usual constituents, but also vulcanizing ingredients. These latter comprise sulphur, an accelerator of vulcanization, which may be a very powerful one, and an activator, usually zinc oxide, which is necessary in order that the accelerator may exert its maximum effect.

The rubber article may be obtained from the latex by any suitable method of coagulation or "setting" with subsequent removal of the water. The heat required for this operation may be sufficient to vulcanize the rubber at the same time as the article dries. Direct coagulation by adding acid is not usually satisfactory, because the conditions require very careful adjustment, otherwise coagulation is not uniform and the resultant coagulum shrinks irregularly, giving a distorted article. The commonest method of operation is that of dipping, and generally resembles the similar process used for making "seamless" goods (see Chapter XII). Suppose, for instance, that it is desired to make a rubber glove, a suitable mould or "former" constructed of glazed porcelain, varnished wood or metal is dipped into the latex mixture and then withdrawn. The moisture is evaporated in hot air leaving a thin film of the dry rubber containing all the ingredients on the mould. A second dipping superimposes a second film on the first, and the process can be repeated until the desired thickness is obtained. If the heat applied to remove the moisture has been insufficient to fully vulcanize the rubber, further heating is applied. The article is now finished and rolled off the former after well chalking. This process, however, is extremly slow, as ten or even more dippings may be necessary to give an article of the desired thickness. There are various ways of increasing the amount of rubber deposited with each dip, so that in some cases a single dip may suffice. Thus the former may be coated with a film of acid which coagulates the adjacent latex, giving a relatively thick coagulated film, or the former may be porous so that moisture may be sucked away from the interior, etc. Perhaps the most ingenious method is based on the use of "heat-sensitized latex," that is, latex so treated as to be unaffected at ordinary room temperature, but which coagulates on the surface of a heated former. The hollow mould or former is, therefore, fitted with inlet and outlet ducts and steam passed through to heat it. A short immersion in the sensitized latex results in a considerable deposit of compact coagulated latex. After removal from the bath further passage of steam through the mould causes the deposit to dry and vulcanize so that no further handling is needed.

A further modification of the dipping process is the electric, or more correctly, electrophoretic, deposition from latex. It is well known that an electric current passed through an aqueous fluid with particles in suspension causes the particles to move towards the unlike electrode and there deposit, giving up their charge. Latex is a negative suspension, so that the particles pass to the anode where they are deposited, building up a thick layer of coagulated rubber in a short time. Hence the name "anode process." There are various difficulties in obtaining a satisfactory deposit. All the particles to be deposited must be negatively charged. Also electrolysis and gas evolution at the electrodes cannot be wholly avoided, and may lead to porosity of the final product. Consequently, the anode process has not been adopted to the extent which at first seemed likely. Nevertheless it is a useful process for the manufacture of some articles, in particular a perforated sheet of any design, as the rubber will not be deposited on any part of the electrode which is protected by an insulating layer.

Latex may also be flowed or spewed into a coagulating medium, and the film of thread so obtained dried and vulcanized in the same manner as for moulded goods. Thus, rubber thread is made in this way and used in the manufacture of the so-called "lastex" yarns. The section is round in contradistinction to the thread obtained by the older methods of cutting it from sheet, which give a square thread. Similarly, also, tubes and tapes may be formed.

The electrophoretic method may be adapted to continuous working, also the use of heat-sensitized latex in an analogous manner, as follows—

As the latex passes down or along a duct or channel it encounters a heated section which causes it to set or coagulate, and a continuous length of the coagulated product is drawn from the end. Motor inner tubes have been made in this way.

There are two points in connection with goods made from latex which may be stressed. Firstly, the process is not adapted for the manufacture of heavily-loaded articles. The difficulties of compounding latex have already been mentioned. To obtain uniform products the loading must be kept uniformly in suspension, and so forth. The pigment must not be allowed to settle out. Consequently, the amount and type of pigment or filler which can be used are limited. The second point relates to quality of the articles. These, speaking broadly, are of higher quality than goods made from dry rubber, because there is no need to mill the rubber. Milling damages it. In fact, in many cases a very light degree of vulcanization suffices for rubber articles made direct from latex. With milled rubber very active accelerators, the so-called "super-" or "ultra"-accelerators, are difficult to use because of the liability to scorching (see page 55) during dry compounding. This difficulty does not arise with latex when the compounding is done wet. Consequently, better results should be obtainable and quicker vulcanizing at lower temperatures. In fact, unvulcanized rubber deposited direct from latex is very tough, and stretches and recovers well.

In the above processes the articles are vulcanized after the rubber has been deposited, but it is possible to prevulcanize the latex. Such vulcanized latex (Vultex-Schidrowitz patents) requires no vulcanizing ingredients added to it, but yields on mere drying of the product a vulcanized article.

APPENDIX

FIRE HAZARDS OF RUBBER MANUFACTURE: THEIR POSSIBILITIES AND PREVENTION

By John Davidson, F.R.S.A., A.C.I.I.

Two things must be considered when computing the fire hazard of any manufacturing process: first, whether the methods employed are themselves likely to induce an outbreak of fire; and second, whether the material under process of manufacture is of an inflammable nature. There are certain hazards common to most industrial risks—hazards from such features, for example, as the construction of the building, its size or capacity, the methods employed for heating and lighting it, its proximity to other buildings, and so on. These are hazards incidental to most industrial risks—although, of course, they vary in their degree of intensity according to the particular circumstances of the individual cases; they are what might be called *normal* hazards, in the sense that they are inevitable where any trade or manufacturing process is carried on, but these incidental, or what I have termed inevitable, hazards become accentuated where there is also a hazard inherent in the nature of the process or in the material under process. With machinery, for example, there is always the risk of fire from friction in the moving parts of the machine, due either to faulty lubrication or to a loose or worn bearing, but that risk is increased if the machine is working on material that happens to be of an inflammable nature, such as is met with in some of the textile industries. In some risks, therefore, the hazard lies in the methods employed in the manufacturing process; in others, in the nature of the material under process; while in others, again, both these factors are contributing to the fire hazard.

A rubber factory belongs to the third of these categories. Not only is the commodity in process of manufacture of an inflammable nature, but the processes through which it is required to go in the course of manufacture involve in themselves many features of hazard. In many of these processes chemical and physical changes are taking place; certain mineral and other ingredients are mixed with the raw rubber to form a compound, and some of these are of an inflammable nature. Artificial heat is applied at various stages of the process—for example, during mastication and calendering, and more particularly in vulcanizing, where the rubber is heated by steam under pressure in vulcanizing cylinders to such a temperature that it becomes semi-fluid. Again, in the manufacture of rubber goods of many descriptions, a rubber solvent is used. This solvent is usually naphtha, a volatile and inflammable spirit, and its use in some departments where rubber articles are being made constitutes one of the chief hazards of a rubber factory.

A rubber solution, or rubber cement, is required for fixing together the various parts of all the many different kinds of rubber goods made in a rubber factory—india-rubber balls, hot-water bottles, rubber shoes, goloshes, waterproof clothing, rubber tyres, and a host of miscellaneous articles. This rubber solution is obtained by dissolving unvulcanized rubber in naphtha, the naphtha acting as a solvent, and is used wherever the article that is being made is built up of different parts, the adhesive quality of the solution effecting a thorough union of the parts. Each worker is supplied with a small tin of naphtha, filled from a larger vessel, which, for the sake of safety, should hold no more than what is required for the day's work. If the factory is turning out these different manufactured rubber goods in quantities, the amount of loose naphtha handled during working hours must be considerable, and in considering the fire hazard from the use of naphtha it should be borne in mind that, despite all the precautions that may be taken in the storage and handling of it, its presence in and about the factory is materially accentuating any other hazard involved in the manufacturing process. Naphtha is a volatile spirit, which means that it quickly evaporates, and when mixed with the air it forms an explosive mixture which, owing to the low flash point of naphtha—below 60° Fahr.—can be easily fired. It will be readily understood, therefore, that should a fire break out from any cause, the consequences will in all likelihood be more serious than might otherwise have been the case. The naphtha vapour, owing to its inflammability, and the fact that, being heavier than air, it may be lurking under machines, benches, and other confined spaces, will assist combustion and accelerate the spread of fire.

In this connection the spreading of rubber, because of the naphtha vapour given off while the spreading operations are in progress, is admittedly the most dangerous of all the rubber processes from the point of view of fire hazard. Naphtha, for the reason just stated—namely, its volatility and inflammability—is a dangerous substance to handle at any time, and the danger is intensified when naphtha is used in any quantity, as in the spreading room. To allow such inflammable spirit to come into contact with a naked light would, of course, be to court trouble, and for that reason everything likely to incite ignition of the naphtha vapour should be rigidly excluded from the spreading

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room. That, however, is not always possible. Artificial light will be required during the winter months, and although the use of incandescent electric light for artificial lighting is safer than most other methods, it does not always eliminate the risk of fire. Fires due to electrical faults and other electrical causes are not uncommon, and while these in the majority of cases may not assume serious proportions, it is not difficult to perceive how serious would be the results of an electrical fire in the spreading room, impregnated as it is with naphtha vapour. Another point to remember in connection with the spreading room is that as the proofed cloth is passing through the rollers frictional electricity may be generated sufficient to discharge an electric spark which might ignite the naphtha vapour. That is one of the dangers inherent in the process itself.

To reduce the risk of fire as far as possible, and minimize its consequences, the spreading room should be a detached building of one story, and freely ventilated to carry off the naphtha fumes. The electric installation, whether for lighting or for power, should be kept under close supervision; all cables should be in screwed metal tubing to prevent accidents from faults; the lighting bulbs should be enclosed within double globes, and flexible lights, owing to their susceptibility to injury, should be prohibited. If electro-motors are used, these should be completely enclosed and kept clean to prevent sparking at the brushes. This applies not only in the spreading room but throughout the factory where naphtha is being used. I have mentioned that frictional electricity may be generated when the proofed cloth is passing between the rollers of the spreading machine. To carry off any electricity generated in that way, the spreading machine should be "earthed," and to deal with a naphtha fire in the spreading room or elsewhere, special fire appliances, such as buckets of sand or chemical extincteurs, should be installed. Happily, the danger from the use of naphtha and other similar volatile and inflammable spirit is so apparent and so fully recognized that every precaution is taken to avoid accidents from that cause.

Incidentally, the spreading department of a rubber factory affords an apt illustration of how a hazard common to most industrial risks, but generally regarded as so remote as to be in many cases almost negligible, becomes a matter of serious importance when considered in relation to the particular manufacturing process carried on. Incandescent electric light, as has already been stated, is regarded as the safest method of artificial lighting, and yet its presence in those departments of a rubber factory where naphtha is used may be a source of considerable danger. This applies to an even greater extent when electricity is employed as a motive power.

Another important consideration, and what should be particularly noted, is the manner in which the reserve stock of naphtha is stored. The question to be determined is how far the fire hazard in the factory generally is affected by the naphtha storage arrangements—whether, that is to say, these are likely to increase the zone of fire. The question can be considered from two aspects: first, whether a fire breaking out in the storage tanks or vessels will involve adjacent buildings; and, second, whether a fire in an adjacent building will involve the storage tanks and by that means be communicated to other buildings which otherwise might have escaped. The general lay-out of the factory may be excellent from the point of view of the fire risk, but these efforts may be neutralized owing to the danger to adjacent buildings from the naphtha storage tanks.

Attention, therefore, should be paid to the location of these tanks and their effect in communicating a fire to adjacent property, thereby increasing the fire zone beyond what might otherwise be expected.

But there are other factors in the rubber process besides the use of naphtha contributing to the fire hazard. In the initial stages of the process of manufacture, namely, washing, drying, masticating, mixing, and calendering—when the crude rubber is brought into a condition suitable for the manufacture of rubber goods—there may not be any particular hazard beyond what is usually found when steam-heated appliances are used, except that some of the ingredients used for mixing with the rubber may, owing to their physical condition, be of a more or less inflammable nature, or, at all events, might tend to intensify the ordinary fire risk by assisting combustion. For example, some of the finely powdered ingredients such as lamp-black or carbon dust would, of course, be liable to ignite in air. The point is one which should be kept in mind, especially in relation to the mixing and storage of these ingredients.

Vulcanizing plays an important part in the manufacture of all rubber goods, and is not the least important of the factors contributing to the fire hazard of the factory. The object of vulcanizing is to amalgamate the rubber and the ingredients which were mixed with the raw rubber during masticating and mixing. This union or combination is brought about by applying heat to the compound and is done by steam under pressure in vulcanizing pans. The hazard from the vulcanizing process lies in the degree of heat radiated by these pans, and the first consideration, therefore, is to see that nothing of a combustible nature is allowed to remain in the vicinity of the cylinders. There should be no woodwork near or within range of the heat radiated by the cylinders—wood floors, wood partitions, lining, or shelving, otherwise it will only be a matter of time before such woodwork will ignite ; nor should anything liable to ignite be allowed to accumulate near the pans. Fires in vulcanizing pans have been caused through waste material such as wood chips, paper, cardboard cuttings, etc., being inadvertently taken into the pans during loading operations and becoming ignited when the pan was heated, and have damaged both the pan and the articles loaded into it for vulcanizing. The same considerations apply in the vulcanizing process as in any other process requiring the application of heat, namely, the risk of anything of a combustible nature being ignited by the heat given off. There is also the risk of explosion from excessive pressure, although the cylinders, like other vessels under steam pressure, are provided with safety devices to obviate that danger.

Other features of hazard may be found in some of the subsidiary processes such as varnishing, especially where a mixture of linseed oil and naphtha is used. Rubber shoes, for example, are varnished to give them a glossy appearance and then vulcanized, a proportion of lampblack being mixed in the rubber compound at the mixing stage to produce black vulcanizing. If the varnish is made at the factory, it will be necessary to determine to what extent that process is affecting the fire hazard. Attention will require to be paid to the manner in which the boiling pans in which the linseed oil is boiled are placed and heated, what materials are used with the linseed oil, and the arrangements for storing the boiled oil—for all these are factors in the fire hazard incidental to varnish making. If old rubber is ground, as will likely be the case, attention should be paid to the methods employed for doing that. Sulphuric acid may be used for dissolving fabric off old rubber and there may be some drying process for drying the ground rubber by artificial heat after washing. Throughout the factory there will be found a variety of drying arrangements, and attention should always be paid to these to ascertain how the fire hazard is being influenced by the various appliances used for drying. Furthermore, where the factory is a large one, producing many different kinds of rubber goods, from the simplest article to tyres for motor vehicles, hazards which are incidental to individual manufacturing processes may be found in accumulation with each other. If, for example, waterproof garments are made, there will be the ordinary hazards of a clothing factory arising from power-driven sewing machines, stoves, or other appliances for heating irons, with, superimposed on these, the hazard from the use of rubber solution.

In addition to the hazards which have been specially mentioned there are others, some of which are peculiar to the rubber process, while others are common to most manufacturing risks and arise from the various machines and appliances used. It is scarcely necessary, however, to consider all these in detail. Only the outstanding hazards have been referred to here—the hazards, namely, that are inseparable from the rubber process and are found existing in all rubber factories, whether these are large or small. There are such a multitude of operations comprehended in the rubber process that it would be almost impossible to consider the fire hazard of all these individually. Some of these operations, moreover, may be found at one factory but not at another—it would depend on the extent of the factory and the class of goods manufactured. What has been aimed at here is to point out on broad lines the hazards generally associated with the rubber process without discussing in detail the particular hazards of individual operations.

Although, of course, there are certain hazards inevitable in the rubber process, these may be to some extent minimized by the adoption of certain precautionary measures, as in the case of other manufacturing or industrial risks. Perhaps one of the main considerations is to avoid accumulation both of risks and of values. To that end the departments should be as much self-contained as possible, so that a fire in one will not involve another; that applies especially where there is the risk of explosion. The fire hazard in storied buildings is greater than with shed buildings, and that is a feature to be taken into consideration in estimating the fire risk of a rubber factory. Cleanliness is another factor affecting the fire hazard, and all refuse, therefore, of whatever nature should be regularly removed and not allowed to accumulate on the floors. Owing to the frictional risk, all machinery should be kept under careful supervision, cleaned, and thoroughly lubricated. This is important having regard to the presence of naphtha vapour about the machines. Another point deserving consideration is accumulation in values. This will apply chiefly in the warehouse where the finished stock is stored. If the building is large, the values congregated there will be important, and these goods are of such a nature that a fire breaking out might damage them to such an extent, either by the direct action of the fire or by the water used in extinguishing operations, as to leave little salvage, resulting in a severe loss.

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