GRIFFIN'S
TECHNOLOGICAL HAND-BOOKS

THE CLAYWORKER'S HAND-BOOK.

NET BOOK.—This book is supplied to the Trade on terms which will not allow of Discount to the Public.

CHARLES GRIFFIN & CO., LTD.

THE CLAYWORKER'S HAND-BOOK.

GRIFFIN'S CHEMICAL AND TECHNOLOGICAL PUBLICATIONS.

Inorganic Chemistry,	Profs. Dupré and Hake,	*net* 6*s.* 0*d.*
Quantitative Analysis,	Prof. Humboldt Sexton,	3*s.* 0*d.*
Qualitative ,,	,, ,,	3*s.* 6*d.*
Chemical Engineering,	J. Grossmann,	*net* 3*s.* 6*d.*
Chemistry for Engineers,	Blount and Bloxam,	
,, ,, Manufacturers,	,, ,,	16*s.* 0*d.*
Foods, Analysis of	A. Wynter Blyth,	21*s.* 0*d.*
Poisons, Detection of	,,	
Tables for Chemists,	Prof. Castell-Evans. Vol. I.,	*net* 24*s.* 0*d.*
Dairy Chemistry,	H. D. Richmond,	16*s.* 0*d.*
Dairy Analysis,	,,	*net* 2*s.* 6*d.*
Milk,	E. F. Willoughby,	*net* 6*s.* 0*d.*
Flesh Foods,	C. A. Mitchell,	10*s.* 6*d.*
Practical Sanitation,	Dr G. Reid,	6*s.* 0*d.*
Sanitary Engineering,	F. Wood,	*net* 8*s.* 6*d.*
Technical Mycology,	Lafar and Salter. Vol. II., Pt. I.	7*s.* 6*d.*
Ferments,	C. Oppenheimer,	*net* 7*s.* 6*d.*
Toxines and Anti-Toxines,	,,	
Brewing,	Dr W. J. Sykes,	
Bacteriology of Brewing,	W. A. Riley,	
Trades' Waste,	W. Naylor,	*net* 21*s.* 0*d.*
Smoke Abatement,	Wm. Nicholson,	*net* 6*s.* 0*d.*
Paper Technology,	R. W. Sindall,	
Cements,	G. R. Redgrave,	*net* 15*s.* 0*d.*
Water Supply,	R. E. Middleton,	*net* 8*s.* 6*d.*
Road Making,	Thos. Aitken,	
Gas Manufacture,	W. A. Butterfield. Vol. I.,	*net* 7*s.* 6*d.*
Acetylene,	Leeds and Butterfield,	*net* 5*s.* 0*d.*
Fire Risks,	Dr Schwartz,	*net* 16*s.* 0*d.*
Petroleum,	Sir Boverton Redwood,	
—— (Handbook),	Thomson and Redwood,	*net* 8*s.* 6*d.*
Ink Manufacture,	Mitchell and Hepworth,	*net* 7*s.* 6*d.*
Glue, Gelatine, etc.	Thos. Lambert,	*net* 5*s.* 0*d.*
Oils, Soaps, Candles,	Wright and Mitchell,	*net* 25*s.* 0*d.*
Lubrication and Lubricants,	Archbutt and Deeley,	
India Rubber,	Dr Carl O. Weber,	*net* 16*s.* 0*d.*
Painters' Colours, Oils, etc.,	G. H. Hurst,	12*s.* 6*d.*
Painters' Laboratory Guide,	,,	5*s.* 0*d.*
Painting and Decorating,	W. J. Pearce,	12*s.* 6*d.*
Dyeing,	Knecht and Rawson. 2 Vols.	
Dictionary of Dyes,	Rawson and Gardner,	*net* 16*s.* 0*d.*
The Synthetic Dyestuffs,	Cain and Thorpe,	*net* 16*s.* 0*d.*
Spinning,	H. R. Carter,	*net* 16*s.* 0*d.*
Textile Printing,	Seymour Rothwell,	21*s.* 0*d.*
Textile Fibres of Commerce,	W. I. Hannan,	*net* 9*s.* 0*d.*
Dyeing and Cleaning,	G. H. Hurst,	4*s.* 6*d.*
Bleaching, Calico-Printing,	Geo. Duerr,	12*s.* 6*d.*

LONDON:
CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

THE

CLAYWORKER'S HAND-BOOK:

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

BY THE AUTHOR OF

"THE CHEMISTRY OF CLAYWORKING," ETC.

[Searle, Alfred B.]

LONDON:
CHARLES GRIFFIN & COMPANY, LIMITED,
EXETER STREET, STRAND.
1906.

Mining Dept
M.C

PREFACE.

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

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

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

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

THE AUTHOR.

June 1906.

CONTENTS.

CHAPTER I.

THE MATERIALS USED IN CLAYWORKING.

CHAPTER II.

PREPARATION OF THE CLAY.

CHAPTER III.

MACHINERY.

CHAPTER IV.

TRANSPORT, CONVEYORS, ETC.

CHAPTER V.

DRYING AND DRIERS.

CHAPTER VI.

ENGOBING AND GLAZING.

CHAPTER VII.

CHAPTER VIII.

KILNS.

CHAPTER IX.

FIRING.

CHAPTER X

CHAPTER XI

CHAPTER XII.

WASTE.

CHAPTER XIII.

THE CLAYWORKER'S HAND-BOOK.

CHAPTER I.

THE MATERIALS USED IN CLAYWORKING.

Clays.

Clay deposits vary so greatly in physical condition and chemical composition, that it is extremely difficult to group them into classes; and the methods employed in working them, as well as the uses to which the different kinds of clay are put, are also so numerous, that in order to obtain the best results each clay must be treated according to its individual requirements and those of the particular branch of trade for which it is intended. On this account it is not here proposed to describe at great length the properties of each of the different clays used in clayworking, but simply to deal with certain considerations which are otherwise apt to escape attention. The primary object of the clayworker is to use the clay he has at his disposal rather than to pay undue regard to the constancy of its composition; and although every care should be exercised to render the variations as small as possible, it is, as a rule, a waste of time to analyse the clay which is being used unless it is bought from an outside firm, under contract as to quality, as is often the case in the production of porcelain and of other high-class wares. The composition of the paste used in the manufacture of the best class of ware requires, indeed, the closest attention not only as regards the clays used, but also as regards the other materials employed, without which clay is almost useless to the potter. These materials are stone, felspar, quartz or flint, bone, barytes, etc. They are, to a large extent, known to makers of sanitary ware as the materials employed for the 'bodies' or 'engobes' used to cover the surface of the cheaper, or stronger, clay of which the goods are chiefly composed.

Common Clay, chiefly used for making bricks and unglazed tiles, is usually worked as a surface deposit. According to its behaviour on drying and in the kiln it is known as 'strong clay,' 'mild clay,' or 'malm' or 'marl.' Other local names are given in different parts of the country.

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

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

Marls or *malms* are clays containing, in the natural state, a considerable proportion of chalk, and may often be made into bricks without any admixture; but as clays containing exactly the proper proportions of clay and chalk are somewhat scarce, it is usual to prepare artificial marls by adding chalk to clays otherwise suitable. The object of the chalk is twofold: in the first place it acts mechanically in diminishing the contraction of the clay during the drying and burning; and, secondly, it acts chemically as a flux during the burning, combining with the silica of the clay so that a much harder and more durable material is produced. It is very important that the chalk or limestone, added or naturally present in the clay, should be in a sufficiently fine state of division, as the presence of lumps far smaller in size than a pea will sometimes cause a brick to fall to pieces. This is because the quicklime (calcium oxide) formed in the brick gradually absorbs carbonic acid from the air, and, in the presence of moisture, tends to cause such expansion that, with the first sharp frost, the brick is unable to withstand the strain and is disintegrated. With certain clays pieces of limestone as small as $\frac{1}{25}$-inch have been found capable of bringing about the destruction of the article in which they occur. When sufficiently finely ground, as much as 25 per cent. of chalk may be present in a clay; but for bricks intended to resist the action of the weather 12 per cent. is usually the upper limit. Much, however, depends on the original composition of the clay used. Such clays are always difficult to burn, as when the finishing temperature is reached vitrification takes place very rapidly and the bricks are particularly liable to lose their shape. As lime compounds form a yellowish substance with oxide of iron, it is impossible to get a good red brick when much limestone or chalk is present. On the other hand, the colour due to 5 per cent. of iron in the clay may, to a large extent, be removed by the addition of about 10 per cent. of limestone or chalk, when, under suitable conditions of firing, a buff instead of a red-coloured product will result.

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

China Clays, *Porcelain Clays*, or *Kaolins* are the purest form of clay known, and consist almost exclusively of alumina, silica, and water. They are less plastic than the common or 'plastic' clays, and generally burn to a very white porous mass; but even the less pure forms are greatly valued on account of their refractory nature, and, under the name of 'fireclay,' are in great demand for the production of ware intended to withstand high temperatures, *e.g.* the lining of furnaces, etc. It is generally thought that the kaolins are produced by the action of the weather on felspar, but their origin is still unsettled. Although the composition of kaolin may generally be represented by the formula $Al_2O_32SiO_2 + 2H_2O$, corresponding to 46 per cent. of silica, 40 per cent. of alumina, and 13 per cent. of water, this is really only true of the carefully washed and purified material. In its native state it is usually contaminated with varying proportions of mica and porphyry, and with some undecomposed felspar. These impurities are removed, when necessary, by washing, the impurities being allowed to settle, and the clay and water run off into drying tanks or hydro-extractors wherein the greater part of the water is removed.

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

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

Porcelain is made of a mixture of kaolin with felspar, chalk, and some form of pure silica such as flint or quartz, heated until the mass becomes partially vitrified and translucent when cold. The mixture is often kept in cellars for a long time before it is used, in order that it may 'mature' by a process of 'fermentation' and so become easier to work. It is said that the addition of a little honey, or sugar, is sometimes made in order to assist this 'fermentation'; but the nature of the changes which take place in maturing is by no means clearly understood, and the value of such additions is uncertain.

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

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

Fireclays may be regarded as a variety of impure kaolin. They are specially valuable for their capacity for withstanding high temperatures. As they contain upwards of 60 per cent. of silica and about 20 per cent. of alumina, their general formula is $Al_2O_36SiO_2$, with varying amounts of water, and small, but noteworthy, proportions of lime, potash, and soda; the last two compounds are commonly grouped under the heading of 'alkalies.' These are important, because the refractoriness of the clay depends, to a large extent, on the absence of more than a very small proportion of lime and alkalies. The fireclays are found in such abundance, and are used in such large quantities, especially in the manufacture of glazed bricks and other sanitary appliances, that they constitute one of the most important materials of the clayworking industry. A Table showing the results of the analysis of samples of fireclay from various parts of the United Kingdom will be found in the Appendix, but it must be remembered that clays which may appear to have a similar composition as far as an analysis will reveal may have very different ones in practice, owing to no figures being given for the relative proportions of combined silica, sand, 'true clay substance,' etc.

Impurities present in Fireclays.—The chief impurities found in fireclay are alkalies, coal, ironstone, and, to a less extent, lime or its compounds, the amount of these impurities being shown by analysis. Without knowing the particular purpose for which a clay is destined, it is impossible to fix any satisfactory limit to the percentage of these impurities, but, as a general rule, it may be assumed that the alkalies should not exceed 2 per cent. (in the best clays they will be far less), the lime and magnesia 2 per cent., as compared with up to 25 per cent. in marly clays, and the ironstone 3 per cent., although the permissible limit of the ironstone will depend on the fineness of the grinding of the clay; and in red-burning clay, three times this amount is not uncommon. The amount of coal and of other organic matter permissible will depend on the uses of the clay: if fired as biscuit, before glazing, a much larger proportion is permissible than if articles made from the clay are glazed green and only fired once. To a large extent the ironstone may be removed from the fireclay, before it is ground, by hand-picking and careful sorting. A skilled picker will often separate three-quarters of the ironstone present, but the work must be entrusted to a thoroughly conscientious man.

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

Where marked openness of texture is required, the addition of 15 to 30 per cent. of hardwood sawdust to the clay is often found useful, whilst for increasing the refractory nature of the clay, it is often mixed with half its weight or less of calcined bauxite, a mineral composed of about 60 per cent. of alumina and 10 per cent. of silica, and one of the most refractory substances known, but possessed of too little plasticity to be employed by itself. The bauxite is best prepared for use by mixing it with a quarter of its weight of good clay, wetting it as in claymaking, and making the mixture up into bricks which are fired in a clean part of the kiln and afterwards broken up and fed into the grinding mill with the ordinary clay.

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

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

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

The colour produced by mineral matters in the clay is also changed by firing, and it is usually more intense in the finished goods than in those which have not been through the kiln. There are, however, some exceptions to this statement, as, for instance, a clay containing both iron and lime compounds. At a low heat, such a clay will burn red owing to the oxide of iron present, but if fired hard the lime will unite with the iron to form a double silicate of iron and lime of a yellowish or cream colour. The conditions of firing will also affect the colour of the goods; thus certain classes of clay, containing iron compounds, will burn red in an oxidising atmosphere, whilst, if the clay be mixed with coal before firing and the air be excluded as far as possible from the kiln, black or 'blue' bricks will result—the difference in colour being due to the formation of less highly oxidised iron compounds owing to the reducing atmosphere employed. This subject has been studied with particular care by Prof. Orton, and his paper, on "The Rôle played by Iron in the Burning of Clays,"[1] constitutes the standard monograph on the subject. As the result of his researches, Prof. Orton concludes that, although the presence of iron, in a finely-divided form, is necessary to the production of a buff or red colour, its mere presence and the size of the particles does not appear to fully explain all the reactions and colours that are produced by its aid. The colouring power of iron in the state of granules is practically nil, but its presence in this form often causes trouble to the clayworker through the production of spotted, mottled and rough, unsightly ware.

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

---

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

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

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

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

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

The oxidation of the iron in the clay must be completed before vitrification is allowed to occur, otherwise oxidation will never be finished, and the clay will either be black or will contain large black areas. Sometimes, if the reduction of the iron has taken place late in the burning, it will show as a dark ring $\frac{1}{8}$-inch deep, surrounding a red core. This is particularly noticeable in certain sewer pipes when the fires have been pushed during the salt-glazing. When clays are burned at temperatures approaching 1200° C., it is practically impossible to admit any excess of air without a special regenerator, and, consequently, it is impossible to prevent an occasional reduction at this temperature. This will not matter much if the clay has been properly oxidized at 900° C. or thereabouts. On the other hand, it may be generally assumed that goods not oxidized at or near this temperature will never be oxidized.

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

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

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

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

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

(*b*) Rich in alumina (20 to 30 per cent.), moderate amount of

---

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

iron (1 to 5 per cent.)—burn yellow to brown, as most plastic clays and fireclays.

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

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

The last two classes do not belong to the refractory clays. There is also another class of clays to which some artificial colouring matter ('stain') has been added, so as to produce a special tint on burning. These are the coloured bodies or 'engobe' clays, and the colours used in connection with them are mostly metallic oxides, with or without a flux of some kind. Being somewhat difficult to prepare, these stains are best procured from dealers in potters' materials. Occasionally beds of coloured clays are found, in which the colouring oxide occurs naturally in a clay of low fusing point, so that it may be used directly for covering clay of a different nature; such clays are generally too valuable to be used for making directly into goods. Certain clays of this nature, which are rich in manganese, are used on the Continent in the manufacture of brown glazed bricks.

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

Plasticity.—The plasticity of clay is the property which pre-eminently distinguishes it from all other substances, for, although there are some other materials which become plastic on the addition of water, they do not possess this property to anything like the same degree as clay. The cause of this plasticity remains to a great extent a mystery, though it is generally understood to be connected in some way with the 'combined water' of the clay, as it disappears when clay has been heated to a temperature just sufficient to drive off this combined water (415° C.). Plasticity may be increased by the addition of glycerin or of syrups and certain gummy substances to the water used in mixing the clay, and a permanently plastic (non-drying) clay of great value for modelling purposes may be made by the use of a mixture of plastic clay, vaseline, and a little oil.[1] Several authorities have advanced the theory that bacteria are the cause of plasticity in clay, but Hecht and Kosmann find that there is not sufficient evidence to prove this, and its probability is made more doubtful by the failure, up to the present, to render lean clays plastic by inoculation. Bischof, an eminent authority on the subject, considers that there is a kind of 'felting' of the particles, partly due to their minuteness, which enables them to adhere more closely to each other than do equally small particles of other substances.

The ancient practice of improving the plasticity of clay by 'ageing' is now seldom practised to anything like the extent which was formerly thought necessary. Where hollow-ware goods of very fine clay are made, there is an undoubted advantage in storing the clay for some time before it is made up into goods, but the keeping of the clay in air-tight boxes for several years, as practised by Wedgwood and other famous potters, is no longer considered essential.

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

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

---

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

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

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

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

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

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

The use of burnt ballast, 'grog,' or sagger material is of great importance in some cases, as by this means a fat, highly plastic clay can have its natural shrinkage reduced to practicable limits, and further, in the case of large goods especially, the addition of such material opens up the body of the clay and provides easier channels for the water to pass from particle to particle of the mass, thus securing a greater homogeneity as well as greater facility for rapid and even drying, and less liability to 'jumping' or 'dunting' in the kilns. Various materials may, of course, be mixed with the clay in order to produce these effects; where it can be obtained cheaply enough the addition of burnt clay of the same composition to that used in the works in an unburnt condition has the advantage of conferring greater strength and rigidity without altering the composition of the clay used. This burnt clay (grog or sagger) is largely used in the manufacture of bulky fireclay goods for the reasons just stated, and because it forms a kind of skeleton which holds the plastic clay to the intended form. Such burnt clay may be obtained from the waste and broken goods on the works; or where there is not a sufficient supply it may be burned specially for the purpose in a kind of limestone-kiln. It is important that the grog should be fully burnt, and yet not sufficiently so to vitrify it and so destroy its binding properties. When broken goods are used, the glazed portions (if any) should be used with care, as they are a source of weakness rather than of strength to the clay with which they are mixed, for grog only acts as a refractory agent up to its vitrifying point. The fineness of the particles of burnt grog which should be added to a clay depends on the purpose and nature of the article to be manufactured. For withstanding sudden variations of temperature, the coarser the grog the better. When once a suitable size of grain has been found, great care should be taken that the grinding is carried out so as to obtain a similar result. In testing the fineness of burnt grog it is not necessary to sift it through a variety of sieves: if two pounds, accurately weighed, be carefully poured into a litre measure, and water run into the latter from a burette or similar accurately graduated measure until the mark on the flask is reached, the amount of water necessary to fill the flask up to the mark will give, indirectly, but with sufficient accuracy, the fineness or otherwise of the grog. In practice it is not necessary to calculate the actual volume-weight of the material; it is sufficient to know that it is of such a nature that 'so many' measures (c.c.'s) of water must be added. If more than this pre-determined volume of water be required, it indicates that the material has been too finely ground; if less water be needed, the grinding must be continued. Unless recourse be had to an expert, the amount of grog which should be added, and the fineness of its particles to obtain the best results with a particular clay, can only be ascertained by experiment. Where sudden changes in temperature occur, the particles of grog should be relatively large (sometimes as much as $\frac{1}{4}$ inch in diameter), but the shape, and especially the ornamentation on the goods, will often prevent pieces so large being used. In such cases a compromise must be effected. Occasionally a mixture of fine and coarse grog is employed. The porous nature of properly burnt grog materially assists in the drying of the goods, but, for some purposes, it is better replaced by other material—sometimes on account of the grog not being available in sufficient quantities, although more frequently in order to produce goods of refractoriness greater than that of the original clay. The effects of improper contraction being shown in drying and firing, reference should be made to these headings and to 'Defects.'

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

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

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

Sand is often useful in grinding the clay, as it enables the mills to get a better 'grip.' When used in moulding, its chief characteristics should be great refractoriness, 'sharpness,' and freedom from staining power, while a sand as free as possible from iron compounds should be used where the colour of the goods is important.

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

Good sand may be rubbed on white paper without leaving any dirty mark, and, if stirred up with water, no permanent turbidity is produced. If a sand will not answer to this test it must usually be purified from clay and dirt by washing in a stream of water, with constant stirring. Special machines are made for this purpose. Sand, quartz, and other forms of silica used for glazes must be extremely finely ground, though the precise degree of fineness depends to some extent on the nature of the clay to which the glaze or engobe is applied: in some cases too finely ground flint is objectionable. The more finely-ground material is, naturally, more difficult to wash, so that either a particularly pure sand is used, or some other purer variety of silica, as quartz or flint, is substituted.

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

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

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

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

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

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

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

Barley and similar grains have been found useful by Mäckler in forming the large pores necessary to prevent scumming in certain kinds of clay. Other waste materials—as naphthaline—have also been suggested.

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

Bauxite is occasionally used without any admixture of clay, but lime water must in this case be employed in the tempering and the bricks prepared much in the same manner as Dinas bricks.

The value of bauxite, which depends on the proportion of alumina it contains, is seriously diminished by even a small increase in the proportion of other oxides. The unburnt mineral often contains as much as 30 per cent. of water, so that, in comparing the results of analyses of different samples, the calculations should be made on the calcined samples. In this country Irish bauxite is commonly used, good specimens of which will contain upwards of 75 per cent. of alumina after ignition. American bauxite sometimes contains as much as 90 per cent. of this constituent.

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

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

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

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

$$1{\cdot}0\mathrm{Al_2O_3} + x\mathrm{SiO_2} + y\mathrm{RO},$$

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

This only applies to clays and other silicates in which the fluxes are in relatively small proportion, and not to such compositions as glazes. In the study of this question the investigation of the fusion points of blast-furnace slags has shed some interesting light, and a triaxial diagram has been devised by Roozeboom, which, with modifications, might serve equally to determine the fusion points of clay mixtures.[1]

Porosity is due to the spaces between the particles of clay composing the mass. The porosity of the fired ware may be increased by the admixture of combustible matter, such as coal-dust, sawdust, naphtha, or grain (barley) with the clay, and these additions are occasionally made to enable the goods to withstand rapid changes in temperature better than they would do if of closer texture.

The addition of these materials does not affect the porosity of the clay before firing, but, by separating the particles further from each other than they are in the natural clay, the spaces produced when the combustible material burns away become filled with air, which, being a non-conducting medium, enables the porous ware to better withstand fluctuations in its temperature. The greater freedom with which the particles can move over each other in such ware is also of assistance in this respect.

As a rule, the purer the clay and the finer it is ground, the less will be its porosity. Overheating the clay will also diminish its porosity by causing a partial vitrification of the material, the resultant glaze or glass filling up some of the interstices formerly occupied by the air.

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

The amount of porosity possessed by a clay (after firing)[2] is calculated from the amount of water which the fired clay will absorb owing to the water replacing the air in the pores of the sample when the latter is allowed to soak in water for some time. The method of making this test is described in Chapter XI. under the heading 'Porosity.'

Although it is usual to calculate the amount of water absorbed in terms of the percentage by *weight*, it is really more correct to

---

[1] The reader interested in this subject might with profit consult the papers by Howe and Boudouard in the *Transactions of the American Institute of Mining Engineers* and the *Journal of the Iron and Steel Institute* respectively.

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

express it in percentages by *volume*, as it is the space occupied by the air that is really to be measured. Where water would affect the results, as in most raw clays, some other liquid, more suitable for the purpose, must be used in its place. Paraffin is very suitable.

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

The firing of specially light and porous bricks is a matter of some difficulty, owing to the large proportion of combustible matter which must be present. The fire has a great tendency to go too fast and so to 'set the kiln on fire,' and in some of the most difficult cases the air supply to the fuel has to be almost entirely stopped and the fires allowed to die nearly out before the steady firing can be proceeded with.

Engobes and Glazes.

Engobes are materials used to cover clay goods and so hide the material of which the goods are made. Generally they consist of mixtures of clays which will burn to the desired colour and so enable a material to be used which could not otherwise be employed on account of its colour. The word 'body' is sometimes used in this connection, but this is best avoided and the word only used to denote the material of which the article is chiefly composed.

Glazes are also materials used to cover the surface of goods—generally with a view to making the articles impervious to water; but frequently the chief use of the glaze is to add beauty to the article and to increase its durability. Although the majority of glazed goods have a glossy appearance, many ornamental pieces have a dull or matt surface. Although the word 'engobe' may be rightly understood to include many glazes, yet it is most convenient in practice to regard only the unvitrified, or but slightly vitrified, coatings as engobes, and to regard the vitrified ones as glazes.

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

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

Clays approximate more or less to the composition of kaolin—a silicate of alumina with the formula $Al_2O_3 2SiO_2 2H_2O$ containing roughly 40 per cent. of alumina, 46 per cent. of silica, and 13 per cent. of water, with small amounts of metallic oxides as impurities. Glazes, on the other hand, are much richer in the metallic oxides, which form compounds with the alumina and silica, having a low melting point compared with that of the clays. The engobes have an intermediate composition, but, provided that they adhere sufficiently well to the goods, their melting point is of less importance than that of the glazes.

The melting point of a glaze depends upon four chief factors :

1. The proportion and fineness of the free silica.
2. The nature, proportion, and number of metallic oxides other than alumina.
3. The ratio between the alumina and silica.
4. The proportion of boric acid.

For low temperatures, glazes may consist almost entirely of lead and silica in various proportions, but at higher temperatures lead cannot be so efficaciously used, and for many classes of ware its employment is to be discouraged. In such cases the composition of the glazes becomes of great importance, and, according to Seger, this lies within comparatively narrow limits, viz. :

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

RO representing the total number of molecules of metallic oxides taken as unity. Thus, if RO represented ·2 molecule of soda

---

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

The symbol RO is understood to mean the sum of all the alkali metal oxide molecules contained in the glaze or engobe or clay divided by the number of such molecules. Hence a glaze whose composition might be represented as

(Na_2O) and ·8 molecule of lime (CaO), the composition of a white-ware glaze should, according to Seger, be between 100 and 400 parts by weight of alumina, and between 1500 and 2700 parts of silica for every 124 parts of soda and 448 parts of lime. Hence for every 100 parts of soda and lime in the proper proportions, from 17 to 68 parts of alumina and from 253 to 456 parts of silica must be present to make a satisfactory glaze. If these proportions are noticeably altered, either the glaze will not fuse at a suitable temperature, or it will devitrify or will not be sufficiently durable for use. Even though it may be necessary to introduce other metallic oxides by replacing all or part of the soda or lime, the total proportion of the molecules must be kept within the limits given, no matter how many kinds of metallic oxides are present or in what proportions they are mixed with each other. As a general rule, however, it will be found that three different oxides will produce a glaze of lower melting point than a similar glaze in which the RO is represented by only two different bases.

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

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

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

Lead is usually introduced in the form of red lead, litharge, or white lead (a basic carbonate). Galena or lead ore is sometimes

consisting of 2 molecules of Na_2O, 8 molecules of CaO, 4 molecules of A_2lO_3, and 35 molecules of SiO_2, would be expressed by the formula:

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

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

$$\left.\begin{array}{l}0{\cdot}2Na2O\\0{\cdot}8CaO\end{array}\right\}0{\cdot}4\ Al_2O_3, 3{\cdot}5\ SiO_2.$$

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

Further particulars of the various methods used in calculating the formulæ of glazes, etc., will be found in Jackson's *Ceramic Calculations* (see Chap. XIV., Bibliography, No. 47).

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

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

1. Simplicity of composition, as flint and lead alone will often make a satisfactory glaze for common ware.
2. Insolubility in water without fritting (see p. 29).
3. Ready combination with other materials and melting at low temperatures.
4. Slight errors in composition not of great importance.
5. High refractivity, hence great lustre (unobtainable with any other element, although barium compounds may sometimes be effectively substituted for lead in glazes containing soda and boric acid).
6. Great mobility, with consequent easy attainment of evenly glazed goods, a result much more difficult to obtain with leadless glazes.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

For some reason the majority of clayworkers use imported flint as the chief source of free silica, but why so great a prejudice should exist against British flints is by no means clear. The contention that they are too chalky is not supported by analysis.

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

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

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

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

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

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

Fluor spar and *cryolite*, with other compounds of fluorine, find occasional employment as fluxes for highly siliceous materials. Other metallic oxides, such as bismuth oxide, antimony oxide, and arsenious acid, are used for special purposes, such as producing opacity at a low heat. Their use requires experience and care, but no further reference to them is necessary at the present moment.

The preparation of engobes and glazes has hitherto been almost entirely confined to rule-of-thumb practice, with the result that many recipes refer to the use of materials, the value of which it is difficult to ascertain. Consequently it may happen that two almost identical mixtures may be thought to be quite different because one or more of their constituents are referred to under different names; thus 'tincal' may appear in one recipe and borax in another without the clayworker being aware that they are practically identical, tincal being simply crude borax. It is probable that the frequent use of plaster of Paris in the same glaze as whiting is due to a similar ignorance of the chemical composition of the materials employed and the reasons for adding them to the glaze or engobe.

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

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

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

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

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

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

Preparation of Glazes and Engobes.—Glazes and engobes are prepared in at least two different ways, according as they are 'raw' or 'fritted.' Engobes, in the limited sense of the word referred to on page 19, are seldom or never fritted, except for special work, but all glazes containing borax, soda, potash, or other soluble substances must be fritted before use in order to render the whole of the glaze material insoluble.

For raw glazes and engobes the materials in the form of a sufficiently fine powder are weighed out, preferably in zinc scoops or in wooden boxes, according to the weight of glaze to be prepared, great care being taken to prevent mistakes in the quantities weighed out, as this would entirely spoil the glaze or engobe. It is, on this account, best to forbid the presence of any person other than those actually engaged in the weighing whilst this operation is going on. Sometimes the materials are only partially ground before being weighed, the final reduction to powder being carried out in an Alsing cylinder, a kind of barrel lined with glazed tiles and revolved either by hand or by machinery. When the materials are put into this barrel a number of balls of hard porcelain are introduced at the same time. If the balls are about three-quarters of an inch in diameter, sufficient should be added to fill the cylinder to about a quarter of its capacity. Opinions differ as to the best proportions of water to be added to the contents of the grinding cylinder; as a general rule about one gallon to every ten pounds of material will be found convenient when the mill is rotated at a speed of twenty to thirty revolutions per minute. When the materials have been ground so fine that on rubbing between the finger and thumb no trace of grit can be felt, the liquid may be passed through a sieve or lawn in order to separate the coarser particles. The fineness of the sieve will depend upon the nature of the glaze or engobe and upon that of the articles to be covered; thus for ordinary sanitary ware, using commercial waterground materials of good quality, a sieve of 60 meshes per linear inch (No. 60) will be sufficiently fine, but for high-class china a sieve with 200 meshes may be necessary. Colours generally require a finer sieve than the corresponding plain glazes, as, if the colouring materials are insufficiently ground, they will fall too readily to the bottom of the glazing tub and the goods will come out too light in colour.

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

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

Some clayworkers add a little vinegar or acid to granulate the clay, but this requires great care, and is not to be generally recommended. For many classes of work it is sufficient to rub the materials between the hands with water until a cream is formed (but this is not practicable when more than about forty gallons are required per week), or a blunger may be used without previous grinding.

Any hard substance which will not affect the composition of the mixture may be used in the grinding cylinder—hence flint pebbles are often used instead of the porcelain balls.

Frits.—As already stated, the main object of fritting is to vitrify the water-soluble constituents of a glaze, and, by rendering them insoluble, facilitate the uniformity of composition of the material when it dries on the goods. It is seldom necessary or desirable to vitrify all the constituents of a glaze in the frit-kiln, as such a proceeding would be a waste of time and fuel. It is, therefore, usual to mix the soluble substances with so much of the flint or other siliceous material of the glaze as shall produce a mass fusible at a comparatively low temperature, and yet not soluble to any appreciable extent in water. The shape of the kiln in which the fritting is carried out depends largely on the amount of material to be fused; for moderate amounts a large crucible with a hole in the bottom is mounted on bricks over a tank of water and heated by a furnace built round it in such a way that the material melts and runs into the tank, more being added to the crucible to replace that which has been melted until a sufficient quantity has been prepared. A commoner way is to place the material in a sagger in the kiln along with ordinary goods, and to remove it on discharging the kiln and to break away the sagger from the solid frit. This is but a crude method and wasteful of the frit, as the portions adhering to the sagger cannot be separated from the latter. Where larger quantities are needed, a proper frit-kiln with a hearth somewhat like a reverberatory furnace used for puddling must be used. When the frit has been sufficiently heated, a plug is removed from near the bottom of the hearth and the fluid frit is run into a pit or tank of water, the object being to granulate the frit by the sudden cooling.

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

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

The roughly-powdered frit as it comes from the water tank is ground to impalpable fineness either between horizontal stones or in an Alsing cylinder, sieved through a suitable lawn or sieve of at least 120 meshes per linear inch and dried or made up into a slip of definite density, usually 28 oz. per pint. For use the frit thus prepared is mixed with the other materials of the glaze, blunged up thoroughly and sieved repeatedly until quite free from coarse particles and thoroughly homogeneous.

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

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

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

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

Colours.

The colour of clay goods and pottery may be (*a*) natural and due to the effect of the heat of the kiln on the materials of which the goods are made, as in the case of red and buff terra-cotta; or (*b*) the colour may be produced by the application of certain metals or metallic oxides or other colouring materials to the surface of the ware, as in ordinary pottery.

The effect of heat and of oxidizing and reducing atmospheres on the colours of various clays will be found described under 'Firing'; the second class of coloured ware (decorated ware) is divided into several classes, according to whether the colour is applied *under* the glaze, mixed *with* the glaze or *over* the glaze on the articles.

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

When only moderate quantities of colour are required, it is generally best to purchase them from a reliable dealer in potters' materials rather than to attempt the difficult task of preparing them from the raw materials. It is, however, very important to deal only with thoroughly reliable firms (and even then not to buy the cheapest grades of colour) so as to obtain materials of a constant composition, as otherwise the clayworker will have the annoyance of finding that his colours vary so much in the different batches as to render it impossible for him to complete sets of decorated ware.

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

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

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

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

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

Some goods may fall into either of these classes, according to the custom of the manufacturer; thus a white-glazed brick may be either 'majolica' or 'faience,' according as it is covered with a white enamel (majolica) or slipped with a white clay and then glazed with a transparent glaze (faience).

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

Stained Glazes.—The simplest of all methods of producing coloured ware is the application of a glaze to which has been added a proportion of 'stain' or colouring matter, bought ready

---

[1] An enamel is different from a true glaze in that the enamels are always opaque, whilst the true glazes are transparent. Thus the distinction between them is not a matter of fusing point, as is so often assumed (though, as a matter of fact, the enamels are usually fired at relatively low temperatures); nor is it a matter of colour, as both glazes and enamels may be of any colour as far as the name is concerned, though the application of certain colouring materials to a glaze may result in an opaque (*i.e.* a non-transparent) glaze being formed; this coloured glaze is then, strictly speaking, an enamel and no longer a glaze. In those glazes which are partially transparent some exercise of discretion is necessary in deciding their nomenclature.

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

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

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

Stained glazes may be equally well used on top of articles which have been covered with a white or coloured engobe. In the case of many varieties of coloured bricks the natural colour of the body-clay is so strong as to spoil the purity of the colour of the glaze. In such cases the bricks are first engobed with a white engobe (p. 26) and are then glazed as usual.

When a glaze is stained with tin oxide, or other materials which make it opaque, it becomes an enamel, the object of enamels being to hide the colour of which the goods are made (p. 32 foot).

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

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

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

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

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

A good recipe is the following :—

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

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

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

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

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

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

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

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

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

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

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

As the temperature at which overglazed ware is fired is so low,[1] the colours used are of almost innumerable variety, but, of course, no aniline or coal-tar colours can be used, as they, like the vegetable dyes, are burnt out at this temperature.

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

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

---

[1] The usual temperatures at which overglaze colours are fired are—

	Seger Cone.	0° C.	0° F.
Lustre ware, ...	022 to 015	590 to 800	1094 to 1472
Soft fired overglaze, . .	014	830	1526
Hard fired overglaze, .	08	990	1814

These figures are only approximate.

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

Overglaze printing is carried out similarly to that for underglaze, but up to the present it has hardly been so satisfactory, though a few workers have obtained excellent results.

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

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

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

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

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

The composition of these liquids is not, of course, public knowledge, but a good liquid gold may be prepared by adding 11 grains of pure tin to 1 ounce of gold dissolved in half a pint of aqua regia. Twenty grains of butter of antimony should then be added and warmed until of 1·800 specific gravity. It is then diluted with water till of specific gravity 1090, and 2 ounces of a 50 per cent. solution of sulphur in turpentine (technically known as 'Balsam of Sulphur') is then added, and the mixture heated with continuous stirring to 180° F. The thick liquid is allowed to cool completely, and is then mixed with five or six times its measure of hot water, so as to wash out the impurities somewhat; the mass is then dried on cloths as much as possible, mixed with twice its weight of turpentine, and warmed for several hours. After standing for a whole day and night, it is poured on to 2 ounces of powdered bismuth spread over the bottom of an empty photo dish, and kept at 212° F. for three hours, after which the liquid may be poured off and preserved as 'liquid gold.' The liquid should be tested, and if too dull when taken out of the kiln, the treatment with bismuth may be repeated.

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

Water and Water-Supply.

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

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

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

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

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

Saline Waters should be avoided, as they cause the formation of an unpleasant scum on the unglazed goods. If this is due to sulphate in the water, it may often be prevented by watering the clay, previous to mixing, with a solution of baryta or barium hydrate which, by forming an insoluble sulphate (which remains evenly distributed throughout the clay), hinders the scum-forming material from being carried to the surface during the drying of the goods. Scum formed by soluble chlorides, such as common salt, cannot be removed, as there is no substance capable of forming an insoluble chloride which is cheap enough to use. Hence sea-water or water containing a notable proportion of sea-water must not be used in clayworking.

Waters containing sulphate of soda are apt to cause frothing and 'priming' in boilers. Until recently this has been a great obstacle to the use of such waters, but this impurity may now be removed by the addition of baryta and by allowing the deposit to settle before running the water into the boiler.

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

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

Waters which are 'permanently hard' are those which contain the sulphates of calcium or magnesium and similar salts. These may generally be removed by the addition of a soluble carbonate, such as soda or pearl-ash, which forms an insoluble carbonate with calcium and magnesium, and a soluble sulphate of soda or potash. The insoluble matter is removed by means of settling-tanks, but the sulphates remain in the water and necessitate the water being blown off from the boiler at frequent intervals. If in large amounts sulphates have a great tendency to cause frothing and priming in the pipes, so that the use of baryta as a precipitant of the material causing permanent hardness is becoming more frequent. Baryta not only forms an insoluble sulphate, but sets free an equivalent amount of free lime, which helps to remove any temporary hardness the water may contain, so that, in practice, the use of baryta does not prove so expensive as might appear at first sight. The water may be tested with phenolphthalein paper, as in temporary hardness, to ensure that a sufficiency of material has been added.

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

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

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

The characteristics of a good purifying plant are:

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

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

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

Fuel.

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

Wood, at one time the principal fuel for the potter, is now only used in those cases where it is absolutely necessary to avoid any chance of the goods being spoiled by the sulphur which is always present in coal. Soft woods giving long flames, such as fir, pine, and larch, are preferred for biscuiting, whilst such woods as birch or beech are employed for the glazing, as they produce a more intense heat. Wood cannot well be used for intense heats, however, on account of the large proportion of water it contains.

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

In choosing coal for kiln-firing it is not only important to select a fuel with a large heating power, because of the saving in carriage as compared with a dirty coal, but to avoid the use of fuels with a high percentage of impurities which sometimes introduce difficulties that even the cleverest fireman cannot overcome.

Coals which are quite suitable as regards the length and nature of their flame are often spoilt by their high percentage of sulphur compounds, some fuels producing a strong odour of burning sulphur. This sulphurous gas is produced chiefly from the pyrites in the coal, which on a moderate heating parts with a portion of its sulphur. This ignites, and forms the very objectionable, overpowering gas so characteristic of burning sulphur.

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

The discoloration of the goods is another matter which must be borne in mind, and the presence of sulphur in the fuel is a frequent source of loss in this direction.

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

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

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

The precautions that should be taken against the over-heating of stored coal are simple. It should never be heaped if thoroughly wet, and should be kept in iron or concrete bunkers in a cool place not adjacent to boilers or flues. The pile should never exceed 12 feet in depth, and should be arranged with efficient ventilating spaces round the sides and at the bottom. In the event of combustion or over-heating occurring, the best plan is to turn the coal over thoroughly; pouring water on the top of the heap is of little use, as it may only penetrate sufficiently to make matters worse. If turning over is impossible, and the heart of the pile is suspected to be alight, an effective method is to ram in a good-sized pipe drilled at the end with several holes. When this has penetrated the surrounding coked fuel, a stream of water should be turned on to it, which will speedily result in extinction of the fire.

Coke is of little use in the kilns, as it produces little or no flame; it is, however, sometimes mixed with coal.

Oil is being increasingly used in the clay trade as a fuel in connection with engines. Its use for kiln-firing is at present in the experimental stage.

Gas as a fuel has scarcely met with the popularity it deserves in connection with clayworking. This is due to some extent to the number of patents of but little value which have been taken out for its use. Clayworkers are therefore somewhat prejudiced against it. Its cleanliness, ease of manipulation, and, under proper conditions, its low cost, will probably make it an important fuel in the near future. The gas used is, of course, 'producer-gas' made from poor coal burning in a current of steam and air. The combustible gases present are chiefly carbon monoxide and hydrogen with a varying proportion of hydrocarbons and other products of the partial distillation of coal. The total percentage of combustible gases seldom exceeds 40, about half this being carbon monoxide. The cost of producer-gas varies with that of the fuel consumed, but, as a rough figure, 2d. or 3d. per 1000 cubic feet may be taken as a fair basis for calculation.

'Mond' gas appears to possess special advantages for kiln heating, although it has not yet been very extensively used for this purpose. It is a kind of producer-gas, but by using bituminous coal and a large proportion of steam the working temperature is lower than in other producers, and permits of the recovery of ammonia, the sale of which bye-product greatly reduces the cost of the gas.

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

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

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

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

Fuel.	British Units.	Calories.
Hydrogen,	62,032	34,462
Carbon,	14,544	8,080
Carbonic oxide,	4,741	2,403
Methane (Marsh gas),	23,513	13,063
Good steam coal, (about)	13,000	7,000
Coal gas (per cubic foot),	700	400
Producer gas (do.),	300	170

The calorific power of a fuel may be determined experimentally in a calorimeter (see 'Tests'), or it may be calculated approximately from the results of an analysis of the fuel. This method, although not strictly accurate, enables one to rapidly sort out fuels when their composition is known, so that the actual tests may be confined to the most likely fuels. According to Dulong, and confirmed by Bünte, who experimented on samples of 200 to 300 kilos. of coal, the calorific power of a fuel in calories is one-hundredth of

$$8080C + \left(H - \frac{O}{8}\right) + 2500S - 600N,$$

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

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

the calorific power would be approximately:

$$\frac{1}{100} \text{ of } \left\{ (8080 \times 82\cdot05) + \left(4\cdot93 - \frac{8\cdot99}{8}\right) + (2500 \times 1\cdot06) \right.$$
$$\left. - (600 \times 2\cdot97) \right\}$$
$$= \frac{(662964 + 3\cdot81 + 2650 - 1782)}{100}$$
$$= 6638 \text{ calories, or } \left(\times \frac{9}{5}\right) = 11{,}948 \text{ B.T.U.}$$

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

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

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

About 12 lbs. of air are usually required.

Oils and Lubricants.

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

The 'body' or viscosity of a lubricant is of the greatest importance, as the more viscous it is the greater will be the pressure which it can sustain without being squeezed out from between the lubricated surfaces, but care must be taken not to use a lubricant unnecessarily viscous or the increase in fluid friction will neutralise the beneficial effects of the lubricant. The *best* lubricant is that which can just keep the moving surfaces apart under the greatest pressure likely to be obtained at the point of contact. For heavy machinery, where the viscosity of the lubricant must be exceedingly great, soft solids are frequently employed instead of oil, the hardness of the material increasing with the pressure on the bearings and ranging from grease through graphite, mica, steatite, sulphur, to various soft metals. Thus for greasing the axles of tubs, clay waggons, etc., a mixture of palm oil with one and a half times its weight of tallow and five times its weight of a 10 per cent. solution of caustic soda in water is often used, the proportion of tallow being increased, if necessary, in hot weather. Rosin-grease is a mixture of similar consistency.

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

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

1. The **viscosity** or 'body' of the lubricant at the temperature at which it is to be used. This property is a fixed one in the natural animal and vegetable oils and greases, but in the case of mineral lubricating oils the viscosity can be increased or diminished to almost any desired extent by suitable treatment and admixture. The viscosity is determined by noting the time required for a certain quantity of the lubricant to flow through a small orifice of accurately measured size, the time required for a similar quantity of rape oil to flow through the same orifice being taken as unity. A rough standard of comparison is thus obtained which is independent of the size of the orifice and the quantity of lubricant. Although the *accurate* determination of viscosity, especially at high temperature, requires considerable experience and manipulative

skill, a sufficiently accurate determination can be made for clay-works purposes with the apparatus originally devised by Allen, which consists of a 25 c.c. pipette enclosed in a wide glass or metal cylinder, which acts as a water-jacket and maintains the lubricant at the desired temperature. The lubricant (previously heated if necessary) is drawn up the pipette to a definite mark, allowed to remain there until of the required temperature, and the time it takes to run out of the pipette is carefully noted. The chief points requiring attention are the temperatures of the water-jacket, the position of the lubricant in the pipette, and the measurement of the time with sufficient accuracy. It will be obvious that this apparatus is only suitable for oils or the less viscous greases; other appliances, which need not be described here, must be employed for testing lubricants used for the heaviest classes of machinery.

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

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

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

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

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

6. The **acidity** of lubricants is of great importance, as the free acid often present attacks the metal bearings and forms soaps which gum and clog the machinery. Although an oil, or grease,

when freshly made may be quite free from acid, it often sours on keeping or by exposure to heat. On this account fatty oils are, as a rule, not suitable for use in engine cylinders unless mixed with mineral oil; and whenever possible mineral oil should be exclusively used for this purpose.

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

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

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

Tallow of very low grade is frequently used.

Foot oils of all kinds are in great demand.

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

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

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

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

Petroleum oils and greases are of very variable composition, ranging from comparatively thin oils (summer dark) to thick, tarry cylinder oils and greases of a 'vaseline' nature.

Of the various '*fillings*' used, gypsum has no lubricating value. French chalk is slightly useful, and plumbago (graphite) has a high lubricating power, especially for wood.

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

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

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

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

Special Oils.

Printer's Oil.—Colour applied to goods by means of printed transfers necessitates the use of a tacky, oleaginous medium as a vehicle for the colour, and one that will neither be affected by, nor cause any injury to, the glaze. Almost every pottery printer makes or uses a composition which he considers superior to all others, but the majority of these 'oils' resemble one or other of the following recipes (see also p. 34):—

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

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

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

Fat Oil and other vehicles for painters' and decorators' materials are best purchased under a quality guarantee (see p. 37).

Cat Oil, largely used in the lubrication of clay in brickmaking, is a mixture of mineral and other oils of very varying composition, its constituents being to some extent adjusted to suit the clay (see Chap. III., 'Making Machinery').

CHAPTER II.

PREPARATION OF THE CLAY.

Mining and Quarrying.

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

The waggons for carrying away the clay should be taken as near as they can be to the place from which the clay is dug, so as to keep the cost of carriage as low as possible. Tipping-waggons made of metal are superior to barrows where they can be used, and there are now on the market a number of different patterns of rails which can be fixed by unskilled men, so that the cost of laying is very small and the greater output soon redeems the initial outlay.

Unusable materials, such as stones, pieces of wood, roots, etc., should be thrown aside at once into a box, kept for the purpose, near every miner. This will be found to be more economical in most cases than the common plan of loading all the material into the waggons, carrying it some distance, and then having to again cart away the rubbish. This is not, of course, possible when the clay is obtained from coal-mines where it is too dark for the preliminary sorting to be accomplished satisfactorily.

It is important that the wrenches, hammers, nails, bolts, and other tools used in connection with the carriage of the clay should be well looked after. It is best to have a box for them when not in actual use, as in this way far less iron will get into the machines than when the workmen are allowed to lay the tools about anywhere and to throw waste nails, etc., about.

If the mining is to proceed without interruption, some means must be adopted for removing any water which may accumulate. Draining-pits, in spite of their initial cost, are often cheaper in the long run than drainage by pumps, but in some works the nature of the site does not permit of draining-pits being employed. In this latter case a plunger or diaphragm-pump is the best for clean water, but for dirty water a pulsometer or centrifugal pump, well cased in straw to prevent freezing in winter, is to be preferred. The exhausted parts of the pit, or quarry, must be so fenced that no damage can occur to the workmen. The angle or slope of the walls or sides must not be greater than 37 degrees from the horizontal.

Clay Sorting.

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

If different varieties of clay are found in the same bed they must be kept quite separate from each other, as they may probably require quite different treatment to render them fit for use. In order to ascertain the best use to be made of them, an expert should be consulted, for in the manufacture of high-class goods it is seldom that a clay can be used without some kind of treatment which shall enable it to mix easily with water, and to be easily worked. The natural agencies of wind, rain, and frost may well be made use of in this connection (see 'Weathering'), supplemented, if necessary, by washing, grinding, and pugging.

Weathering.

The object of exposing the clay to the action of the weather, especially in the winter months, is to bring about its disintegration. It is, in fact, an attempt to accelerate the action, which has been going on for thousands of years, by which the various rocks are resolved into their different constituents, and the great clay deposits produced from which the clayworker obtains his raw material.

The chief agents concerned in the weathering of clay are water and frost; the water soaks into the pores of the clay and at a sufficiently low temperature is converted into ice. In passing from the liquid to the solid state water increases in volume, and in expanding reduces the clay more or less completely into powder.

As this breaking-up depends on the presence of water, the clay should be kept sufficiently moist and should be spread out in such a way that as large a surface as possible should be readily and completely exposed to frosts. In many works this watering of the clay is omitted because of the absence of a water supply. If metal tipping-waggons are used for the clay, these may easily carry water to the pit.

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

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

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

It is therefore important that the clayworker should estimate in the early autumn what will be his daily requirement of clay during the ensuing year, and to arrange for spreading it out to weather. Where continuous work is carried on, the clay should be continually set out for this purpose.

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

After weathering, the clay may be sent direct to the pug or tempering mill, or it may be thrown into pits and covered with water in order to further ripen and mellow it.

Clay-Washing.

If the clays used are mixed to any considerable extent with gravel, small stones, or other foreign matter which cannot be picked out by hand, they must be washed or screened through fine sieves, according to the nature of the impurities they contain. Some clayworkers urge that washing the clay is more economical than grinding and screening, as less power is required, and the product is superior; but the relative efficiency of the two methods must necessarily depend upon the kind of clay used. As the process of washing produces a particularly homogeneous product, it is often advisable to use it even when the clay is free from gravel, coarse sand, etc. There is also the advantage, when the clay has to be transported over considerable distances, that the 'clay-slip' can be readily pumped through pipes to where it is required.

The clay, previously saturated with water, is ground to pulp in a 'wash mill,' consisting of a circular water-tight tank, provided with a stirrer or mixer; the stones and other heavier particles fall to the bottom of the tank and are removed, whilst the lighter particles are carried away by the water, a screen being used to prevent any wood, paper, etc., from entering the pits. China clay is usually washed in a trough in which a stirrer revolves horizontally.

As most, if not all, clay-washing appliances are based on the difference in specific gravity between the water-borne clay and its impurities, the success of the operation will depend on the speed of the flow as well as on the volume of the water, being so regulated that whilst as little of the clay as possible shall sink to the bottom of the tank, owing to an insufficient supply of water, there shall, on the other hand, be a minimum quantity of foreign matter carried off with the clay which would not be the case if too rapid a current of water were employed. Here, again, it is not practicable to state exactly any speed of flow which is suitable for all cases, as so much depends on the nature of the foreign matter present. Seger, however, gives the following velocities and dimensions of grains, and these definitions are generally accepted as standards:—

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

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

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

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

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

For the washing of many kinds of clay on a large scale, however, the water usually has a greater velocity, although it should not much exceed 4 feet per minute, as otherwise the proportion of small stones in the clay will be unduly large.

It is often economical to tip the clay, previous to its being washed, on to a fairly steep slope about 10 yards long, and to wash it down this into the mill with a sufficiently strong stream of water; many small stones are thus kept out of the mill itself, which consequently does not so often require cleaning.

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

The pits are often heated by the gases from a small stove passing underneath and around the sides, so as to facilitate the evaporation of the water from the clay; but, occasionally, basins are built on a gravel soil by throwing up banks of earth and clay, so that the slurry when run into these basins gradually dries as the water soaks into the soil.

This somewhat crude method is, at the present time, being rapidly replaced by the use of filter presses for the better kinds of clay, from which the water is removed by subjecting the slurry, contained in cloth bags, to considerable pressure.

Filter-cloths are particularly liable to a kind of mouldy growth which destroys them, but this may, to a large extent, be prevented by treating them with various solutions sold for the purpose by manufacturers of potters' materials. All filter-cloths should be numbered, and an account kept of the dates when they were put into use, repaired, or discarded, as carelessness and waste can thus be minimised. Press cloths need (1) careful folding, (2) frequent washing, and (3) wetting before folding.

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

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

It frequently happens that the addition of a 'fat' clay to the main stock is necessary in order to improve the latter, and that great difficulty is subsequently experienced in breaking up ('dissolving') the richer clay, as it remains in lumps, and causes unnecessary loss of driving power in the machine. In such a case two methods of treatment are feasible: the clay may be dried, either artificially or by being placed in a roomy shed and frequently turned over; or the water may be added to the clay for washing in very small quantities at a time, allowing each quantity to be absorbed by the clay before the next is added. The use of *warm* water has been found to be of great value by some clayworkers, whilst others prefer to pass their clay through the pug mill, cutting it up into thin strips with a self-acting cutter and then washing. Complete drying of the clay, however, is the best remedy for difficult washing, although care must be taken that the clay is not heated above 100° C. (=212° F.).

The water from the filter-presses should be run into settling tanks, from which the sediment can be cleaned out periodically and returned to the scrap-blunger. A pail or two should also be kept ready in the event of a cloth bursting. Absolute cleanliness is essential in all operations connected with the washing of the clay.

Grinding.

In working certain clays, especially those containing limestone and other hard minerals, it is necessary to crush them so that they will the more readily mix with water and so become plastic. In order to make the output of the grinding machinery as effective as possible, it is customary to remove all pebbles and similar useless material which can be picked out by hand before sending the clay to the mill, although the facilities offered by the use of rollers for working up all sorts of material with the clay induce some clayworkers to pay but little regard to the suitability of the materials thus introduced. Edge-runners and rollers both have their own advocates for crushing the clay: the former have the advantage of greater power, but the latter admit of better regulation of the size of the crushed material. It is important that each clayworks proprietor should determine what is the best distance between the rollers for the particular class of clay he is working; if too close together the output is unnecessarily limited and power is wasted, whilst if the material is insufficiently crushed, the finished goods will lack durability or the clay will be difficult to mix with water. The use of disintegrators is advisable for clays which cannot be easily ground by the ordinary rollers, as lumps of dry clay can be fed into the disintegrator and reduced to such a size that the material becomes very easy to grind when it is passed through the rollers. Up to the present the use of a disintegrator without any after-treatment with rollers has not proved successful.

If the material is very moist, edge-runners in a pan mill will grind it most efficiently. Opinions differ as to the advantages of the revolving and stationary pans (Chap. III.), and the pan may be either perforated (to allow the ground material to pass away) or not.

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

Glaze materials and similar products are most conveniently ground in a small pan mill or in a ball or pebble mill. In most cases it is cheaper to buy them ready ground.

Mixing or Tempering, Pugging.

In order to bring the clay into a plastic condition it must be mixed with water, unless it has been previously washed or made into slip. Washed or 'slipped' clay must have the excess of water removed by (1) drying (either naturally or artificially), or (2) by means of a filter-press.

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

As time is required for the water to be absorbed by unwashed clay, it is often placed in pits, or sumps, and covered with water and left for some time. If sand, or other materials, are to be added to the clay, such additions may be most conveniently made at this stage. Clay which has been treated in pits in this way is commonly said to make better ware than that which has been mixed with water in a mill. Hence, when the clay is to be made into vessels with very thin sides, or walls, it is sometimes stored or 'matured' in air-tight boxes, where it cannot lose much of its moisture, for several months or even years. Under these conditions putrefaction of the organic matter in the clay takes place, and the clay becomes more 'mellow' and workable. Different clays vary greatly in the extent to which they are improved by this treatment. Exactly what takes place during the maturing is by no means clearly understood, but it is probable that the bacterial action which takes place increases the plasticity of the clay, although it has not yet been definitely proved that this plasticity is due to the bacteria (see p. 11). Of recent years this prolonged storage has been to a large extent abandoned and the clay worked more in the machines.

In order that the clay may absorb the water readily it must be reduced to powder by passing it between rollers; it is then carried to the pits, where it receives its necessary quantity of water, baryta, etc. In order to ensure that the clay is not removed too soon, it is advisable to arrange the pits in the form of an oblong or ellipse, so that they may be filled and emptied in regular order. With some clays the water must be added in very small quantities at a time, and with others warm water is advantageous (see p. 56).

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

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

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

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

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

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

As dry materials in the plastic clay will interfere with its being properly worked up into goods, clay which has become dry on the outside should be treated with sufficient water to make it plastic, and be again put through the mill.

CHAPTER III.

MACHINERY.

Boilers.

The types of boilers used for steam production in clayworks vary greatly according to the purpose for which they are used, from the simple vertical boiler to the most completely fitted water-tube boiler made. An ideal boiler is one which can supply the maximum of steam required at the lowest possible cost. In view of possible extensions of the works, however, it is never wise to put in a new boiler without ensuring that it has ample power for producing more steam than is ever likely to be required. Too large a boiler, on the other hand, by having unnecessarily large radiating surfaces, will waste heat. As in most clayworks the steam is required almost as much for heating (drying) as for power, there is no advantage to be gained by using a boiler making very dry steam, and, although in engine driving dry steam is to be preferred, where the boiler is used for heating as well as for driving moderately dry steam is best. Where coal is cheap, great refinements in 'economical' steam production may actually result in financial loss.

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

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

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

According to Molesworth, for each nominal H.P. a boiler requires—1 cubic foot of water per hour, 1 square yard heating surface, 1 square foot grate area, 1 cubic yard capacity, 28 square inches flue area, and 18 square inches flue area over the bridge. Also that for a cylindrical double-flued boiler of standard make, one-sixth of the length × diameter = H.P. approximately.

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

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

Better results than these have been frequently obtained.

The coal consumption per H.P. depends on the boiler as well as on the engine. The 3 lbs. per H.P. per hour for a non-condensing and 2 lbs. for a condensing engine is good practice, though half these figures are sometimes reached.

Where the cost of fuel is considerable, it is wise to make occasional tests of the 'commercial efficiency' of the boiler, *i.e.* the cost of evaporating 1 lb. of water. In this way it is not infrequently found that a saving may be effected by using a slightly more expensive fuel!

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

It must always be remembered, however, that even 'automatic' stokers require skilled attention if good results are to be obtained. Where unskilled men are employed as firemen for a number of boilers, the use of mechanical stokers may effect a saving, but the general consensus of opinion seems to be that a really skilled man is superior to the best mechanical appliance. As clayworkers are more or less trained to recognise the necessity for skilled firemen at the kilns, they are more ready to employ similarly skilled men at the boilers, though there is a great tendency in some works to think that "anyone who can handle a shovel can fire a boiler," although such a neophyte would never be entrusted with a kiln.

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

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

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

The temperature of the feed-water on entering the boiler varies greatly in different works. In many engineering establishments it is heated by economisers to a temperature of 300–315° F. The water is fed into the boiler either by means of a pump or an injector; if pumps are used a pump-governor is often advisable to maintain a practically constant speed of working even under considerable variations of pressure tending to make the pump race.

Some boilers are fed by gravity, but this implies the existence of a considerable pressure of water or of a closed tank containing the feed-water, which is forced in by gravity and steam pressure into the boiler.

The injector is an appliance by which the energy of a jet of steam is imparted to a column of water so as to force it, partly by suction and partly by pressure, into the boiler. A detailed description will be found in most works on the steam engine, and so need not be given here. There are several types in use, the best for ordinary purposes being those which both lift and feed the water into the boiler, thus doing away with the necessity of any head of water in the supply. It is also more convenient to have a self-starting injector than one with a positive action only. Injectors use as much steam as a pump, but as this steam is returned to the boiler with but little loss, and the instrument is so simply made that it is seldom in need of repairs, the use of injectors has become very extended. In ordering, care must be taken that the injector chosen is capable of dealing with water at the temperature at which it is to pass into the boiler, or trouble will ensue, as some—if not most—injectors cannot deal with water at a temperature above 100° F.

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

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

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

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

The chief stoppages of feed are due to: (1) leaky suction, (2) stoppage in suction pipe or in nozzle, (3) water too hot for the injector, (4) steam pressure too low.

Boiler Troubles (*Corrosion and Scale*).—By corrosion is generally to be understood the action of water or of some of its impurities on the plates of a boiler. It is usually due to acid in the water, or in the 'scale-preventors,' or to galvanic action set up by pieces of metals other than iron which may find their way into the boilers. Sometimes oil from the engines undergoes hydrolysis and produces a corrosive acid. When acidity is the cause the water should be made slightly alkaline by the addition of a little lime-water, as in softening (p. 40). To prevent galvanic corrosion, sheets of zinc are usually suspended inside the boiler, so that they are partly immersed in the water, and by their electrolytic action become attacked themselves instead of the boiler plate.

Scale is formed by a variety of substances. Most of these have the power to make water 'hard,' and their removal has been discussed on page 40. The removal of scale from the boiler itself must usually be accomplished by means of a hammer and chisel. Petroleum is sometimes employed to loosen the scale, but its use is accompanied by considerable risk on account of its great inflammability. One of the best ways of using it is to allow the water in the boiler to cool completely, to pour in the petroleum, and allow the water to run slowly out of the boiler. When completely emptied it is refilled with clean water, heated as usual for a few days, and then again emptied and the scale scraped or chipped off. With very hard scale, however, it is best to have the scale itself analysed by an expert, who will then be able to suggest a chemical which will soften it and so avoid the risks attending the use of a chisel. Some engineers prefer to leave a scale of about one-eighth of an inch thick in the boiler, especially at the water line, to prevent corrosion. This is particularly the case with water containing magnesium chloride, which is decomposed in presence of steam into magnesia and hydrochloric acid—the latter corroding the boilers.

Overheating and collapse of the plates are usually caused by faulty circulation in the boiler, due either to faulty construction or to a deposit of non-conducting matter. Fatty acids or the corresponding lime soaps often combine with the boiler deposit to form a very adhesive non-conducting coating. Mineral oils cannot do this, but occasionally they attach themselves to particles of scale and produce a similar result in a rather different way. The best method of preventing overheating is to employ a good fireman and to use a well-designed boiler, taking every care that no oil or boiler-scale gets into the boiler. The oil may be kept out by an efficient filter, the scale by using only softened water. The design of boilers lies outside the scope of this work, but as the scale is usually most abundant where there is least circulation of water, a careful study of the distribution of the scale will often give valuable information as to the circulatory system.

Priming, or the throwing of water violently into the pipes from the boiler, is usually due to oil or to soluble salts in the water. The latter are a frequent result of softening waters, containing gypsum, with soda. The substitution of baryta for soda will often prove to be the best remedy, this substance now being on the market at a sufficiently low price for its use in this connection. Oil is also a frequent cause of priming when exhaust steam from the engine is allowed to enter the boiler without previous filtration.

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

1. The production of dry steam.
2. Increase in volume of the steam due to higher temperature.
3. Better use of the steam in the cylinder, less loss by condensation—hence greater efficiency of the whole plant.
4. Lessened strains on the boiler.
5. Saving of upwards of 10 per cent. in fuel consumption.
6. Smaller total heating surface per H.P.

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

Engines and other Sources of Power.

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

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

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

Lubrication should be undertaken regularly and systematically, and all used oil should be carefully collected and placed in a 'saver,' so that it may be used again instead of being wasted. A little attention in this respect greatly facilitates the work of keeping the engine clean. Where high-pressure engines are employed, it is especially necessary to avoid the use of animal fats and oils as lubricants, as these are apt to decompose (particularly in the presence of steam) into stearic and other acids which corrode the metal-work and may in this way cause a direct loss of power. The bearings should be examined from time to time whilst the machinery is in motion, and if any are found to be getting hot, more lubricant must be applied, or if this does not succeed, a mixture of graphite (blacklead) and oil may be applied to the heated part. Should this also fail, the machinery must be at once stopped and the cause of the heating ascertained and remedied. Local heating of this kind is sometimes due to the stoppage of the oil-hole of the bearing; hence it is advisable to clean these holes out from time to time. As it is only the oil that is actually in moving contact that is of value as a lubricant, the flooding of any part with oil is generally only a waste of good material and serves no useful purpose (see also p. 46).

The bearings must not be run with loose caps, and the brasses must be sufficiently tightly screwed to make a good bush (a liner being inserted if necessary), but they must not be too tight, or trouble will ensue. With gas engines especially, loose bearings must be attended to at once.

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

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

The primitive form of packing was hemp-yarn saturated with tallow, but for high-pressure steam asbestos is usually substituted on account of its heat-resisting properties. With very high piston speeds white metal is frequently added to the asbestos, either as a central core or woven in. Care should be taken that the diameter of the packing used is sufficiently large: if anything it should be slightly larger than the space it is intended to fill, and the length such that the ends just butt, leaving no space or overlap. Where soft metal packing is used its flexibility and contact with the rod are ensured by the use of springs assisted by the steam pressure. Though somewhat greater in initial cost, it will be found more economical to use metallic packing on all rods over 1 inch diameter, provided that it is properly fitted, kept well lubricated, and the drainage of condensed water provided for.

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

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

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

It must, moreover, be observed that different works are provided with very different facilities for economical working, and it does not by any means follow that what one works can do is equally applicable to all. Thus, in many works, the latest milling and making machinery has been put down with but little regard to the location of the engine-house and the description of engine. It suffices most managers to know that the engine can supply the necessary power—the cost of so doing is comparatively seldom considered—so that even with the best machinery the engine may be located in some out-of-the-way corner, clogged up with dirt and water from leaky valves and condensed steam, and be in a general state of dust, mess, and slop, with steam blowing to waste at several places. If the proprietor of such a works can summon enough courage to have the matter properly investigated, and to try the effect of following the advice of a competent engineer, he will be surprised at the economy which will result. It is very unfortunate that in so few works 'diagrams' of the engines employed are taken at frequent and regular intervals. The cost of doing so is small, and the indications obtained are of great value in pointing out the defects of the engine and their increase by wear and tear, and in preventing to a large extent the annoyance of finding a serious breakdown as the result of the engine not having been properly under inspection, as described later.

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

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

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

Although for brick and other works where the drying of the goods is chiefly carried out by means of steam the power for driving the machinery will, naturally, be a steam engine, it will often be found that when additional or new sources of power are required, the use of a *gas engine* will often prove more economical than that of one driven by steam. This is particularly the case with gas engines having a suction-producer attached. Until recently the gas used for engines has been chiefly that supplied for illuminating purposes by the local gas company. This in several respects is not the most suitable as fuel, it being almost entirely manufactured for use as an illuminant. With engines of moderate size, on the other hand, a gas-producer of the ordinary type which supplies the gas under pressure usually entails an unduly large expenditure on the producer. If, however, the engine is so arranged as to draw the gas into itself by suction, a much smaller and less expensive producer is possible, with the result that gas engines may play an important part in the machinery of the clayworks of the future. They have numerous advantages over steam engines in regard to economy of fuel, and need but little attention, while no steam boiler or boiler attendant is required, and hence there is a saving of capital which would otherwise be absorbed by the erection of a chimney and of other accessories to a boiler.

There are several forms of gas engines and producers on the market which are quite suitable for use in clayworks. Readers who are interested should consult some of the many works published on this subject. Even in brickworks the increasing use of tunnel-driers will probably result in the greater use of gas engines, as these driers do not, in many cases, need a large boiler for the production of steam, but are, to a large extent, heated by the waste products of the kiln fires.

General Machinery.

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

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

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

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

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

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

(*a*) Machinery for preparing the clay.

(*b*) Machinery for making articles.

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

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

Grinding Machinery.

Clay Grinding.—Grinding is an operation which requires more care than it often receives if the material is to be brought into its proper state of fineness at a sufficiently low cost. The exact amount of grinding required will depend on the clay itself and on the articles into which it is to be manufactured.

It is, in almost every case, of the greatest importance that the clay should be sufficiently weathered (p. 52) before it is sent to the grinding plant, as in this way considerable wear and tear on the machinery may be avoided and a far better product result. In fact, it may be stated as true for the majority of clays, that unless the clay is well weathered before use, some inconvenience is bound to be experienced either in the lack of durability of the goods or in the additional expense of working the clay. There is no agent known which is so perfect a disintegrator as the action of the weather for making the particles far finer than can be obtained by grinding alone, and in consequence giving a greater plasticity and ease of manipulation.

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

In the first class of clays are those containing a notable proportion of stones, and if these are to be removed some form of sieve must be employed. The usual method is to pass the material between conical stones or rollers in which the clay is flattened and passes through the rolls, but the stones remain behind and are taken away by a supplementary roll provided with points, though in many cases this is not necessary. For this method to be effective it is essential that the clay shall be sufficiently soft and 'open'—a hard shale cannot be treated in this manner. When clay is admixed with sand and similar materials which it is necessary to remove, it may be roughly ground and then washed, when the sand will settle out before the clay and may in this way be separated (see p. 54). As, however, the washing of clay is very costly, it is only undertaken in the case of the best classes of goods where a specially pure clay is needed.

For certain purposes it is usual first to pass the clay through rolls set a definite distance apart, and to crush the stones somewhat while allowing of the greater portion being separated, by passing the clay in a pasty condition through a cylinder, the perforations in which will allow the clay, but not the stone particles, to pass. As some of the stone gets crushed sufficiently fine to pass through these holes, the separation is by no means so perfect as by washing; but it is far less costly and is sufficiently effectual for many purposes. The cylinders used are closed at one end, and the sides (and sometimes the closed end) are perforated. The clay is passed in at the open end of the cylinder until the latter is full, and a piston is then forced into the cylinder and forces the clay through the perforations, the stones remaining inside the cylinder. When no more clay can be squeezed out the piston is withdrawn, the stones removed, and the operation commenced afresh. It pays to have two cylinders so arranged that whilst one is being acted on by the piston the other may be filled with the stony clay, an output of 70 cubic feet of clay per hour being easily obtainable in such a case.

When the whole of the clay, as delivered to the mill, requires to be crushed, it is often desirable to use some form of '*Stone-breaker*' if it is at all hard and in sufficiently large pieces. This is especially the case with rock clays worked in large quantities; where smaller amounts are to be ground the material may be broken up into small pieces by a hammer. For grinding burnt material (pitchers, saggers, broken bricks) it is advisable to use a preliminary breaker of this kind; for most purposes a modern type of *Disintegrator*, in which an axle carrying radial beaters dashes the material against a serrated outer casing, a portion of the circumference of which is fitted with gratings to separate the powdered material, will be found most convenient. A speed of about 3000 revolutions per minute will usually be found the most economical, and provided that pieces of metal are kept out of the material the machine will run for a long time without needing repairs. In any case it is very important to only use a disintegrator in which the beaters may be easily and rapidly replaced (as is the case in all the best makes), and if this precaution is observed the damage done by breakage is rarely serious. In order to avoid 'vibration' it is necessary that machines running at such high speeds should be carefully balanced; this is best accomplished by taking out the spindle and allowing it to roll on two carefully levelled knife edges, and filing or chipping the heavier parts until it will remain indifferently in any position.

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

Disintegrators are rapid workers, but are not very economical of power when used to grind to great fineness; they should, therefore, be used to grind the clay to pieces of about half an inch diameter, but no finer result than this should be sought to be effected by their means.

Owing to the manner of their construction, disintegrators are most suitable for dry clays and for those which do not feel moist and yet are not perfectly dry; they are not well adapted for very fat plastic clays, but fortunately the latter can be readily dealt with in rolls. A 'smeary' material of this nature is, however, always a source of trouble when it has to be crushed.

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

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

When the clay contains any notable proportion of calcium carbonate (limestone or chalk), it is necessary to grind it much finer than would otherwise be necessary, as, unless the particles of the carbonate are so fine that they are perfectly distributed through the clay, they will, after burning, form small masses of lime, which will swell when the goods are exposed to damp air and so bring about the destruction of the articles. If, however, the particles are sufficiently finely ground, they combine with the clay or are too small for their expansion to have any material effect on the goods.

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

It is very important in grinding with edge-runners that the clay which has been crushed to a sufficient fineness should be immediately removed from the mill; its continued presence amongst the coarser clay only prevents the latter from being properly ground and so lowers the output of the machine. It would appear at first sight as though this would be best accomplished by making the bottom of the pan into a sieve by perforating it with innumerable holes over its entire surface, but in practice it is found that this weakens it too much, and it is, therefore, the custom to allow the runners to roll on a solid plate and to remove the clay from this to the outer, perforated portions of the plate by means of scrapers attached to the main axle in the case of a fixed pan or to the framework of the mill when a revolving pan is employed. The centrifugal motion imparted to the clay in the latter case is of great assistance in rapidly separating the fine clay, and this may be increased very considerably by perforating the sides of the pan as well as part of its base, and collecting the fine clay thus separated by means of an outer casing. The size of the perforations in the pan will vary with the different purposes for which the clay is to be used; for ordinary bricks $\frac{1}{4}$ or $\frac{1}{2}$ inch square holes or slots may be used, but for glazed bricks, sanitary goods and finer ware, the holes should be circular, and not more than $\frac{3}{16}$ inch in diameter, whilst for some purposes it is necessary to employ even finer perforations. Although the holes tend to wear most at the top, it is advisable to let them taper outwards (*i.e.* become larger in diameter as the bottom of the plate is approached), so that they will not clog up in use. From the point of view of durability the best pan mill is the one which has the greatest output for the smallest pan area, consequently the scrapers must be kept in proper relation to the bed if efficient work is to be obtained. For pans with small circular perforations the scrapers should be hard down on the bed, and both bed and scrapers must be true to each other; with slotted beds it is better to allow some clearance, as the clay is not so finely ground.

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

Continuous mills are quite practicable as far as grinding the dry clay is concerned, but for wet grinding they have not, up to the present, proved very successful, although a continuous mill of this description, which shall be simple in construction, shall not leak and so cause the machinery to become blocked with clay sludge, and is capable of giving a product of uniform fineness and plasticity, is greatly needed.

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

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

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

To secure the greatest output edge-runners must not be overloaded, and must be fed regularly.

The Pendulum Mill, first used in the United States, has a crushing roller rigidly attached to the lower end of a vertical shaft, suspended by a universal joint in such a way as to force the roll centrifugally against a ring or die. To the underside of the roll ploughs or stirrers are attached, and a fan above it raises the finer particles and throws them against the screen placed above the die. The pulley speed of the machine is 200 revolutions per minute, and a die of 30 inches in diameter is said to give an average output of 30 to 40 cwt. per hour of material passing a No. 50 sieve. This mill has the great advantage of suffering but little damage from pieces of metal which may obtain access to it by accident, and the arrangement of the screen is such that its life is considerably longer than that of an ordinary screen over which the material flows.

It is chiefly used for grinding fine materials of a dry nature, as flint, spar, chalk, etc., and is particularly valuable in the manufacture of Portland cement.

Glaze Grinding. — The grinding of materials for glazes, whether in the raw or fritted state, is usually carried out by means of (1) edge-runners (p. 75), (2) horizontal grind-stones similar to those in a flour-mill, and which give a much larger proportion of flour than do edge-runners, or, (3) preferably in an Alsing cylinder or a Ball mill. The latter consists of a circular vessel lined with vitrified tiles and partially filled with flint pebbles or porcelain balls. The vessel is rotated until the material (which has been previously mixed with a suitable amount of water) is sufficiently finely ground. The door of the cylinder is then replaced by a fine grating and the contents are allowed to run out. The amount of water, the length of time, and the fineness of the grating will depend on the nature of the materials to be ground. The note on an earlier page as to the necessity for care in grinding mixtures of plastic and non-plastic materials is especially noteworthy in the case of glazes; if they contain plastic clay it should not be added until near the end of the grinding, and then it should be in the form of a thin slip, otherwise it will adhere too strongly to the balls and unground particles, and so will seriously impede the grinding. The use of water in grinding is now almost universal with materials which have to be very finely ground for glazes. Not only is it more healthy for the workmen, but the amount of material which is lost as dust in dry grinding is, to a large extent, saved when the materials are ground in a thoroughly wet state or in the form of slip. Grinding mills for glaze materials are not usually fitted with arrangements for removing the ground material as in the case of clay mills, but the materials are kept in the grinders until it is considered that they are sufficiently finely ground—when they are passed through a sieve of moderate fineness (say 80 meshes per linear inch) and then through one of the proper fineness (*e.g.* No. 100, 120, or 200). In order that this may be done effectively and without undue loss of time, it is necessary to have plenty of water present, *i.e.* the slip must be very thin, weighing not more than 26 or 28 oz. per pint, according to the material and the fineness of the sieve.

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

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

When only small quantities of glaze, or engobe, are required, hand-blunging must replace that of the machine. The materials are first broken up moderately fine (especially ball clay), and are then well mixed by means of a wooden mixer or beater, perforated with a number of $\frac{1}{2}$-inch holes.

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

Where very fine clay ware is manufactured, the clay for the bodies must be blunged up in a similar manner to that just described, sifted, filter-pressed, and then pugged or wedged in order to mix it thoroughly. For coarser work it is not usual to make the clay into a slip, but simply to mix it with water in a tempering machine or pan mill, as described on pages 57 and 85. The one sifting of the dry clay as it comes from the grinding mill is then made to suffice.

Sieves and Sifting.

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

For effective sifting the clay must be fairly dry, must not contain too large a proportion of fine matter, and must not be sticky. The first and last of these characteristics are obvious, as wet or sticky clay will adhere to the riddle or sieve and so prevent further separation of the particles. If, however, the clay is made up into a sufficiently thin slip, the water with which it is mixed acts as a vehicle and carries it through the sieve. Except in the cases of clays used for engobes and bodies of fine quality, or clays which are washed before use, it is not usual to work the clay into a slip before passing it through a sieve. Such a process is too costly for most kinds of clay, and consequently they are sifted in the dry state, the clay being carried to the riddles direct from the mill by means of a shoot or an elevator. If a riddle is working perfectly the material which will remain on it, or which is shot off in the form of 'tailings,' will contain no material which, on passing over the riddle a second time, will pass through it. In practice it is seldom that so perfect a separation is obtained, for various reasons. For instance, even if the clay put on to the riddle is in such a fine state that it is capable of wholly passing through, it will be found that there is a certain proportion of 'tailings,' the exact amount of which will depend on the kind of riddle used, its length, and the time the material takes in passing over it. On this account the efficiency of the riddle as a separator will be highest when there is not too much fine material in the clay.

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

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

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

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

Wires arranged in parallel, as in the Piano riddle, are excellent for granular clays, but in some cases they have not proved satisfactory owing to particles of material lodging between the wires, and so altering the extent of open space between them.

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

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

There is no definite line of division between riddles and sieves, though it is usual to apply the latter term to the finer form of riddle. In the potteries, silk is much used for the final sifting of bodies and glazes, and for sieves made of this material the term 'lawn' is used. Sieves and riddles, when made of metal, are usually named according to the number of holes in a linear inch of the material—thus, a sieve with 60 holes per linear inch is designated as '60 mesh' or 'No. 60.' Occasionally sieves and lawns are quoted by numbers denoting the number of meshes per square inch, but as this is liable to cause confusion, and has no special advantage over the lineal measure, it is to be deprecated. It is common to denominate sieves in this way in France and Germany, and to state the number of holes per square centimetre as the 'number' of the sieve. To convert a sieve measured on this system into the corresponding English one, take the square root of the foreign number, multiply this by 10 and divide by 4. Thus a German sieve No. 900 has 900 meshes per square centimetre. The square root of 900 is 30, which, multiplied by 10, gives 300. This divided by 4 gives 75 as the corresponding number for an English sieve.

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

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

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

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

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

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

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

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

Mixing Machinery.

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

1. Tempering by spades, or in smaller quantities by the hands or feet.
2. Pugging.
3. Panning in a pan mill with edge-runners.

4. Blunging, the materials being in a state of powder, to which sufficient water has been added to make, when thoroughly incorporated, a thin slip.

Blungers are described on page 79.

Tempering.—The first method is only used for small quantities of clay, and then only when better appliances are not available. Hand-wedging is, however, still employed in some factories for the better class of clay bodies which, being naturally rather short, require a considerable amount of working to render them fit for use. This process then becomes a final process, the object of which is to secure thorough mixing of the materials after preliminary treatment with a pug mill.

Clay puddling, in which the mixing is done by the worker's feet, is still practised in connection with the manufacture of crucibles for steel.

Pug Mills.—The pug mill consists of a metal cylinder placed either vertically or horizontally. A shaft running through its centre from end to end has attached to it a number of blades or 'knives' arranged like the threads of a screw, so that, as the shaft turns, the knives cut the clay, mix it and carry it forward through the cylinder to be re-cut and mixed by every fresh blade with which it comes in contact. In this manner a very homogeneous product is obtained, especially if the clay mass is passed through the mill several times. For clays requiring a large amount of mixing an open pug mill is frequently employed in which there are two shafts, each bearing a number of blades working side by side, the knives being so arranged that they cannot come into contact with each other. After passing through this preliminary mixer, the clay is passed through a pug mill of the ordinary closed-in form. The open pattern has the advantage of enabling the mixing of the clay and water to be watched during the early stages, an important matter when it is desirable not to get too much water into the clay paste. When the material to be pugged is the product of a filter press, the open mixer may be omitted.

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

Pug mills require some little attention in order to work them efficiently. They must not pass the clay through too rapidly or it will not be thoroughly mixed. On the other hand, if allowed to work too slowly, time is wasted to no purpose. Much depends on the particular kind of clay and the purposes for which it is intended; hence it is not advisable to give speeds for different sizes of mills; each clayworker must try for himself what is the maximum speed at which his mill may be driven and yet produce a well-pugged mass.

As regards the relative advantages of vertical, as compared with horizontal, pug mills, it is generally considered that vertical mills absorb less power, but that horizontal mills mix the clay better. It is desirable, in using the horizontal form, to insert 'counter knives,' if these do not already exist, inside the circumference of the mill to prevent the clay mass from being carried round and round without being mixed properly. This will sometimes happen with a horizontal pug mill without counter knives.

The shape of the blades on the shaft varies somewhat with different types of mill. For most clays it is convenient to have the blades arranged 'four-square,' so that every fifth blade is in a straight line. The blades do not lie at right angles to the shaft, but are arranged in a helicoidal form so as to impart a forward motion to the clay. The presence of one or more fixed knives increases the output by preventing the rotation of the clay.

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

Various other combinations of crushing and mixing machines are used in different districts, each having some special advantage for the particular clay they are designed to work, the great tendency at the present time being to accomplish in one machine all the different operations necessary in the preparation of clay for use. This works well for certain purposes, and economises power and space in addition to requiring a smaller initial outlay in the building of new works. The great disadvantage is that it is often sought by these means to avoid the use of natural processes, particularly that of weathering, and to use the clay directly it comes from the pit. This is an unfortunate tendency, as there is no question that clay which has been properly exposed to the action of the air, rain, and frost before grinding makes goods of far better quality and durability than if it is sent straight to the machine. The use of these 'universal' machines also tends to throw too much work on one part of the plant for which it is most probably least fitted. A pug mill, for instance, is not well adapted for giving shape to the column of clay which passes out of it, and any attempt at doing this will result in the material being less efficiently pugged than would otherwise be the case, owing to the backward pressure on the blades of the mill. If this back pressure were constant throughout it would simply mean a loss of power, but as it varies with the length of the column of clay which projects from the mouth of the pug mill, and is cut off from time to time, the homogeneity of the clay is often interfered with and reveals itself in unsound goods when the latter come out of the kiln. For driving the clay through a mouthpiece in order to give it a special shape the blades of the pug mill should be of a different shape and more powerful, as their object then will simply be to act as a conveyor and not to mix the clay. They should, therefore, be placed in a small supplementary cylinder, at the end of the pug mill proper, so as to work independently. When this is done the increased percentage of sound goods will rapidly repay the slight additional first cost, while the additional power required is so small that it may be neglected, as in many cases it is less than that consumed by the pug mill, there being so great a back pressure on the latter as to drive the clay backwards instead of forwards. This can be saved by having a separate conveyor for the mouthpiece. A further point to be considered in pug mills is that as new knives work better than worn ones the blades should not be kept in use too long.

The **Pan Mill** is often preferred to a pug mill for thoroughly incorporating water and clay when the clay is simply ground and then mixed into a plastic mass. It is difficult to judge of the relative value of the two machines, as some clays are not sufficiently intimately mixed by treatment in a pug mill, but require the water and clay particles to be thoroughly ground together before a honogeneous product results. As a general rule it may be stated that a pug mill should be used in preference to a pan mill where the clay permits of its employment without requiring to be passed through the pug mill more than twice. If this is insufficient a pan mill is to be preferred.

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

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

Particular care and no little skill is required in the mixing of clay by these machines, as unless the proportion of water and the size of the clay particles are kept pretty constant the resulting goods will differ in size, a matter of considerable importance in the manufacture of glazed bricks, tiles, etc.

Blungers are employed for the mixing of clays, bodies and glazes with water, and in other cases where the proportion of water to material is at least 1 : 1—that is to say, where a 'slip' is to be produced. This class of machines has already been described on page 79.

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

Making Machinery.

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

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

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

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

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

Brass mouthpieces have not proved successful, owing to the softness of this metal causing them to wear away too quickly, but thin, brass lining sheets have obtained considerable popularity on the Continent. In this country a steel-lined die is usually preferred. In choosing a mouthpiece, attention should be paid to the time it actually takes to reline it, as well as to the probable number of bricks or other articles which can be made before a fresh lining is necessary.

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

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

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

(3) The wires should be fastened to the cutter in such a manner that they may be immediately replaced when broken; for this purpose new wires ready fitted with ring ends should be at hand, as otherwise serious loss of time and output may ensue. The wires should be so fixed in the holder that the bricks or other articles cut are exact in size. This means that the clamping of the wires must be strong and not liable to get out of adjustment. It is advisable to test the distance of the wires from each other several times each day by means of a zinc gauge. In order to get well-shaped articles it is absolutely necessary to keep the wires taut and to see that the cut faces of the goods are true and square, some of the machines now on the market having a strong tendency to give a curved face. The chief limit to the quantity

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

(4) Lubrication should be carefully attended to, but care must be taken not to waste oil. A notable saving may be effected in many cases by erecting the cutter on a large base-plate with sides about 3 inches high and with a hole at one corner to allow of the oil being removed. If this base-plate is supported on four levelling screws similar to those used for scientific instruments, but proportionately stronger, it will be found much easier to adjust the table of the cutter to the exact level of the die than is ordinarily the case.

Brick, Pipe, and other Presses.—The word 'press' in clayworking is applied indiscriminately to two entirely different classes of machinery, and some care is needed not to confuse them. The first class consists simply of a pug mill (or similar appliance for mixing the clay with water to make it plastic and homogeneous), to which a mouthpiece, or die, is attached, so that the clay issues from the machine in a definite shape according to the articles being manufactured, as in the case of wire-cut bricks and tiles. The second class of machine is used exclusively for the shaping of the articles, and consequently greater and more regular pressures can be applied than is possible with the first-named.

The combined clay-mixers and presses are referred to on page 89.

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

The goods may be pressed either in the form of a somewhat damp dust or in a more plastic state, some classes of clay being worked more easily by one method than by the other. The method most suitable for any particular clay must be determined by experiment, as it is almost impossible to say from a mere inspection of the clay which is the best. Each clay must, in fact, be studied by itself, for some clays press best when in a very plastic and moist state, whilst others require to be on the 'dry side,' and others again may be pressed in the form of dust. Thus, in the case of a clay rich in sand, the rough-formed article must be fairly dry, as, if too much water is present, no cohesion of the particles will be possible except at very excessive pressures. At the same time such a clay must not be allowed to become too dry, or the resulting goods will have no strength. It is always desirable to weigh a few of the articles of standard size during different stages of drying and to press these, and, after burning, determine which proportion of moisture is the most suitable; the same weight may then be used on future occasions, and if the goods weigh more than this, the drying may be continued for a little longer before they are pressed. This method is far preferable to the rougher plan of simply inspecting the goods to see whether they are ready for the press, and it will be found that, when large numbers are to be pressed, the saving of time by having a more accurate test of the condition of the goods amply compensates for the somewhat greater trouble of weighing a few of them from time to time.

The advantage of the drier, stiffer goods needing less drying before they go to the kiln is obvious, but there is the disadvantage that the air imprisoned in the drier clay by the pressing may expand in the kiln and so cause the goods to burst, similarly to the blowing of goods which are put too wet into the kiln. It is, however, easy to distinguish in the fired goods whether the bursting has been caused by air or by excess of moisture. It has further been found, by innumerable observers, that clay in its leather-hard condition is much less liable to damage by rough handling than it is when in the white hard state; hence goods which have been dry-pressed are more seriously damaged in the handling, and it is difficult to obtain sharp arrises on bricks and quarls unless the greatest care is taken. In order that stiff-pressed goods may have the same cohesive power after firing, it is often necessary to heat them to a somewhat higher temperature than is necessary for plastic-pressed goods, as the finer particles of clay in the latter get pressed into more intimate contact with each other, whilst in the former this contact must be obtained by heating to incipient vitrification. For a similar reason much greater power is necessary for pressing stiff clay than when it is in a more plastic state.

The softer the clay used in the press the greater is the necessity for lubricating the die. For most purposes mineral oils are to be preferred, as they do not so easily act on the lime contained in many clays and so form soapy matter which is a frequent cause of unpleasant blotches on the surface of the fired goods. Sand is sometimes substituted for oil in working soft-mud machines. With care and a suitable machine and clay this is all right, but if an inferior sand is used, or if the mould does not go exactly into position before it is filled by the clay from the die, the bricks or other articles will stick.

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

There are at the present time many expressions in use with regard to the plasticity of the clay fed to the press which are to some extent misleading, as they seem to imply the use of entirely different types of machine, although this is not found to be the case when the machines are examined. At each end of the scale we have 'plastic' or 'soft' clay and 'dry' or 'stiff' clay respectively, and these terms are sufficiently definite to be well understood, but when combinations of these terms are used the nomenclature at once becomes confused. Such terms as 'stiff-plastic,' 'semi-plastic,' etc., may have a claim for advertising purposes, but are of little use in actual practice. When once it has been determined, as the result of careful experiment, what proportion of water in the clay gives the best result for the press, this proportion should be adhered to, and little or no attention paid to what are more or less fancy terms, such as those instanced.

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

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

Pipes are made in a press of entirely different character, consisting essentially of a chamber to contain the plastic clay and an annular die through which the clay can be expressed. Small pipes may often be made from a suitable mouthpiece attached to the pug mill, but when ordinary or larger sizes are required the back pressure exerted by the clay is usually so great as to render the process useless. For such pipes it is therefore usual to employ a piston acting directly on the clay contained in a cylinder to the lower end of which is attached the die. In this way the whole force of the machine is exerted on the clay column, as there is no chance of it forcing its way backwards if the piston is kept in order. The pressure required being so great, light machines driven by belts are not generally suitable for pipe-making—an effective pressure on the clay equivalent to 60 lbs. of steam at the engine is as little as can be relied on for successful work. It is also important to have the 'set-off' at the correct angle for the particular class of clay used—45° is most often suitable, but is not equally suitable for all clays, and the best working angle, taken from the inside surface of the die-plate to the forming edge of the die, can only be correctly determined by trial and experiment, and, when once determined, should be rigorously adhered to.

Lamination, though generally the result of using clay in a faulty condition, may also be due to the bridge of the die being too near its mouthpiece and so leading to the breaking up of the clay.

Owing to the relative thinness of the material used, it is necessary that the clay shall have been very carefully prepared beforehand, if pipes of any considerable size are to be made. If put through the press in too soft a state the pipes will lose their shape on standing. If the clay be too stiff it will not be sufficiently compressed, and a more or less laminated mass with the possible production of 'dragon's teeth' or the splitting of the sides of the pipe may result. For a similar reason the clay used for making pipes should not have a contraction of more than 1 in 12, and the total loss of weight from 'white hard' to coming out of the kiln should not greatly exceed 6 or 8 per cent. If a particularly fat and plastic clay is used, the shrinkage may be brought within reasonable limits by the addition of a suitable proportion of burnt clay which has been passed through a No. 12 or a No. 20 sieve (p. 83), according to the nature of the clay and the size of the pipe, it being always remembered that pipes should be made of a body which burns to a slightly vitrified state. If the clay is particularly porous when fired, part of the burnt clay added may be replaced by a suitable quantity of broken pottery or other more fusible and non-plastic material.

Considerable difficulty is often met with when piston presses are used on account of the air bubbles which form on the thickness or 'web' of the pipes owing to the clay not having been pressed sufficiently tight into the cylinder when the press is filled. In spite of the valves on the machine, this air fails, therefore, to escape when the press is worked, and the bubbles can only be prevented by a more careful filling of the press or by using a machine of the continuous type which corresponds to any ordinary pug mill or wire-cut-brick press.

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

The best known are the *jolley*—which is, briefly, an upright spindle carrying a mould to form the outside of the article—and the *jigger*, which is a piece of wood, steel, or fired clay fixed to an arm in such a manner that when the jolley is revolved the jigger cuts away the excess of material from the inside of the vessel to be made and presses the clay at the same time to the shape of the mould on the jolley. In this way the inside and outside of the article are made simultaneously and with great rapidity. For some purposes the jigger may be more conveniently employed to form the outside of the article, but the principle is the same in each case, viz., the replacement of the skill of the presser or moulder by mechanical means, with a resulting increase of speed as well as a corresponding decrease of cost. Before being placed in the jolley the clay is beaten out in the form of a slab of suitable thickness, called a 'bat,' by a special machine, a method which is found to be much more rapid than the older one of batting out by means of a plaster batter by hand. It has not, however, been found suitable for the production of very large slabs, though a certain amount of success in this direction has already been obtained.

The chief points requiring attention with these machines are :—

1. Absolute cleanliness of all the parts, so that the machine works with perfect smoothness, as an uneven motion, or jarring, will prevent satisfactory goods from being made. Hence due attention must be paid to the oiling.

2. Accurate adjustment, especially of the jigger. To ensure this it is best to allow only a thoroughly capable man to set the tools, and, by providing a sufficient number of tools, to secure that a tool once set need never be altered, but may be simply taken from the holder and replaced by another. This may be easily accomplished by having suitable attachments for the tools. Each tool should then be marked with a number, so that full particulars regarding its size, use, etc., may be immediately found when required. A card index is useful in this connection.

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

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

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

Certain classes of ware require to be turned on a lathe after they come from the jolleys, but the lathes used for this purpose differ so little from those used in other trades that a special description is unnecessary; greater care is, however, required to ensure smoothness of motion. These lathes are, for the most part, turned by hand, it being found that the continual variation of speed required is difficult to get with a power-driven lathe; in addition to this, each turner requires the presence of an assistant for various purposes; as the time of the latter is not fully occupied he may well spend some of it in turning the lathe. The increasing use of electrical fittings makes turning one of the most important methods in the formation of ware, hence considerable attention should be paid to the accuracy with which the work is carried out, as this is an essential qualification for much of the ware used in scientific and electrical work.

Throwing, formerly one of the most interesting branches of the potter's art, is rapidly declining, the work being now accomplished by mechanical means at lower cost and with more regularity. From an artistic point of view, however, this decadence of the thrower is to be regretted.

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

The size of the mould is of great importance, due allowance being made for shrinkage of the clay, as there is always a certain alteration of shape which takes place after the article has been removed from the mould owing to the pressure exerted as the result of its own weight. On this account moulds are frequently made rather 'out of the square,' so that when the articles have dried they may be quite symmetrical. The exact amount of allowance to make for this purpose differs with different clays, and must be found by experience. The use of moulds is, however, familiar to all clayworkers worthy of the name, and the difficulties experienced and the means of overcoming them are so well known that further description is unnecessary here.

When plaster moulds are used, care must be taken that a suitable class of plaster is used and that the *correct* proportion of water is used in mixing it, a matter which does not receive the attention it deserves, or the moulds will be too soft to wear well. It is also unwise to seek to economise by a very sparing use of iron rods in the construction of large plaster moulds, as the loss by breakage when they are omitted overbalances any saving in iron. The wearing power of plaster moulds is also greatly increased by drying them thoroughly between each time of filling for the first few days of their use; this treatment appears to make them harder and less liable to 'rot' than when the drying is omitted. Plaster moulds also last longer if they are well dried before being put away into store. Breakage and damage of moulds is always a source of trouble in a clayworks; it can be minimised by frequent and regular inspection and by a careful system of 'registration,' which shows exactly what moulds each maker has in his possession and for which he is held responsible. For this purpose it is essential to have a good mould-store, so that the makers may return the moulds as soon as they are done with, for it is unreasonable to expect men to be responsible for moulds which have to lie about the works for want of a proper place in which to keep them. A little care on this point will soon repay itself, both in the increased life of the moulds and in the saving of time lost in hunting for a mould which has been out of use for a year or more but which is suddenly required. A catalogue of moulds in stock (preferably worked on the card index system) will be found of great service in this connection, and by keeping it strictly 'up to date' and weeding out all old and destroyed moulds, it may be made a valuable factor in the search for moulds which, in so many works at the present day, takes up so much time unnecessarily.

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

CHAPTER IV.

TRANSPORT, CONVEYORS, ETC.

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

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

Tramways are, in many respects, the most suitable means of transport for goods and material about the works, as they can be used in bad weather and under conditions when other appliances will fail to work. The original cost of construction is not excessive, and the cost of maintenance is small if the road is well looked after. If allowed to get into a bad state, tramways tend to cause great losses through broken goods and through excessive wear and tear of the waggons, as well as waste of power if the waggons are moved by rope haulage. If the waggons are to be moved by men it is not well for them to hold more than three-quarters of a cubic yard of material, and for most purposes rather less than this capacity is preferable, whilst for pony traction on a fairly level track about twice this capacity will be found convenient. If the waggons are unnecessarily small, time will be wasted, but if they are too large additional men will be required to assist, who, at the same time, do not need to exert much power and hence cause a waste of money.

If the track crosses the public road, it is desirable to have some form of brake attached to the waggon, or, if this is not thought advisable, the pony should be fitted into fixed shafts and not into the usual form of loose chain traces. In this way the pony, by backing, will be able to stop the waggon almost instantaneously, unless the track is very steep, whereas with the chain traces the momentum of the waggon may lead to a greater difficulty in drawing up suddenly if necessity arises. For tracks entirely on the works this precaution is not quite so necessary.

As transport by waggon may easily form an expensive item in the cost of production, it is wise to keep a careful look-out on the average cost per waggon of the different kinds of material, and, in some cases, to pay by the waggon-load, or ton, rather than by time. This remark applies with equal force to horse haulage, but to a less extent when the transport is worked mechanically.

The requirements of a good waggon, tub, lorrie, bogey, or whatever other name these articles may be known by, in different parts of the country, are: (1) strength, (2) lightness, (3) stability, (4) compactness, (5) easy running. Ball-bearings are increasingly used in the construction of waggons, and it is, in any case, desirable to oil or grease the waggons at very frequent intervals if they are to run freely; (6) easy discharge. This is particularly important in the case of 'tipping-waggons.' Some of the more recent designs of waggon for clayworks are particularly convenient in this respect, and combine great natural stability with remarkable ease in emptying.

Waggons and tubs drawn by ropes and chains are referred to on page 103 (Haulage).

It is essential that the track for tramways should be well laid on soundly bedded sleepers to which the rails are securely fastened, preferably by means of bolts, which are cheaper in the long run than the more usual nails. Special care is needed in the case of points, particularly movable ones. In planning the tramway system of a works care should be taken to avoid inserting too many points, as these affect the smoothness of the running, and may consequently cause damage to clay articles in transit to the kilns, etc., and also make it necessary for the waggon to run more slowly over the points in order to prevent it being derailed. Points are, however, to be preferred to turn-tables, and the latter should only be used when really necessary; it will often be found quicker to take the waggon several yards further and use points than to have a shorter distance and use a turn-table. Much will depend on circumstances, and in some cases turn-tables cannot be avoided. When used they should be kept in first-class condition so as to turn easily.

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

If care is taken in arranging the working places of the different workmen, considerable sums of money may often be saved in the transport of clay to the makers. Thus in many yards it is easily possible to run the clay direct on to the maker's bench by a little arrangement, whereas at the present time it is all carried to one heap and is re-distributed from thence by means of barrows or other conveyances, thus involving a double handling. This clumsy plan may often be avoided by having a gangway some 8 feet above the floor of the making sheds for the waggons to run on. These waggons are preferably of the side-tipping pattern, as the rails need not then be broken to allow of emptying out the clay.

Road Traction, whether by horse and cart or by the more modern traction engine or motor van, is usually cheaper for local deliveries than the railway. The most convenient type of cart is an ordinary tip-cart of about 2 cubic yards capacity, but if the district is very hilly a somewhat smaller cart would probably be more convenient. With steam waggons much greater loads can be carried and over roads which would be almost impassable for a horse, but the roads must be sufficiently good to stand the weight. This is a difficulty in some districts where there is a considerable number of bridges. Quite apart from these heavier vehicles, however, there is a great field for the use of motors to replace the ordinary horse-drawn vehicles for cartage, especially in brickworks with a large local trade or situated some little distance from the railway. Except for motors of the light delivery-van type, it is necessary that the driver should be a skilled motor mechanic, capable of telling from the beat of his engine whether anything is the matter and of repairing it at once. This means higher wages than a horse-driver's, but the increased output of the motor as compared with that of a horse and cart will largely compensate for this. It is strongly to be recommended that all motors and traction engines in regular use should not be used more than five working days and should be thoroughly overhauled on the sixth. Including such repairs as re-boring cylinders, re-tubing boiler, and other more extensive repairs, it is not safe to reckon on more than 240 working days per year.

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

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

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

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

Haulage by rope, or chain, is, next to the use of ponies, the most common method of moving waggons, corves, and similar vehicles for relatively short distances. The use of rope or chain haulage for this purpose is, to a large extent, a matter of choice; in some cases a combination of the two is used—part of the track being controlled by a chain, with rope terminals for the better winding on the drum.

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

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

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

In some cases the loaded waggons may be made to haul up the empty ones without the use of any power. Where this can be managed it should be done, not merely for the sake of economy, but because the weight of the empty waggons helps to steady the full ones in their descent.

It is important to choose a good attachment for fastening the waggons to the chain or rope. The automatic clips for this purpose are not, as a rule, to be recommended. One of the best on the market at the present time consists of a clip which surrounds the rope and which is opened and closed by a quick-acting screw.

The so-called **Ropeways** (or Aerial ways) are a modification of rope haulage, in which the rope, instead of pulling the waggon along, actually carries it. To this end the 'waggon'—which is usually in the form of a box or large bucket—is permanently attached to the rope, and the material is filled into it at one end of the track and emptied at the other by releasing a pin which causes the bucket to tip over or allows one side of the bottom to fall out. Various details require considerable attention in the construction of this means of transport, but they may safely be left in the hands of the contractors, who will advise as to the best speed for the rope, the size of the buckets, etc. Where the nature of the ground does not permit the construction of an ordinary tramway (as when a deep valley intervenes between the source of supply and the destination of the material), this method of transport has the advantage of low first cost, small maintenance charges and a high capacity. It is particularly suitable for conveying clay and coals from the pit to the works, as it is, to a large extent, independent of the relative position of the two places, and at the same time the intervening ground may be used for any purposes for which it may be suitable.

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

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

Belt and Chain Conveyors are mostly used for carrying material (chiefly dry ground clay) for short distances in an almost horizontal direction. The belt is made of strong woven hemp, or specially prepared canvas (rubber stretches too much), and the edges should be bound with cord, to prevent their wearing too rapidly. Belts of thin laths and of metal sheets are occasionally used, but cotton, hemp, or canvas belts are the most common. As the material stretches considerably in use, it is desirable to have some means of regulating the tension, either by moving one of the rollers on which the belt runs, or by adding an additional ('lazy') roller to take up the slack. To secure economical working it is essential that the belt should travel at a fair speed, but an excessive rate must be avoided, especially with finely ground clay, or the material will be wasted in transit by being blown off the belt. Chains cannot well replace belts for conveying purposes, as in clayworks in most cases the material would drop through the links of the chain. If, however, buckets or boards are attached to the belt or chain, it practically becomes a bucket or drag-plate conveyor.

Screw and Worm Conveyors are seldom used as such in clayworking, although in pug mills the clay is usually forced forward by some such means.

Drag-plate and *Bucket Conveyors* are really modifications of the simple belt conveyor, designed for lifting goods through a greater angle than would be possible with a plain belt. In the drag-plate conveyor the width of the belt is of small importance, and it is therefore reduced as much as possible, and a chain or metal rod is frequently substituted on account of its greater strength and durability. To this 'belt' plates of wood or iron are attached at right angles to the direction of travel and on the lower side. These plates are of such a size as to fit loosely a metal or wooden trough which runs the whole distance the material has to be moved. On setting the conveyor in motion the plates are moved forward, dragging with them any material which may have been placed at the beginning of the trough, carry it to the end, pass over the pulley, and so back to the beginning of the trough, where they again draw the material forward. The importance of the trough will be seen when it is observed that its sides practically convert the plates into temporary scoops. The weakness of this form of conveyor for ground clay is that it is very prone to stick fast if the clay becomes wet by exposure to the weather, otherwise it is a useful and very practical appliance for clay transport. There is a considerable amount of friction on the inside of the trough, as the material passes along it, with the result that not only is power absorbed unnecessarily, but there is also a great tendency to contamination of the clay with the material of which the trough is composed. The use of bucket conveyors greatly reduces this friction, and this form of transport is usually preferred in a clayworks, where it is, as a rule, highly important to keep the materials as pure and clean as possible.

Bucket conveyors (or 'elevators') are commonly formed of a series of small vessels ('buckets') attached at regular distances from each other on an endless belt or chain. These buckets dip, at the lowest point of their travel, into the material to be carried, and, as they fill, are carried up to the top of the elevator where they turn upside down and so empty themselves.

Some workers prefer a belt and others a chain as the medium for carrying the buckets; it would appear that the wear of linked chain is very great and tends to introduce iron into the clay (when this material is being carried), so that for most purposes a belt of leather or of specially prepared canvas (such as 'balata') will be found best; indiarubber stretches too much, though it may be used for light work. The bucket chain is also very heavy when used in great length for a small slope, though when the rise is steeper this weight is of less moment. For wet clay the bucket chain is more economical than the belt, as it does not rot so soon.

The capacity of the buckets must be determined by the quantity of the clay turned out per minute by the mill, and care must be taken that, no matter at what speed the buckets are driven, they are still capable of carrying away the whole mill output. If this is not the case, and the buckets are too few in number or too small in size, the elevator will become choked and damage may be done if it is stopped. Thus, if a mill were grinding 50 to 60 tons of dry clay per day, or 2 cwts. per minute, this would need a bucket capacity of at least $2\frac{1}{2}$ cubic feet per minute (on the assumption that ground dry clay measures 25 cubic feet per ton). In actual practice an allowance of 3 cubic feet per minute would be better, as the buckets are seldom quite full. If each bucket has a capacity of 100 cubic inches (or $\frac{1}{17}$th cubic foot), at least $17 \times 3 = 51$ buckets must be filled each minute. If the number of revolutions of the belt are known, the number of buckets which must be on the belt may be readily calculated. It is, however, not advisable for the buckets to travel at a greater speed than 200 feet per minute or they will throw the clay about too much, especially if they discharge on to a riddle.

It is difficult to calculate the exact sizes and strengths of chains suitable for conveying if the particular patterns are not known; hence it is better to consult reliable makers and to be guided largely by their advice in such cases. The great point is to have ample capacity and power so that no choking can take place.

The power used to drive these elevators is usually obtained by gearing, or belting, from the main shaft of the grinding mill. This method has the advantage of not requiring much power, but also the disadvantage (often met with in edge-runner mills) that when the mill runs very slowly, from over-feeding or other causes, the buckets will also travel slowly, and their carrying power may thus be reduced more than the grinding power of the mill, with the result that the buckets become overloaded and finally choked and the elevator stopped.

The tightness of the belts or chains must also be determined by trial, and if they slip too much the belt may be shortened or 'lazy rollers' fitted so as to take up slack. Further notes on belts will be found below.

Excavators are usually a form of bucket elevator in which the bucket is provided with claws in order to dig into the workings and so remove larger quantities at a time than would otherwise be the case. It is frequently necessary to only use one 'bucket' —often of about a cubic yard capacity—which is dragged by force up the side, or face, of the working, the steel claws breaking up the ground and scooping it into the bucket. This is then raised clear, swung over a cart, or truck, and emptied by means of a chain which releases a catch. Such an excavator is, it will be seen, a combination of crane and bucket elevator modified to suit its special purpose and of great strength. With such an appliance, working under favourable conditions, it is easily possible to cut up a face of clay and load it into waggons at a cost of about twopence per cubic yard.

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

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

Belts for use in clayworks should be made so as to resist the combined action of damp and dust; hence the material of which they are composed should be dense, waterproof, and not apt to stretch. Leather belts—although excellent in every way—are now considered too expensive for long drives, and are being rapidly displaced by those made of composition into which rubber, canvas and similar materials enter largely. Balata, Teon, and Camel brand are three of the best known of this type of belt.

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

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

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

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

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

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

The width of a pulley should be somewhat greater than that of the belt; 1 : 1·2 is a very suitable ratio, so that a 5-inch belt will be carried on 6-inch pulleys, though some engineers would prefer 6½-inch.

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

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

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

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

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

The cost of transmitting power by belting is a difficult matter to estimate. The loss of power resulting from carrying steam at moderately high pressure through well-covered pipes is much lower than that due to the use of shafting for a similar distance, and the loss when belting is used is still greater. The question of cost is one which must be dealt with by an experienced engineer on the spot, who can take into consideration all the circumstances of the case.

All belting should be washed occasionally with soap and tepid water, and afterwards oiled with castor, or neatsfoot, oil. Rosin, colophony, and similar adhesives should not be used. When the works are closed for the winter months it is especially necessary to grease the belting well and to put it away in a dry place. Dubbing is the best grease for this purpose, but the belt should be carefully cleaned from all dirt before it is applied. When well saturated with the grease the belt should be rolled up and kept in this form until it is again required.

Rope-driving has already been referred to as giving a smoother drive than belts, a matter of great importance in connection with making machinery. The following additional notes may appropriately be included here.

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

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

The thickness of the ropes used varies from 1 inch to 1¾ inch, according to the amount of power required and the diameter of the pulleys which can be used. As explained, the rope must fit the sides of the groove and not touch the bottom.

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

Ropes for driving purposes are usually driven at a speed of 3000 to 4800 feet per minute; above this speed centrifugal action begins to seriously interfere with efficiency.

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

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

Lifts in clayworks are chiefly of the 'cage' variety, and are principally used for conveying goods from one storey of the building to another. There is a considerable difference of opinion as to the desirability or otherwise of lifts, but their employment would seem to be unavoidable in places where the ground-floor space is limited on account of the value of land, etc.

The ordinary lift consists of a box, or cage, raised or lowered by means of a rope working on a revolving drum, or reel, driven by a suitable engine. Although, if carefully worked, such hoists may be run very smoothly, there is a great tendency to uneven running, which is serious in the transport of pottery and similar goods in the unfired state to the kiln.

Hydraulic lifts are much steadier in their motion, but have the disadvantage of higher first cost. This may, however, be usually compensated by the smaller quantity of goods spoiled in transport and by the greater safety of the lift for the men using it.

Hydraulic lifts are worked in two ways—directly and indirectly. In the direct method the pressure of the water on the bottom of a steel rod which supports the cage and works in a watertight tube is made sufficient to lift the cage to the desired height. The water on being allowed to run out of the cylinder causes the cage to sink. By this means a sudden downwards fall is impossible unless the cylinder bursts—a catastrophe which is to a large extent prevented by the support it derives from the surrounding masonry. In the indirect method a chain, or rope, is used, as in the ordinary lift, but instead of a drum on which the chain is wound the free end is attached to the roof or some convenient support at a considerable height from the ground, and a pulley placed on the slack part of the chain. To this pulley is attached a rod, working in a watertight tube, and fitted with a piston at its lower end. The pressure of the water on the upper surface of this piston causes it to descend in the tube, thereby drawing down the chain, or rope, and so hauling up the cage (fig. 1).

As the rod is attached to the middle member of a compound pulley system, the distance it travels is only half that travelled

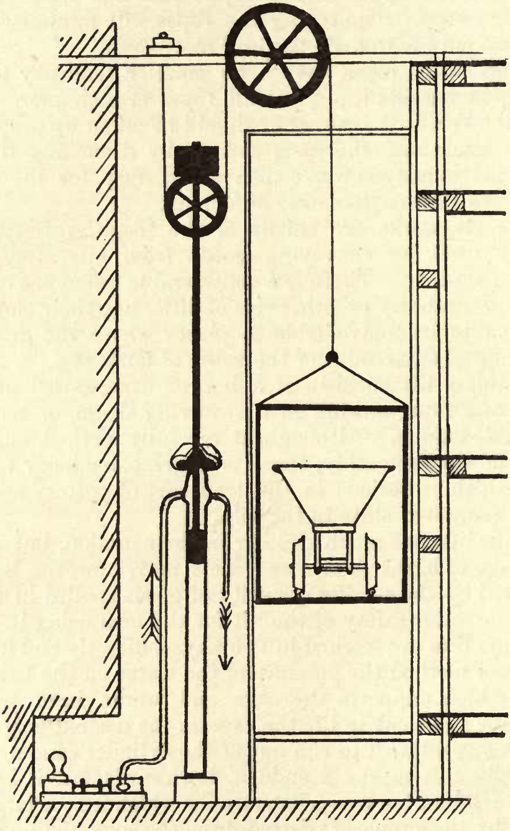


Fig. 1.

by the cage: it may therefore be used with advantage for long lifts, but is not so safe as the direct lifting appliance shown in fig. 2.

Water-ballast lifts are occasionally met with, and, when water is cheap, are a convenient form of hoist. The principle of working is very simple—two cages are used with one rope over a single pulley, and so arranged that when one cage is at the bottom of the lift the other is at the top. Each cage contains a large tank (usually placed beneath its floor), which can be filled with water at will. When it is desired to lift the cage loaded with goods, water is run or pumped into the tank of the upper cage in sufficient quantity to more than balance the load of goods. The catch holding the cage is then released, and the loaded cage rises to the height required; a brake or catch is then applied to prevent its rising too far. When it is desired to lower the cage again, the water is run out of the tank, care being taken to leave sufficient in to prevent the cage from falling too rapidly. Though a primitive form of hoist, this plan is working satisfactorily in several places. The supply of water as well as the emptying of the tanks

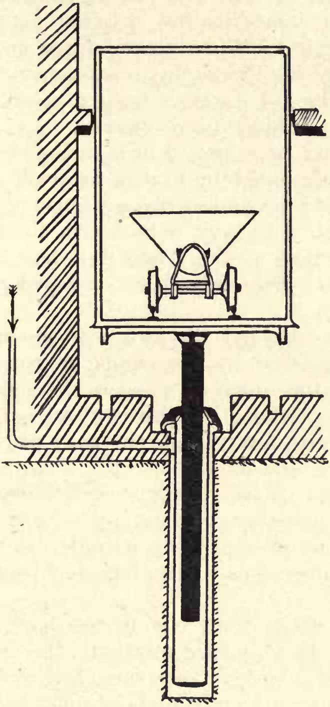


Fig. 2.

when necessary can be made almost automatic, and the water can be used over and over again, so that the actual working cost is extremely small. The chief point in construction is to provide sufficiently large pipes for the conveyance of the water to and from the tanks on the cages.

Cranes are only used to a very limited extent in clayworks, and such as are employed are chiefly of the simple hand-winch type. The designs of cranes is out of the range of the present work, but certain points require frequent attention in order to secure efficient service. When steam cranes are used, they should be placed in charge of a thoroughly competent man, as any accident is much more likely to be serious with a steam crane than with almost any other machine in a clayworks.

Great care should be exercised in lowering goods with a crane, the speed being regulated by brakes to avoid suddenly stopping the goods, as this is an almost certain cause of breakages. Even the sudden contact of a heavy weight with the ground will often cause serious damage to the crane if it has been lowered with great rapidity and has only been stopped by touching the ground.

When goods are beyond the sweep of the crane-arm, but can, nevertheless, be reached by the chain, or rope, care should be taken not to lift too much at once, as the moving of the chain outwards from the vertical is equivalent to lengthening the arm of the crane, and with heavy loads this may result in straining the machine beyond its safe limit.

The construction of the crane hook is a matter requiring considerable care, as probably more accidents have resulted from the hooks breaking than from any other single cause. Particulars as to the sizes and dimensions will be found in books of Engineering Tables.

The metal of which crane chains are made tends to undergo internal changes in structure owing to the irregular strains to which the links are subject. They should, therefore, be thoroughly annealed at regular intervals, certainly not less than once every three years.

For hand cranes the winch handle should have a radius of 15 to 18 inches (17 inches is the best), and the height of the axis of the handle should not be more than 3 feet 3 inches nor less than 3 feet from the ground. The power of the crane should be so proportioned to the work to be done that a continuous speed of 220 feet per minute shall be attained by the men's hands, so long as they are actually working the crane. The actual pressure exerted by each man should not be expected to exceed 20 lbs.

for regular work, though a somewhat larger amount may be obtained once in a while.

Certain regulations imposed under the Factory Acts in regard to the fencing off of lifts, cranes, etc., and the conditions under which they may be used for persons as well as goods, must be ascertained from the proper authorities, and fully adhered to, as the official inquiries which follow accidents are not only inconvenient to the manufacturer, but also tend to prejudice his customers against his goods. For this, if for no higher reason, all lifts, etc., should be fitted with safety appliances, so that, in the event of a breakdown, damage to life and limb may be prevented, or at least reduced to a minimum.

Pumps.—For the conveyance of water, clay slip and other liquids, some form of pump is usually necessary, the particular variety depending on the work to be done. Thus hand pumps are largely used on account of their portability, especially for irregular work.

Steam Pumps are better where there is sufficient work for their almost constant use. They must not be too far removed from the boiler, however, or the amount of condensed steam formed will prevent their efficient working. Steam pumps may be constructed with or without pistons; in the latter case the steam acts directly on the water to be raised, or indirectly, as in the diaphragm pumps or in the centrifugal machines.

The *ordinary pump* (with piston or 'bucket lifts') can be used for almost all purposes, though for very dirty water other varieties are more suitable and less liable to become choked. For general work it is difficult to beat the three-throw pump of the best makers.

The horse power required to lift x cb. ft. of water per hour from a depth of y feet is equal to

$$\text{H.P.} = \frac{x \times y}{20909}.$$

The quantity of water which will be delivered (in cb. ft.) per hour

$$= \frac{D^2LMN}{37}.$$

where D = diameter of pump-barrel in inches.
L = length of stroke in inches.
M = Efficiency of pump (usually ·66).
N = number of strokes per minute.

Allowance must be made for friction and to overcome the inertia of the pump; this is often taken as $57D^2 \times H$, where $H =$ height of lift in feet. The valve area should be such as to give the water a velocity of 250 feet per minute.

For the transport of clay slip nothing is better than a well-made plunger pump with long stroke (24 to 30 inches). A foot-valve is necessary on the suction pipe, and the pump must be placed close to the surface of the slip, or slurry, to be transported. The wear and tear is small, even with sandy clay, and a pump with 4-inch plunger will deliver over 900 gallons of thick slurry per hour with 15 strokes per minute.

For filling *filter presses* a special force pump is required capable of working against great pressure. It is driven direct from the shafting, and must be well fixed in position on account of the great strains it undergoes. Such a pump should also be provided with a safety pressure-valve which opens when the press is full and overflows into a special tank, or into the ark. To prevent ramming, an air-cushion (a piece of pipe about 3 feet long closed at one end) should be attached to a T-joint in the supply pipe between the pump and the press. The fittings of pumps used for filling filter presses need continual supervision, as they rapidly wear with the great pressure and the contact with the clay. Unless they are kept in good condition they will waste time in filling as well as cause a wastage of clay by leaking.

Diaphragm Pumps are popular on the Continent for transporting slurry and dirty water, but as they are essentially hand pumps they are not adapted for large deliveries. The internal wear and tear is exceedingly small compared with that of an ordinary pump, as in the diaphragm pump the ordinary piston, or bucket, is replaced by a diaphragm of rubber which rises and sinks with the motion of the pump rod and so produces the necessary vacuum. The barrel is made short and wide on account of the shorter stroke of the diaphragm. Repairs are simple and not expensive.

The *Pulsometer*, though far from efficient as a thermal engine, works so admirably in many situations where other pumps cannot be used that it finds a sphere of usefulness peculiarly its own. It requires no fixing, but can be slung into position and used with very dirty and gritty water, although not so well for slurry. It consists essentially of two bulbs side by side, which are filled alternately with water and steam, the vacuum caused by the condensation of the latter causing the water to fill the bulb. The valves are of the simplest possible make, and the pump will work for several years without need of repairs. The capacity varies from 900 to 80,000 gallons per hour.

The *Centrifugal Pump* is particularly suitable for a large delivery of water (not necessarily very clean) at a moderate or low lift. It consists of a wheel with curved blades which revolves rapidly in a casing, the water being drawn in at the centre and discharged at the circumference in a manner similar to a 'fan.' Centrifugal pumps are not suitable for use with long suction pipes, but the pump itself may, when necessary, be immersed partially in the water. A foot-valve may be used with this class of pump, but it is not so satisfactory as when the water can flow direct into the pump. The horizontal pattern appears somewhat easier to clean than the vertical type. A small tank should be provided at a short distance above the pump to contain water with which to start it, as, unlike some other forms of pump, the centrifugal type will not start until it is full of water. The arrangement of the blades, guide passages and some other portions of the interior require careful construction and adjustment, but these are matters for the pump manufacturer rather than for the clayworker and pump user.

In choosing a centrifugal pump care should be taken to select and fix one which can be readily opened and cleaned or repaired and the wearing parts easily and cheaply renewed. The engine may be direct coupled to the pump, or a belt may be used for driving, the speed of the pump and the power required depending on its size and on the amount of water it is required to pump per hour.

Hot-water Pumps.—That the ordinary pump will not transport hot water is well known; the reason being that when the piston rises so as to produce a partial vacuum the pressure on the hot water is reduced, and as some of the water is immediately converted into steam the pump is unable to produce a proper vacuum but simply draws steam indefinitely. The water should flow into the pump by gravity, and care should be taken that the composition of the valves and packing is suitable. When pumping hot water against a considerable pressure (as when filling a boiler) it is advisable, if possible, to pump into feed-heaters, and from thence, by pressure, into the boilers. By this means only cool water passes through the pump.

Further information on the use of pumps for feeding boilers will be found in the chapter on Boilers (p. 63).

Air Lifts and Siphons.—In addition to pumps of various kinds, water is now often conveniently moved by means of compressed air. An exceedingly simple way of raising water from a narrow bore-well is to insert a tube down the centre of the rising main and to blow air through this at constant pressure. If the main dips sufficiently below the surface of the water the air escaping from the lower end of the air-tube will, in rising through the main, be broken up into short cylinders, air and water alternating, and in this way the water will be lifted to the desired height. This method is useless for working against pressure, but is often convenient for draining a place where, on account of sand, etc., choking the valves, an ordinary pump cannot be used. It is, however, essential to have ample submersion of the main or the air will not break up properly and no water will be lifted. Hence this arrangement will never pump a well dry, nor can it be considered at all an economical method.[1]

Siphons are only employed to a very limited extent in clayworks. As is well known, they consist of a tube or pipe bent into the shape of an inverted U, with one arm shorter than the other. The shorter arm is placed inside a tank or other vessel to be emptied, the longer one forming the outlet. To start the siphon it must first be filled with water before inserting it in the tank, or, if the siphon be a fixture, the level of the liquid in the tank must be higher than the top of the siphon before it will begin to act. It is also essential that the end of the longer arm be at a lower level than that of the shorter one. Various modifications of this simple siphon have been patented from time to time, and are largely used for regulating the supply of water for various purposes. Thus a tank of washing water or of clay slurry can be arranged to settle for a certain length of time, at the expiration of which the excess of water will be automatically drawn off by a siphonic arrangement. On the other hand, a certain quantity of water can be measured automatically and a given volume supplied to a tank, or other vessel, when required, by the use of a 'dosing' siphon. Such an arrangement is often of great value in a glaze house or similar places where definite volumes of water are often needed.

Fans and Chimneys.—For the purpose of furnishing draught, chimneys and fans are chiefly used. The chimney is most in favour for this purpose, as it is generally thought to cost nothing to work it. This is not by any means always the case, and there are numerous instances where the air supply to a boiler fire or for ventilating or drying purposes might be more cheaply obtained by mechanical means, such as a fan. The reason for this is that the draught produced by a chimney is proportional to the difference in temperature between the air inside and outside it, and as this difference must usually be caused by the burning of fuel, this is an expensive way of bringing about the desired result. Where heat is unavoidably carried through a chimney, as is often the case with kilns, its energy may sometimes be utilized for air transmission in a very economical way. At other times mechanical

---

[1] Messrs. Isler & Co., Bear Lane, Southwark, S.E., are pioneers in the "Air-Lift" line, and Adams' Hydraulics Ltd., York, in patent siphons.

power is cheaper. Further information on chimneys will be found by referring to the index.

Fans are generally essential when temperatures higher than that of the atmosphere are used for drying goods, and when the output of a drying plant is intended to be large, as chimneys cannot usually overcome the air resistance in such a case. Chimneys are also less under control, and are more influenced by external conditions of the atmosphere.

Fans are constructed on two main lines—for sucking in and for blowing out air. There is, naturally, much controversy as to the respective merits of these plans, and it is extremely difficult to decide definitely in favour of one rather than the other, as much depends on the local conditions. Suction fans are often preferable because they produce a more even circulation of the air in the room where the goods are piled some distance from the floor, on shelves, etc., but for an open room the 'cone' of air formed by a blowing fan is sometimes an advantage.

Fans are of two main types—screw and centrifugal; the former are more suited for moving large volumes of air at a comparatively low velocity and against little or no resistance, but they are quite unsuitable for forcing air through narrow passages (between goods, etc.) or against high resistance. The greatest effective pressure of a screw fan is about $\frac{1}{2}$ inch of water or $\frac{1}{3}$ to $\frac{1}{5}$ ounce per square inch. Centrifugal fans may be used more efficiently as blowers, though even with them there is great loss of power in forcing the air through narrow channels, and round sharp angles, or from narrow to wider channels, or the reverse. Centrifugal fans should be provided with vanes of sufficiently wide radius or they will be wasteful of power owing to the insufficient supply of air to the centre. When used for drying delicate goods, the air should be filtered before being blown into the chamber. Two wire-gauze frames with loose wool between form a suitable filter, which admits of easy cleaning; flannel is often used, but requires frequent washing. It is important that the filter should be kept in good condition, as if it gets choked with dirt the air supply will be seriously diminished.

The volume of air moved by different types of fans varies greatly with the make and size of the fan, and the published figures, emanating as they do almost entirely from the manufacturers, must be taken as the maximum output under the best conditions. The author has, however, found that after several years' use a 48-inch Blackmann (screw) fan is still moving 20,000 cubic feet per minute with an average expenditure of rather more than 2 H.P., a value well within the limits claimed by the makers of the fan.

CHAPTER V.

DRYING AND DRYERS.

Drying.

It is very desirable that each master clayworker should be as fully acquainted as possible with the changes which take place on drying the particular clay he is using, as it is chiefly by such knowledge that he will be enabled to secure the efficient and economical working of his plant.

In ordinary plastic clay the water present fills all the interstices between the clay particles, but as the clay dries this water evaporates and air takes its place. The actual removal of the water takes place at first at the surface of the clay, its place being taken by water from the inside of the clay so long as the pores of the clay can transmit it by capillary action. This is the first stage of the drying, and it varies in duration with the proportion of water which has been added to the clay. It is also the stage where the largest amount of contraction occurs, as the clay particles tend to move over each other and to take the place previously occupied by the water, with the result that the amount of contraction generally approximates in volume to the amount of water evaporated. A strong, porous clay which requires a large proportion of water to make it plastic will consequently contract considerably at this stage, whilst a milder, more permeable and sandy clay, with less 'water of manufacture' in its composition, will show much less shrinkage and will require a shorter time for drying in the first stage.

The completion of the first stage of the drying may be determined by drying a carefully weighed and measured block of clay and repeating the weighing and measuring at frequent intervals; as soon as the loss in weight commences to be greater than the loss of volume of the block by shrinkage the first stage of drying is complete. If metric weights and measures are used no calculation will be needed, as the loss of weight in grammes can be compared directly with the loss of volume in cubic centimetres; if, however, English weights and measures are employed the loss of volume (shrinkage) measured in cubic inches must be multiplied by 0·578 in order to convert it into fluid ounces, which can then be compared with the loss of weight in ounces.

As distortion is a common result of unequal shrinkage caused by some portions of the goods losing moisture more slowly than the rest, all small projections should be covered over until the thicker portions are nearly dry.

In the second stage of drying, evaporation takes place far more rapidly than the change in volume of the goods, and the completion of this stage is characterised by no further shrinkage taking place; the clay is then no longer plastic.

In the third stage of drying, evaporation of the water takes place entirely from the inner parts of the clay, no shrinkage or change in volume of the clay occurs, and the spaces left by the removal of the water are filled with air; there is now little or no danger of distortion, and the drying may be carried out as rapidly as desired. It therefore pays to accelerate the drying at this stage.

As the shrinkage is less when the clay is dried rapidly from the start, since the clay particles do not then have time to move so freely over each other, it is advisable to dry goods as rapidly as possible, but as in the second stage of drying the outer surfaces tend to dry more rapidly than the inner portions of the clay, cracking will probably ensue if the water be removed too quickly. This is one of the chief reasons why each clay-worker should determine how rapidly he may safely dry his clay so as not to waste both time and money by having it too long in the dryers.

In the case of large articles, especial care is needed to ensure their being thoroughly dry, and many enterprising firms now insist on every such article being marked with the date of manufacture (either plainly or in cypher), and are in this way able to learn whether goods have been sent too soon to the kilns or whether they have been delayed unduly in the dryers.

Although with small pieces of clay the colour will often show when they are dry, this is not the case with larger goods, so that with the latter it is well, when they are urgently needed, to weigh them at frequent intervals, and to continue the drying for at least twenty-four hours after they have ceased to lose weight. It is hardly needful to remark that damp or 'green' goods should never be sent to the kilns.

Methods of Drying.—Although various methods are employed for drying clay goods, they may be arranged in two groups, according to whether cool or warmed air is used. This division is indeed an arbitrary one, as in both cases it is the air which acts as a vehicle for the removal of the water. It does this by means of its power of holding a definite quantity of water as it were in suspension, the exact quantity varying with the temperature of the air, just as hot water will dissolve a larger proportion of soda than cold water will. If air at a high temperature and saturated with moisture be cooled, it will no longer be able to retain all the water, and will deposit some of it in the form of dew, the amount deposited depending on the degree of cooling which the air has undergone. Thus air at 80° F. will retain nearly twice as much water as the same volume of air at 60°, so that if the air at 80° be cooled to 60°, it will deposit about half its contained moisture; whilst if, on the other hand, the air be warmed from 60° to 80°, it will, at the higher temperature, be able to carry more water than at the lower, and if a damp surface be exposed to its action, the latter will part with its dampness until the air has absorbed sufficient water to saturate it, whereupon no further drying will take place. If the damp body does not contain sufficient moisture to saturate the air, it will be completely dried by the air. It is therefore important to keep the air in the dryers at such a temperature that it is unsaturated, and to remove it as soon as its capacity for taking up water from the goods has been reached. The instrument used in measuring the moistness of air is called a hygrometer (see 'Tests'), and by its means it is possible to learn at any time whether the air will dry the goods efficiently or not. This is important, as in this country air at ordinary temperatures is generally more than half saturated with moisture.

When cold air is used for drying the goods the amount required is not usually of much importance, but if hot air is employed, the cost of heating must be taken into consideration. This cost will vary with the method of applying the heat, but there are certain limits which it must reach. It is a proved fact, for instance, that a brick of dry clay weighing 7 lbs. can be raised from 60° to 61° F. by only 1·4 units of heat, but if the brick contained $\frac{1}{2}$ lb. of water, as it probably would do before drying, it would require no less than 537 units of heat to drive off this water, and at the same time raise the temperature of the brick by one degree. In other words, there can be no drying without the absorption of a certain definite amount of heat by the water evaporated from the goods, although the temperature of the goods may remain the same throughout. This seeming contradiction disappears when it is remembered that the terms 'heat' and 'temperature' are quite distinct, though they are often confused in the popular mind. In a general way, if heat is applied to a substance, the temperature of that substance will rise, and *vice versâ*, but under certain conditions this is not the case. The application of heat to water or to certain materials containing water is one of these.

As is well known, temperature is usually measured in 'degrees'—two scales of degrees being in common use, viz., the Fahrenheit (F.) scale, on which the melting point of ice is represented by the number 32 and the boiling point of water at normal pressure by 212; and the Centigrade (C.) scale, in which these two points are represented by 0 and 100 respectively (see under).

Heat, on the other hand, is measured in 'British Thermal Unit' (B.T.U.) or in 'Calories' (Cals.), one B.T.U. being the amount of heat required to raise the temperature of one pound of water one degree (from 60° to 61° F.), and one Calorie being the amount of heat required to raise one kilo. of water one degree Centigrade (from 0° to 1° C.). Hence 1 B.T.U. = ·252 Cal.

The amount of heat which is required to drive the water from a wet substance, and yet which does not raise the temperature of that substance, is called the 'lost' or 'latent' heat, or, more correctly, the 'heat of vaporisation.' The amount of heat thus rendered latent in the conversion of water into vapour has been very carefully determined by Regnault and other observers, who found it to be 967 B.T.U. or 537 Cals. when water, at its boiling point, is converted into steam of the same temperature, and proportionately more if the water is at a lower temperature. The actual amount of heat used in effecting vaporisation at any particular temperature may be found from the following formula:—

$$L = 1114 - {\cdot}695\ F., \text{ or } l = 606{\cdot}5 - {\cdot}695\ C.,$$

where L = Latent Heat in B.T.U., l = Latent Heat in Calories, and F. and C. represent the temperature according to the Fahrenheit and Centigrade scales respectively.

Clay and similar materials require less heat to raise their temperature by a given amount than the same weight of water; in fact, most clays, when perfectly dry and free from combined water, only need one-fifth as much heat to raise their temperature one degree as the same weight of water would require. From this it follows that the minimum number of heat units which will be needed to raise the temperature of the goods (when perfectly dry) is as follows:—

$$\text{B.T.U.} = \frac{\text{Weight of goods in lbs.} \times \text{rise in temp. in deg. F.}}{5},$$

$$\text{Calories} = \frac{\text{Weight of goods in kilos.} \times \text{rise in temp. in deg. C.}}{5}.$$

Thus in the first case just quoted, to heat a brick weighing 7 lbs. from 60° to 61° F. needs $\frac{7 \times 1}{5} = 1{\cdot}4$ B.T.U. if the brick be dry.

In the second case the latent heat of ½ lb of water at 61° F. $= 1114 - {\cdot}695 \times 61 = 1114 - 42{\cdot}4$ per lb. $= \frac{1071{\cdot}6}{2} = 535{\cdot}8$.

Total B.T.U. to dry brick and raise its temperature to 61° F. $= 1{\cdot}4 + 535{\cdot}8 = 537{\cdot}2$.

If the weights had been in kilos. (7 lbs. = 3·078 kilos. and ½ lb. = ·227 kilos.) and the temperatures in °C. (60° F. = 15·5° C. and 61° F. = 16° C.) the calculation would have been:—

To raise temperature of dry brick ·5° C $= \frac{3{\cdot}078 \times {\cdot}5}{5} = {\cdot}77$ Cals.

To drive off water at 16° C.—

$$= (606{\cdot}5 - {\cdot}695 \times 16) \times {\cdot}227 = (606{\cdot}5 - 11{\cdot}12) \times {\cdot}227$$
$$= 595{\cdot}4 \times {\cdot}227 = 135{\cdot}15 \text{ Cals.}$$

Total heat-units required, ·77 + 135·15 = 135·92 Cals.

It is, of course, to be understood that the results so obtained are the *minimum* values, and that in most cases considerably more heat will be required in order to replace that lost by radiation, etc.

The Amount of Air required for Drying depends upon (*a*) the dryness of the air, (*b*) the pressure, (*c*) the temperature of the air and of the goods, (*d*) the volume of air, (*e*) the area of exposed surface of the goods.

The dryness or otherwise of the air is determined by means of a hygrometer (see 'Tests'). The amount of air required will vary inversely as the amount of moisture it contains; thus if 50 lbs. of air were sufficient to dry ½ lb. of water from a brick at 75° F. when the air is only 50 per cent. saturated with moisture, about 100 lbs. of air at 75 per cent. saturation would be required to effect the drying of another brick containing the same amount of water. For at 75° F. 50 lbs. of air at ordinary pressure can hold almost exactly 1 lb. of moisture; so that, if only 50 per cent. saturated, it would have only ·5 lb. moisture in suspension, and could take up another ·5 lb. from the brick; but if 75 per cent. saturated, it would contain ·75 lb. moisture, and so could only take up another ·25 lb. from the brick, with the result that to evaporate $\frac{1}{2}$ lb. of water $50 \times 2 = 100$ lbs. of air would be needed.

A Table showing the amount of water required to saturate air at different temperatures will be found in the Appendix. This Table also shows the great increase in water-carrying (drying) power which air undergoes when its temperature is even slightly raised.

The specific heat of air is only ·237; that is to say, ·237 unit of heat is required to raise 1 lb. of air 1° F., whereas to raise the temperature of 1 lb. of water the same extent would require 1 unit, and 1 lb. of dry clay would require ·2 unit (B.T.U.). Hence, to calculate the number of lbs. of air required to evaporate 1 lb. of water from a given weight of clay, it is necessary to first calculate the 'latent heat of vaporisation' at the particular temperature at which the drying takes place (p. 123), and then to divide this by the product of the fall in temperature of the air as the result of its passing over the goods and by ·237. Thus the minimum weight of air which will yield sufficient heat to drive off 1 lb. of water from a piece of clay weighing 10 lbs. (= 9 lbs. clay and 1 lb. water), the air being supplied at a temperature of 90° F. and being cooled by the clay to 65° F., will be $L = 1114 - (\cdot 695 \times 65) = 1069$.

$$\frac{1069}{(90 - 65) \times \cdot 237} = 180\cdot 6 \text{ lbs.};$$

and as each lb. of air requires ·237 B.T.U. to raise its temperature 1° F., assuming the air to be at 50° F. before heating to 90° F.,

$$180\cdot 6 \times \cdot 237 \times (90 - 50) = 1712 \text{ B.T.U.}$$

will be required to heat the air sufficiently for this purpose. In addition to this a certain amount of heat will have been absorbed by the heating of the water in the clay from 50° to 65° F., and also in heating the clay, viz.,

Heating 1 lb. water 50° to 65° $= 1 \times 15 = 15$ B.T.U.,
Heating 9 lbs. clay 50° to 90° $= 9 \times 40 \times \cdot 2 = 72$ B.T.U.,

or a total of 1799 B.T.U.

If the goods are supported on wooden racks or on iron cars, a further quantity of heat will be required to raise the temperature of these. This is calculated as follows:—

Weight of supports × rise in temperature × specific heat of support.

The specific heat of wood may be taken as ·55, and that of iron as ·114.

Losses of heat by radiation are not easy to calculate; they may easily amount to a quarter of the total heat supplied if the drier is carelessly designed or badly managed. In addition to these losses of heat there is another caused by the fact that it is not generally advisable to allow the air to pass away in an almost saturated state, as it is then liable to deposit some of its moisture on the goods at the end of the dryer; it is usual, therefore, to pass the air out at about 90° F.

The volume of air required may be calculated from the weight of air required as follows:—

$$1 \text{ lb. air} = \frac{(\text{Temperature } ^\circ \text{F.} + 491) \times 13{\cdot}35}{491} \text{ cubic feet}$$

$$1 \text{ kilo.} = \frac{(\text{Temperature in } ^\circ \text{C.} + 273) \times {\cdot}8}{273} \text{ cubic metres,}$$

the air being at standard pressure (30 inches or 760 mm.) in both cases.

Thus 1 lb. air at 32° F. measures 13·35 cubic feet, and 1 kilo. at 0° C. measures 0·800 cubic metre.

The Rate of Evaporation depends upon (*a*) the dryness of the air, or, conversely, upon the vapour pressure, which varies with the temperature; (*b*) the volume or weight of air available; (*c*) the temperature; (*d*) the area of exposed surface of the goods.

It will thus be seen that, provided a sufficient amount of air is supplied to carry off all the moisture in the goods, the drying will take place most rapidly when a large surface of clay is exposed to very dry air. But as the relative dryness of air increases very rapidly when the air is heated (see Appendix), it follows that the hotter the air (providing that it is not saturated with moisture when cold), the more rapid will be the drying, though hot air which is nearly saturated will not dry the goods no matter what its temperature may be. It is too seldom realised that in damp summer weather the air, though of higher temperature than on a dry winter's day, may yet be more nearly saturated with moisture, and so less capable of drying goods. In such a case the air must be still further heated, until it is sufficiently removed from its saturation point to do its work satisfactorily.

Supply of Heated Air.—As the quantity of heat required for drying is considerable when artificial heat is used, it is desirable to utilise sources of waste heat when possible. Thus a large amount of heat can often be obtained by passing the air through pipes or 'economisers' fitted in the kiln-chimney flue, or the waste heat from the engine exhaust may be used to supplement, though it cannot entirely replace, live steam direct from the boiler.

The chief sources of heat are:

Coal or coke.
Steam (live or exhaust).
Hot water.
Kiln gases.

One pound of good coal will, on complete combustion, yield on an average about 7000 Calories or 13,000 B.T.U., so that, in the example given on page 45, the 1712 B.T.U. required will be furnished by about $2\frac{1}{4}$ oz. of coal. Coal cannot, however, be used directly in many cases, so that the indirect means of flue gases, steam, or occasionally hot water, are used.

Coke is sometimes used instead of coal for drying-floor fires, but unless very carefully tended the variations of heat cause irregular drying, and there is a general waste of heat because different parts of the floors cannot be shut off when the goods are dry.

For further information on the calorific power of coal and coke, see Fuel (p. 44).

Steam, on account of its high latent heat and moderate temperature, is admirably adapted for the transmission of heat in drying clay goods, especially as it yields as much heat as ten times its weight of water, or forty times its weight of air, cooling from 200° to 100° F.

As few engines are capable of utilising more than 25 per cent. of the total heat in steam by converting it into mechanical power, it is often economical to use the exhaust steam for drying, though the condensed water it contains necessitates more of it being required than if live steam were employed. In any case the plant must be capable of using live steam at night and at such other times as the engines may not be in use.

One pound of good coal will convert from 8 to 10 lbs. of water into steam, which on condensing will yield 7750 to 9670 B.T.U., according as the water is cold or at the boiling point.

As exhaust steam cannot heat the air used for drying to more than about 160° F., it is generally wise to use as much of it as possible on account of its low cost and to supplement it with live steam to raise the temperature of the air, when necessary, from 170° to 180° F.

When exhaust steam is used it is necessary to prevent any back pressure on the engine, or the higher boiler pressure which will be required will rapidly neutralise any economy which would otherwise have resulted from its use.

Hot-water pipes are still largely used in the Potteries, and where the goods have to be frequently handled this method of heating has its advantages, the heat being less concentrated than when steam pipes are employed. The water may be under low or high pressure, according to the heat required in the pipes.

Superheated steam has practically no advantage over ordinary live steam for drying purposes.

Kiln gases or flue gases are often available as a source of heat, and should be used when this can be done economically. With the commonest classes of goods they may be diluted with air until reduced to a suitable temperature and then passed over the goods, but for most purposes it is best to pass the gases over tubes through which air is drawn or through tubes placed in the dryer in a manner similar to steam pipes, or the air may be heated by passing it through a radiator which is heated by the gases. This latter method has the advantage of keeping the air clean, but it is not quite so economical as the former.

The available heat in kiln or flue gases may be calculated thus:

(*a*) Calculate the weight of the gases from molecular formula.

(*b*) Multiply the weight of the gases by ·237 and by the difference in temperature at which the gases enter and leave the drying room in ° F.

N.B.—0·237 is the specific heat of the gases.

Thus a Hoffmann kiln of modern type will supply about 5000 cubic feet of gases at 200° F. per minute if a fan is used, instead of a chimney, to create the necessary draught. Supposing that these gases are cooled in the dryer to 100° F., the heat units available per minute will be:

(*a*) The weight of 5000 cubic feet gases measured at 200° F.

$$= \frac{1}{\frac{200}{40} - 11{\cdot}58} \times 5000 = 301 \text{ lbs.}$$

(*b*) Weight × sp. heat × difference in temperature = 301 × ·237 × 100 = 7133 B.T.U., or ·6 lb. coal.

Dryers.

In order to determine the value of different dryers it is necessary to ascertain the cost in fuel and upkeep per unit of goods made. The latter may be taken either as 1000 pieces (*e.g.* bricks) or as a ton of clay, depending on the kind of goods manufactured. The length of time required for drying the goods must also be taken into consideration as well as the capital cost of the installation.

The number of heat units (B.T.U.) required by the goods must be first determined, as described under 'Tests,' and the amount of fuel used by the dryer in supplying this amount of heat ascertained. This will give a means of comparing the dryers as far as cost of fuel is concerned, but to this must be added, as stated, the cost of upkeep (wages of attendants, etc.) and a correction for the time required.

In comparing different dryers it is also important not to fall into the error of supposing that, as some manufacturers claim, heat can be used over and over again. From what has been said in the section on drying it will be understood that this can only occur when the air or other heating medium is at an excessively high temperature in the first place—a state of affairs which should never be allowed, as it not only means a waste of heat, but is also likely to result, sooner or later, in the production of damaged goods.

The most important methods now in use for drying clay may be classed under four heads:

(*a*) Drying in open (unwarmed) air.

(*b*) Drying by air heated outside the dryer.

(*c*) Drying by conduction, *i.e.* by contact of the goods themselves with a hot floor, the heating of the air being of secondary consideration.

(*d*) Drying by radiation, the goods being at the same time supplied with warm air to carry off the moisture.

Hacks.—The first of these methods can only be used for comparatively rough (cheap) goods, such as bricks, and then only during the summer months. It costs little, but is very slow. The uncertainty of the weather in this country prevents the method being used in its most primitive state, and a covering of some sort is necessary, and 'hacks' are therefore used. The ground used should be as even as possible, and, to secure efficient drainage, it is often convenient to dig small trenches in the direction in which the hacks run, and to use the soil so turned up for the foundation of the hack itself. Some consideration must be given to the direction of the hacks, and in this country they should usually run north to south or north-east to south-west. For most bricks the centres of the hacks should be about 10 feet apart, the hacks themselves being 2 feet 6 inches wide and 4 inches above ground level. They should be evenly sprinkled with a fairly thick layer of sand. The length of the hacks will vary with the shape and size of the ground; about 80 yards is by no means uncommon. A ground area of one acre is usually sufficient for a million bricks. The bricks are set on the hacks by means of boards similar to those used in 'setting down'; they must on no account be handled by the workman's bare hands or their shape will be spoiled. The hacks are set one level at a time, so as to enable the bricks first placed to become sufficiently stiff to carry the row placed on them; the total height will vary with the nature and stiffness of the clay, but will usually be equal to eight or nine bricks.

The covers for hacks (hack caps) may be portable or fixed. In former days the hacks were simply covered with straw, but this is neither satisfactory as a covering nor so cheap as proper wooden or galvanised covering. With very delicate clays dried on hacks, straw is still often used in addition. The portable form consists of boards nailed so as to form a roof of the ordinary 'A' cross section, about 3 feet long and 3 to 4 feet wide.

In order to keep the ends protected, matting or loose boards must be provided. The matting is preferable, as it effectively keeps off the rain whilst permitting a free circulation of air.

The chief disadvantages of hack drying are its extreme slowness, the loss through bricks damaged by the weather (5 per cent.), and the very considerable expenditure necessary for repairs. The wheeling to and from the hacks, skintling, attending to matting, etc. are also expensive, and it may be taken as a general rule that, from the machines to the kiln, the bricks cost at least 3s. 3d. per 1000 for drying.

In order to overcome the excessive slowness of the drying at ground level, trestles are sometimes used, particularly in America, to raise the bricks a few feet and obtain greater circulation of air. The use of such trestles is particularly advantageous at the beginning and end of the season and in wet weather. The trestles are permanent, and are spaced so that the cars can pass between them when charged with brick pallets. For wire-cut bricks a self-loading set of pallets may be picked up when fully charged, wheeled to the ground and there deposited in rows, and when dry are conveyed in the same manner to the clamps or kilns. These cars effect a great saving in time over barrows, as they can carry 200 bricks or more at a load. The bricks on the trestles are protected from the weather, when necessary, by canvas roofing hung on wires, so as to form a roof and sides. This protection is very efficient and cheap.

Sheds.—Drying sheds provided with racks for the goods form an improvement on the simpler hacks. This form of dryer is frequently found over Hoffmann kilns on the Continent, the racks being placed transversely to the building, although, in some places, no attempt is made to supply warm air. Ventilation is secured by means of louvres in the roof and by movable shutters at the sides. The repairs of this form of dryer are very small, and the loss of goods through the weather practically nil; no skintling is necessary, and no expense is incurred in storing the covers, etc., through the winter. On this account the use of a permanent shed is less expensive than hacks, being not usually more than 2s. 6d. per 1000 bricks, but an additional charge of interest on capital, amounting to at least 6d. per 1000, must be added to this amount.

Artificial Drying.—Artificial drying is chiefly to be distinguished from the so-called 'natural' drying just described, in that the latter uses a large volume of air at a comparatively low temperature, whilst the former uses a smaller volume of air at a higher temperature, thereby securing greater control and rapidity in drying, which, with delicate clays, or goods liable to spoil on exposure, more than compensates for the cost of the fuel.

The simplest method of artificial drying consists of placing the goods in contact with a hot floor or other substance in such a manner that the goods themselves, as well as the air around them, become warmed; the warm air thus carried off the moisture, and is changed, in the more effective dryers, by some simple process of ventilation. At the present day, however, the most successful dryers employ a combination of convection and radiation, and the goods are only to a very limited extent placed in contact with hot solid bodies. In many modern dryers, too, the goods are moved through the dryers, which are consequently given a more or less tubular or tunnel-like form, though for many goods a travelling device of this kind has not proved satisfactory.

The heat for the dryers may be supplied from kilns, coke fires, coal fires, or steam. The heat from kilns may be obtained by means of flue gases, or by drawing air over the hot goods in kilns which are cooling; this latter method has the advantage of using air free from soot and other condensation products which tend to spoil the goods. Portable heaters of various kinds are also used, on occasion, for supplying hot air to the dryer. Ventilation must be carefully attended to, and secured by natural means, or by the use of fans, chimneys, etc. Sometimes the heated air is allowed to find its way out of the dryer as best it can, but this is not a desirable method of getting rid of the moisture, as there is a great tendency for it to become deposited on the goods themselves.

The use of steam or fuel-heated floors is widespread in England, although it has found but little favour abroad. The fuel consumption is high for a simple heating floor, averaging 1 lb. of coal for every 3 lbs. of water evaporated, but a considerable lower cost may be obtained by using a mixture of exhaust and of live steam. The great danger of such floors is that the goods tend to crack if the heating is carried out rapidly, as there is so little movement of the air, and 'steam' may frequently be seen rising from the goods. This is, however, bad practice. If steam is used, some arrangement should be made for draining off the condensed water. For many purposes it is desirable to carry the steam in overhead mains, and to take branches off these to different portions of the floor. Considerable skill is required to build the flues under the floor so as to secure even distribution of the heat, and at the same time to render the flues steam-tight. The floor is often covered with a thin layer of cement to make it damp-proof, but this causes a great loss of heat. The joints between the bricks or slabs, of which the floor is made, should certainly be cemented. Where a clay can be dried very rapidly without harm the floor may be covered with iron plates, but it is difficult to keep them steam-tight, and they rapidly lose their heat when the steam has been cut off, as, for example, during the night.

A particularly useful floor of this class consists of hollow slabs, or quarls, usually salt-glazed and bedded in cement, the joints being made with the same material. This floor is very clean, easy to construct, and of great durability. It was originally known as Sabine's patent, but hollow quarls of this type are now made by several firms on the Continent for various purposes where a light fireproof flooring is required. The price is about 7s 6d. per square yard, brick-covered flues with cement bed and covering costing about 9s. to 10s 6d. Iron plates cost much more per square yard, but the output from them is more than double that of the other floors mentioned, so that, where they can be used, they are really the most economical.

In some dryers the flues are separate from, and above, the floor instead of below it, and therefore take the form of pipes, usually of about 6 inches diameter. When these are used the goods are generally placed on racks, so that the heating really takes place by radiation. Unless, however, some system of distributing the air evenly throughout the dryer is used (an extremely difficult matter), this method cannot be made really economical. The ordinary hot-water systems so common in the Potteries are worked on this system, which is more suited for drying goods of the highest class, where steadiness of drying is an important consideration and where the goods have to be repeatedly handled during the drying. The use of hot water under pressure is becoming increasingly common, and radiators of various types are proving useful for rooms which must be kept at 70 degrees or so throughout the year, as in the manufacture of much 'small ware' of high quality.

For some classes of work it is convenient to let the steam pipes used for heating simply lie in open trenches in the drying room, a rough lattice-work being placed over the top or the goods being placed on boards which lie across the trenches. A greater movement of the air in the room is thus secured, and the goods are less liable to crack, as they are not in actual contact with a hot floor.

In the ordinary drying stoves in the Potteries numerous shelves are provided in a kind of huge cupboard, on the bottom of which a grid of hot water- or steam-piping is placed. Sufficient room should be left between the floor and this piping, and between the piping and the bottom shelves, for both floor and pipes to be swept out, as pieces of clay fall from the goods, and, in course of time, tend to prevent the heat being properly distributed through the dryer.

The 'stove' or dryer will vary in size and construction with the class of goods made (for a plate-maker it should not be less than 12 feet in each direction), and the shelves should be attached to a vertical iron shaft which can be rotated so as to bring a different set of shelves to the front when it is turned. By this means much time and space are saved. As heat alone will not dry goods, some form of ventilator should be fixed at the top of such a dryer, and should be kept clear and open. The shaft holding the shelves will require occasional oiling so that it may turn easily; if too stiff, the goods may be spoiled in turning it. Doors should be provided, but they should be kept shut as much as possible so as to keep in the heat, and two or more frames of shelving may be placed in the same casing, although it is generally better to keep them separate, so that one may be allowed to cool for emptying, cleaning, etc., without disturbing the rest. The grids of steam pipe may be supplied with either live or exhaust steam, and should have all the pipes draining to one spot—an inclination of 1 in 20 being usually desirable to give sufficient fall for the condensed water. The steam inlet must always be at the highest point in the grid. The trap for draining off the water must be kept in order. The foreman potter alone should control the steam-cocks for these dryers.

Ventilated dryers are, on the whole, the most satisfactory and economical for most classes of goods which do not need handling after they have once been set aside to dry. The general idea is to draw a current of air through, or over, a heater to distribute it among the goods to be dried, and then to remove it at such a temperature that it will not deposit any of its moisture on the goods. The heater may consist of a special appliance of the kiln flues, or of exhaust steam from the engines in the factory, it being generally understood that as much as possible of the heat shall be obtained from sources which would otherwise waste it, so that the greater part of the heat may cost nothing. It is seldom possible to obtain all the heat required in this way, and supplementary heaters (live steam, coke or coal, etc.) must therefore be provided for use when required.

The motion of the air is controlled and regulated by means of a chimney or a ventilating fan, each of which has its special advantages and disadvantages. On the whole a well-designed fan of ample capacity may be preferred, as it is independent of the changes in atmospheric temperature and pressure, while the power consumed is so small that it is really compensated for by the increased certainty and rapidity with which the goods can be dried.

A number of simple and efficient methods of chimney ventilation are used in connection with Hoffmann kilns, as when the chimney is used to draw a current of air over the goods in the chamber last fired and into a chamber in which the goods are drying. This can, obviously, be only used where the goods are fired in an open kiln; if placed in saggers they would never dry. In the Peterborough district the goods are often placed in one of the kiln chambers and a small fire is built at the wicket, the dampers being so arranged that the products of combustion, very largely diluted with air, are drawn through the chamber into the chimney. The heat thus introduced is so slight as not to damage newly-made bricks of the dryness usual in Peterborough, and as only about ¾ ton of coal is used for the six days occupied by the drying, the method is one of the most economical known. Where the goods are liable to scum, however, this method is not suitable.

The use of fans and chimneys for dryers is chiefly practised in connection with the most modern form of dryer—the tunnel. Of this dryer there are numerous forms, which may, however, be divided into two main classes: (1) those in which the goods travel and dry progressively, and (2) those in which the goods travel in one direction whilst the air travels in the opposite direction.

The air in these tunnels is heated by waste gases from the kilns, by exhaust steam, live steam, or by coke or coal fires. The heat from the kilns is rarely sufficient, except for bulky goods of relatively small weight, small hollow goods and similar articles. If exhaust steam is employed great care must be taken that no back pressure is put upon the engines, or it will prove more costly in use than live steam direct from the boiler. The use of coke or coal is often rendered inefficient, because the gases resulting from their combustion are allowed to escape at a comparatively high temperature into the air, so that this heat is lost. Live steam is too costly to use alone; hence as much heat as possible should be obtained from the waste kiln-gases and from the exhaust steam, the deficiency being made up with live steam or coke fires.

In using steam it is best to pass it through a radiator or grid of pipes over which the air to be heated passes. This grid must be well trapped, and care must be taken that the trap is kept in thorough working order. The pipes composing the grid may be arranged in vertical or horizontal rows, or it may take the form of a long pipe repeatedly bent upon itself, as in the Wolff dryer. The essential point is that there must be a sufficient surface of heated pipe to raise the air passing over it to the required temperature and to prevent any back pressure on the engine if exhaust steam is used. The condensed water is, whenever possible, returned to the boiler-feed, but before it enters the boiler it must (if exhaust steam has been used) be carefully freed from oil, or an explosion may occur in the boiler.

A considerable increase in the capacity of a dryer may be made by the construction, when it does not already exist, of a false ceiling of corrugated (not galvanized) iron, over which some of the heated air is allowed to pass. This causes a considerable radiation of heat from the top of the dryer downwards, and if it is provided with openings at intervals to allow some of the heated air to rise and be carried away, it will be found that the goods are less liable to crack when they travel in the opposite direction to the air current.

The use of a false ceiling and of a heat radiator below the goods form two of the main features of the Wolff dryer. The radiator, already mentioned, consists of a number of pipes connected in series, so that the uncondensed steam flowing from one is caused to enter another, the operation being repeated until no steam is left to escape uncondensed from the last of the series. In this way the heat rises gradually from about 95° F. at the cool end to 115° F. at the hotter. In this, as in all dryers on the 'inverse' system, there is a great tendency for condensation to occur on the goods when they enter the dryer, and a 'tempering' room or preliminary warmer must be used for delicate clays. Motion is imparted to the air by means of a tall chimney of wood, but if a fan is used instead it would be an improvement, as it would eliminate variations due to changes in the atmosphere. The Wolff dryer is heated entirely by steam, and does not therefore work so economically as some forms in which waste heat from the kiln is used.

The weak point of all 'inverse' dryers is that the air must be passed out into the atmosphere at not less than 90° F., and even then it must not be saturated with moisture or the latter will condense on the goods. When, on the other hand, the goods are first treated with cold air which is gradually heated as the goods progress through the dryer (both travelling in the same direction), no condensation can possibly occur, and a serious difficulty is thereby overcome. The hot air at the end of the dryer is not allowed to pass out, but is returned to pipes at the cooler end, so that it may, in passing through them, warm the air near the entrance to the dryer. As a smaller volume of air is required than with the inverse dryer, and the goods are for a considerable time in contact with practically cold air, the most delicate clays may be dried with safety. The makers of the Moeller and Pfeifer dryer, which is of this latter type, claim to dry any class of bricks in one of their dryers on this 'direct' principle in twenty-four hours. The direct system of drying originated, apparently, on the Continent, and the Moeller and Pfeifer dryer, which is an improvement on one by Bock, is probably the most efficient on the market, but is unfortunately expensive both in first cost and in power. This is due to the number of fans employed and to the arrangements made for giving the air in the dryer a spiral motion. Various attempts have been made to simplify the construction, and the dryer designed by Mr. A. E. Brown appears to accomplish most, if not all, the work of the more expensive dryer at a considerably less cost. This is brought about by the use of a false ceiling with an overhead flue, through which the hot air from one end of the dryer is returned to the cooler end. The radiation of heat from this ceiling is said to entirely obviate the necessity of providing mechanical means for imparting a transverse direction to the air in the dryer. The heated goods (bricks) are run into a small cooling chamber, where they are cooled by air drawn over them before it passes to the radiators, which are heated by waste kiln gases, by exhaust steam, and by a supplementary coke furnace. The designer states that the use of live steam instead of coke effects no economy. The necessary suction and air movement is produced by a single fan placed near the cool end of the dryer.

The relative costs of drying will be found later (see Table at end), from which it will be seen that artificial drying is preferable to natural even in the case of bricks, not only on account of the greater rapidity of output, but also because of the reduced risk of damage to the goods. In addition to this it must be remembered that heat alone will not dry goods; ventilation must also be provided to carry off the moisture, and for this purpose a fan is usually more convenient than a chimney, because it can be better regulated. It is to be noted that the air current must be gentle and evenly distributed, as a strong, irregular current warps and cracks the goods.

For further particulars and more detailed descriptions of dryers, the reader is referred to the work on *Brick Drying*, by A. E. Brown. See Bibliography at end.

In making calculations as to the amount of heat required for drying a given weight of a certain class of goods, it must always be borne in mind that there are, in addition, certain losses by radiation, etc., for which allowance must be made. In some cases the additional heat required to make up for these is very considerable, but it is scarcely possible to calculate its amount with exactitude without long and tedious calculations. As an instance of the sort of losses which are met with, it may be mentioned that a 5-inch cast-iron steam-pipe with steam at an absolute pressure of 115 lbs., will, if uncovered, condense about 1 lb. of water per foot per hour, in doing which 1000 B.T.U. are liberated.

CHAPTER VI.

ENGOBING AND GLAZING.

The application of an engobe or glaze to clay goods may be made either before or after the first firing of the goods, according to the shape and nature of the goods themselves and to the properties of the clay of which they are made. The primary object of firing the goods before engobing or glazing them is to increase their strength and so lessen the chances of damage through roughness in handling, though in the case of very large or very delicate articles it is not usually possible to apply the engobe or glaze to the raw goods, no matter how much care is taken, unless special methods of application are employed. Whenever it is possible to do so, it is better to apply the engobe, or glaze, or both, to the green clay, so that the article is only once fired, as in this way a greater uniformity between the clay, the engobe, and the glaze is secured than when these are fired at temperatures specially adapted to bring out a special quality in each, without much regard to the rest.

Glazes and engobes are prepared for use in the form of slip by grinding the materials to impalpable fineness and mixing them with water, or, in the case of certain coloured materials used in decorative work, with fat oil or some other vehicle. It is generally advisable that the materials should be insoluble in water, as otherwise uniformity of composition of the mass after it has dried on the goods is almost impossible. The case of vaporous glazing must be considered separately. When it is necessary to employ soluble substances, such as soda or potash compounds, it is usual to render them insoluble by 'fritting' or heating them with silica in some form in which it can be used in the glaze; the silicates thus produced can then be ground with the other constituents of the glaze or engobe in the usual ways. In fritting it is necessary to choose proportions and materials which will form as fusible a frit as possible in order to save unnecessary expense in firing. Substances which are much denser than the main constituents of the glaze or engobe may be mixed more completely if fritted with some relatively light constituents; this is especially important when a very small proportion of a very dense material is to be evenly distributed throughout the mass. The fritted and still molten mass is generally run into water to disintegrate it and allow of its easier pulverisation. It is not always necessary to actually melt the materials together in order to render them insoluble; in many cases raising the temperature of the mixture comparatively slightly is sufficient. It is not necessary to have the materials to be fritted very finely powdered, but they must be as thoroughly mixed as possible, and the heating must be uniform throughout the mass. In the case of lead frits care must be taken that the atmosphere is not reducing, or metallic lead may be formed. Although fritting is sufficient in most cases—indeed, over-heating will often do more harm than good—complete vitrification of the material is necessary when a perfect mixture is required.

The grinding is usually carried out in water in either stone mills or in Alsing cylinders containing pebbles or balls. Fineness of the product combined with high output are the chief points to be sought in considering the efficiency of such mills. If the glaze contains a notable proportion of clay, this should not be added until near the end of the grinding, as its early addition prevents the effective pulverisation of the harder materials. The grinding must be continued until at least 90 per cent. of the material has been reduced to so fine a powder that it can be washed through the lawns or sieves, as otherwise the glaze will probably not have the desired composition owing to some of the harder constituents not being sufficiently finely ground. The stones of the mills and the porcelain, or stoneware, linings of the cylinders need to be frequently examined, or the time required for the grinding will be materially lengthened.

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

Although at one time sieves for glaze were almost exclusively made of silk or similar material, the use of phosphor-bronze is rapidly on the increase; it is harder than brass or copper, and is, therefore, not only more durable and less likely to contaminate the slip with particles of metal, but it is capable of being woven into materials of ample fineness for most of the potter's needs.

The fineness of the sieve through which the glaze slip should be passed is to some extent a matter of individual choice at the present time, as different workers vary considerably in the fineness which they consider necessary. Excessively fine grinding should be avoided as being unnecessarily costly, but the material must be so well ground and so intimately mixed that its composition is as uniform as possible. A sieve with 30 meshes per linear inch is only suitable for relatively rough work, but it is seldom necessary to use one with more than 200 meshes to the linear inch. Between these limits the particular size of mesh must depend on the nature of the materials used and the work to be done; sieves with 60, 80, 100 and 120 meshes per linear inch are in frequent use and are well adapted for most glazes.

In expressing the size of sieves it is necessary to note that the number of meshes may be given per *linear* inch or per *square* inch, the latter being less convenient as involving greater numbers; thus

60 meshes per linear inch = 3,600 meshes per square inch.
80 „ „ = 6,400 „ „
100 „ „ = 10,000 „ „

When Continental meshes are referred to it should be remembered that 1 inch = 2·5 cms. and that 1 square inch = 6·25 square cms., so that the size of mesh of a sieve may be expressed in four different ways:

No. (p. 83).	Meshes per linear inch.	Meshes per square inch.	Meshes per cm.	Meshes per square cm.
30	30	900	12	144
60	60	3,600	24	576
90	90	8,100	36	1,296
100	100	10,000	40	1,600
120	120	14,400	48	2,304
150	150	22,500	60	3,600
200	200	40,000	80	6,400

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

Both glaze- and engobe-slips should be kept for some weeks before use, as not only is the material improved by keeping, but it also allows of samples of each batch of glaze being put through the kilns before it is actually used in the works, and so saves the possibility of loss through an error in compounding the glaze. With a stock of slip in hand it is also possible to repair the mills or cylinders properly whenever it is necessary.

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

The precise manner in which the slip is applied to the goods varies with its composition and with the nature of the goods themselves. Four methods are in general use—dipping, pouring or teeming, painting, and sprinkling or spraying. When the glaze is in the solid form and not a slip it may be applied by dusting or by volatilization.

In *dipping*, the ware, usually in the biscuit state, is immersed in a vessel containing the slip in such a way that the article is completely covered with a uniform coating of the material. The relative proportions of solid matter and water in the slip is of great importance in securing a coating of the correct thickness. If too little water be present the coating will be uneven and too thick, whilst if an excess of water is present an insufficient coating of material will be given to the article. The correct proportions can only be found by making slips of different strengths and sending trials dipped in these through the kilns. The strength of the slip is a function of its specific gravity, and is most conveniently expressed in terms of "ounces per pint"; that is to say, a pint of the slip accurately measured is carefully weighed, its weight, in ounces, being used to express its relative density. When the correct weight per pint has been once ascertained for a particular slip and for a particular workman, the slips can always be made up to this weight until the workman, or the composition of the slip, is changed. As the personal equation is an important factor in dipping goods, each workman may require a slip of a different density, though most dippers of experience can tell with great exactitude the density of a slip by merely placing their hand and arm in it.

In order that a slip may be suitable for dipping, it is necessary that it should contain sufficient plastic material to enable it to adhere to the article when it is dry; hence it is seldom advisable to frit all the constituents of a glaze, but the more plastic materials should be added to the powdered frit. When, for any reason, this is not possible, the adhesiveness of the slip may be increased by the addition of a little dextrin, starch, or gum; this will also prevent the slip 'settling' too rapidly, although where this settlement is very pronounced the material is best treated with gelatin or oil and painted on to the goods (p. 143).

Hard-fired ware does not absorb the water from the slip so readily as more porous ware, and should therefore be dipped in a slightly thicker glaze, whilst specially soft or porous ware should be first dipped in water and then into the slip. Moderately-sized articles—when sufficiently stoutly made—may be dipped in the green state, the slip having a density of 26 to 28 oz. per pint. This cannot be done in the case of very large or delicate pieces, as the strain would be too much for the clay if the goods were dipped in an unfired state.

It is important that the dipper shall not move his fingers over the goods whilst dipping, or parts will not be glazed; a hook is frequently used to prevent the man's fingers from touching the goods where they have to be glazed. Retouching of those parts of the articles which have been insufficiently coated with slip is generally necessary, but the less this is required the better.

Dust on the goods before dipping must be carefully and completely removed, and it is essential that grease of all kinds (including perspiration) should be rigidly excluded from the goods, unless the grease is applied with the definite object of preventing the article from taking the slip in certain parts.

It will sometimes be found that an article which has been dipped in engobe ('body') will not take the glaze properly on a second dipping; in such a case the addition of dextrin or gum will often facilitate the adhesion of the second coating, or the article may be passed through the kilns and dipped when the engobe has been fixed by firing, or both engobe and glaze may be painted on.

Various defects in engobing and glazing are treated under their special headings and in the chapter on 'Defects.'

Much may, however, be done by attention to small details, such as the removal of superfluous slip from different portions of the articles, retouching where the coating of slip is thin, carefully mixing the slip and seeing to its freedom from impurities and coarse particles of all kinds.

In cases where the articles are too large, or are in other ways unsuitable for dipping, the method of *pouring* or *teeming* may be used; that is to say, the engobe or glaze may be poured over the object, an even coating being obtained by a dexterous turning of the hand. This method is especially used for glazing the inside of vessels, or for those bodies which are only slightly porous and so will not retain a sufficiently thick coating of material when dipped.

The slip should be somewhat thicker than for dipping; the addition of gum or other adhesives may be made, or not, as is found to be desirable. Retouching with a brush dipped in the slip is generally necessary.

Painting is the commonest means of applying a number of different colours and glazes to a piece of ware, and the great value of art ware of the best class is chiefly due to the skill with which the colours are thus painted. For this purpose the colours are mixed with fat oil or other medium and applied before or after the vessel has been glazed, according to the effect which it is desired to obtain. The art of painting in this way would, however, require a treatise to itself to describe it efficiently.

The application of engobe and glaze by means of a brush is, however, so important in certain cases that reference must be made to it here. When articles with designs in high relief are to be executed in glazed or engobed ware, it will often be found that when they are dipped the excess of material accumulates in the hollows of the ware and so tends to destroy the outline or to induce crazing. In other cases too, such as when the goods are too large to be dipped and their shape does not allow of simple pouring, the material may conveniently be painted on. The ordinary engobe or glaze slip may be painted on the wet clay with a camel-hair brush, and any inequalities of surface smoothed out before the engobe is quite dry. This method gives excellent results in careful hands, but with less skilful workers it is desirable that the slip should be made pasty or even solid. As, however, the mere omission of water introduces other difficulties, it is usual to add some solidifying medium, such as gelatin, to the slip. The proportions of slip and of gelatin will naturally vary with the amount of water in the slip and with the temperature of the workshop, but for slip at 28 to 30 oz. per pint, 6 oz. of good gelatin per gallon will usually be ample. This proportion will convert an ordinary slip into a blanc-mange-like mass, which can be easily and rapidly applied to the goods with an ordinary sash-tool brush. It will generally be found that several coats are necessary before a sufficiency of material has been applied, but even then the method allows of a fairly rapid output, and, in addition, has the great advantage that the goods may frequently be painted in the green state and so the cost of biscuit firing is saved. In summer the gelatinized slip melts and is not then capable of being applied satisfactorily; it may be restored to its solid condition by cooling it sufficiently, provided that putrefaction has not set in, or a little formalin may be added to the freshly-made slip.

The material may be *sprayed* on to the goods when a varied and not too thick coating is required. An arrangement of two tubes at right angles to each other, and similar to the 'atomiser' used in toilet accessories, is employed, the glaze or engobe being in the form of a thin slip. This method is scarcely suitable for covering coloured clays with an opaque white slip, as it is difficult to get a sufficiently even coating of sufficient thickness without a great expenditure of time. For applying a graded or shaded effect in colour on the top of a glazed or vitrified article, this method is particularly useful. In order to obtain dark tones, it is desirable to let one coating of the sprayed material become dry before another is applied, or the slip may trickle into unpleasant-looking masses. The older method of sprinkling the glaze on to the goods by hand or with a brush is now almost obsolete.

Dusting or sprinkling the powdered glaze material on to the goods whilst they are still damp is only used for the commonest sorts of earthenware. The dust is usually applied by means of a sieve, but as glazes so applied are usually highly plumbiferous, the process is so dangerous to the workmen that it should be discarded.

The principle of *volatilisation* is largely used for certain classes of goods, the two commonest forms being 'salt glazing' and 'flowing.'

Salt Glazing was first introduced into England by the Brothers Flers in 1690, and is still considered to be one of the simplest and most perfect methods of glazing, although it has the disadvantage that it can only be applied to certain highly siliceous varieties of clay, as basic, aluminous clays will not decompose the salt sufficiently to yield a good product.

Although the process of salt glazing is simple, there are many points which require very careful attention, or failure is sure to follow.

Assuming that the clay is right (and it is difficult to say without actual trial how much alumina or how little silica a clay may contain, and yet give a satisfactory salt-glazed product), it is important that it shall be of as constant a composition as possible, and of a suitable fineness. It is here that so many workers fail when they try to make their clay more siliceous by the addition of sand or flint, for unless the free silica so added will pass through a sieve of at least 100 meshes per linear inch, it will not be sufficiently finely divided to decompose the salt. As pure silica does not 'salt' easily or perfectly, it is necessary to avoid an excess of this substance—too much is almost as bad as too little.

Apparently the proportion of alumina and silica may vary very considerably and yet the clay be able to take a good salt glaze, but so far as experiments have been made, it would seem that for every 100 parts of alumina contained in a clay, there must be not less than 270 and not more than 750 parts of silica.

The exact nature of the reaction which takes place between the salt and clay is not absolutely known: moisture appears to be necessary, hence damp salt is used. But this is by no means always the case, though most authorities maintain that the action takes place directly between the free silica of the clay and the salt with the production of sodium silicate and hydrochloric acid.

The salt is added through openings in the kiln in such a way that it does not fall directly on the goods themselves, the precise point at which it should be added being left in most cases to the kiln-man's own judgment. The result is that some men salt too early, and others hesitate until it is too late. Others rely on the colour of the goods or on the examination of 'trials' drawn from the kilns. The most satisfactory way is to heat the goods to the point of incipient vitrification. This point must be determined by an expert once and for all, for the particular clay used; it is the maximum point to which the clay can be heated without change of shape. This temperature having been determined, it is then easy, by means of Seger Cones to raise the temperature of the kiln to this point, usually about 1290° C. or Cone 8, and then to apply the first dose of salt. As the addition of the salt lowers the temperature very considerably (often as much as 200° to 300° C.), it is desirable to add the salt in at least two or three portions, at intervals of twenty minutes, in order to allow of the temperature being maintained at the proper point. The nature of the atmosphere is important; for light bright-glazed goods it should be oxidizing, with a plentiful supply of air to the fuel, but if dark goods are required, a reducing fire, with as little air supply as possible, must be used. It should, however, be remembered that a reducing fire will not give such clean-looking goods as an oxidizing one, and that unless great care be taken, carbon or soot particles may be deposited on the goods and cannot be afterwards removed. As a general rule the burning fuel will supply sufficient moisture for the glazing to take place; if it does not, the salt may be damped. It must not, however, be so moist as to stick together, or it will not be evenly distributed throughout the kiln. 'Tears' are consequently formed where an excess of salt has accumulated.

The amount of salt required varies with the manner in which it is applied and with the setting of the goods. It will generally be found that from 10 to 20 ozs. per cubic foot of goods is necessary.

It is also important to remember that the salt acts on the walls of the kiln as well as on the goods, and that this is especially the case where the kilns are built of bricks containing plenty of free silica; whenever possible the bricks should be made of clay rich in alumina, mixed with bauxite, if necessary, to render it sufficiently refractory.

Irregularities in colour are commonly attributed to the loss of heat due to the salt. This is seldom correct: it is the faulty heating after the addition of the salt that is chiefly responsible for piebald goods.

Opinions differ as to the length of time the heating should be continued after the addition of the salt; equally good results can apparently be obtained by continuing the firing for eight, ten, or twelve hours, provided that the temperature is not allowed to fall. Provided that the glaze has had sufficient time to form properly, so that the reaction between the salt and clay is complete, any additional firing is simply a waste of fuel and time, and may even produce crystallisation of the glaze.

The cooling of salt-glazed ware should be as rapid as possible consistently with the safety of the goods, as slow cooling, especially at first, tends to a dulling of the glaze and often to crystallisation. Prolonged soaking of the kiln after the final batch of salt has been added is, for a similar reason, undesirable.

It is necessary to have a sufficient draught through the kiln to cause the uniform dispersion of the salt particles as soon as they have decrepitated, this decrepitation being one of the most useful properties of salt, and greatly facilitating its use as compared with that of other soda compounds.

Salt-glazed ware may be coloured by painting with colours which form fusible compounds with the glaze itself, but which are, of themselves, infusible at the temperature of the kiln; it is, however, essential in this case that a fully oxidizing atmosphere be preserved in the kilns or the dark colour of the salt glaze will spoil that of the other colours.

In **flowing**, the goods are decorated with a material capable of forming an easily volatile chloride, and are then heated in a sagger containing a small vessel of chloride of lime, or one of the numerous other 'flowing powders' now on the market. The chlorinated atmosphere which thus surrounds the decorated article converts the colouring material into the chloride which is again decomposed by the silica of the clay, so that the colouring matter is 'condensed' on the previously white portion of the ware. A pretty shaded effect is thus produced. The chief oxides used for this kind of decoration are those of cobalt (blue), copper (green), nickel (brown), and iron (yellow), the last not being, however, very satisfactory.

In some cases the whole of the glaze is volatile, and is simply placed in cups in the saggers, the vapours being decomposed by the silica of the clay. Though only a slight glaze ('smear') is produced in this way the method is well adapted for work in very delicate relief, where it is especially important that the cavities shall not be filled with an excess of glaze. In both this and the foregoing case it is necessary that the saggers should be well luted in order that the vapours may not escape before they have done their work.

Whatever be the manner in which the goods are coated, whether with an engobe of clay or of glaze, it is necessary that the room in which the operation is performed should be as free from dust as possible, and, to prevent confusion in the placing of goods in the kilns, it is advisable to keep each colour separate, and even to stain the materials with a little aniline dye. This will burn off in the kiln, but its use is invaluable in preventing goods being accidentally placed in a wrong part of the kiln.

It is also very necessary to keep the engobe and glaze materials free from all kinds of oil or fatty matters, including sweat.

Finally, for rapid and efficient working it is necessary to have plenty of shelf or stillage room on which to dry and store the goods before they are sent to the kilns, and to insist that the goods are despatched to the latter in proper order, after all unnecessary drops and splashes of glaze or engobe have been removed.

Vitrified Ware, which has a more or less glossy surface, is produced by mixing various fluxes with the clay of which the goods are made, with the result that the glaze, instead of being confined to the surface, is distributed throughout the whole thickness of the ware. Attempts have also been made to utilise the tendency of soluble salts to rise to the surface of the goods during drying in order to glaze them; thus soda and potash salts have been mixed with the clay and have been more or less completely carried to the surface on drying, but in the kilns the material still left in the body of the ware often causes it to lose its shape, or the surface glaze is so uneven as to be practically useless.

CHAPTER VII

SETTING OR CHARGING.

METHODS of setting or charging goods into the kiln vary with the nature of the goods themselves, but are roughly divisible into three classes:—

(*a*) Setting direct in the kiln itself (bricks and unvitrifiable ware).

(*b*) Setting in cupboards built of quarls, quarries, or slabs.

(*c*) Setting in saggers or fireclay boxes erected in piles with a roll of clay between each sagger. This method is chiefly used when the goods would be spoiled by the direct action of the flame, and when it is not desirable to fire them in a muffle kiln.

A description of each method of setting would be out of place here, but the following points should have constant attention:—

(1) As many goods as possible should be put into the kiln so as to secure economy of fuel, but, on the other hand, if the goods are unduly crowded (and in particular if they are coloured) some of them will be spoiled. When kilns are set on piecework there is a great likelihood of their being incompletely filled.

(2) When various sizes and shapes of goods or saggers are set, care should be taken that they are well and solidly built together, as the expansion on heating causes movement amongst the goods and this is increased by the contraction of the clay, so that unless skilfully set they may easily fall and suffer damage.

(3) Although damp goods should never be placed in a kiln, yet if this rule be broken in special circumstances, they should be placed in such positions that they cannot harm other goods. For this reason they should be set where they will be heated last of all the goods in the kiln, so that the steam they evolve may not condense on other and cooler goods.

(4) Glazed goods, when not burnt in saggers or in muffle kilns, should be so placed that their glazed faces are together and are protected as much as possible from direct contact with the

flame. Under no circumstances may glazed surfaces be placed opposite to unglazed ones or the former will be spoiled.

(5) For glazed goods, the inside of the saggers or the muffle should be covered with a coat of glaze (waste glaze will do), as otherwise the beauty of the glaze on the goods will be spoiled.

(6) Coloured glazes must be placed according to their composition, as a slight variation in the heat will often make a considerable difference in the colour. The best positions can only be found by trial, but, as a general rule, the lighter and more delicate the shade the more moderate the heat which will be required. At the same time it is not wise to place coloured goods too near the walls of the kiln, as crazing and chilling are thereby facilitated.

(7) In brick setting great care must be taken to leave sufficient spaces between the bricks to secure a good draught, and at the same time these spaces must be carefully regulated so as to obtain as even a draught as possible in the different parts of the kiln. "Finger-room" is correct, but rather vague; two stretchers to five headers is much more accurate.

It is best to put a double row of headers on the bottom of the kiln (fig. 3) so as to ensure sufficient draught. If the bricks are sufficiently well made they may be set in this way throughout, otherwise headers and stretchers must be set alternately one above the other. Towards the top of the fire-screen the bricks may be set rather closer, so as to secure sufficient heat at the top of the kiln.

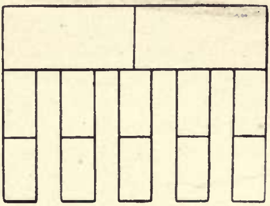


Fig. 3.

In order to ensure the fireboxes being directly under the fireholes in a continuous kiln, a lath of 1–4½ inches diameter may be passed into the kiln through each fire-hole to act as a guide to the setters. Laths for setting the bricks horizontally are also desirable in the absence of really skilled setters ('placers').

If the bricks are to be glazed later, their faces must be set together so as to prevent damage by exposure to the flame. Where difficulty is experienced in getting sufficient top-heat in a continuous kiln, Niendorf's plates may be used. These are small tiles placed vertically in the fuel shafts in such a way that they may be knocked level one after the other as the different parts of the kiln get sufficiently heated, and in this way raise the fuel in the shafts.

(8) Careless handling of the goods by the placers is a source of

great loss in some factories, especially in brickworks. The greatest care should be taken to keep the arrises clear when setting or they will be chipped, and the bricks spoiled for best work. The workman should use a board wrapped with several thicknesses of cloth or felt when standing on the bricks, so that his boots do not damage them.

(9) A careful record of all goods placed in each kiln should be kept, and used as a check when the goods are discharged.

(10) Great care is needed in setting certain classes of goods that the glazed portions do not adhere to the sagger or to other parts of the kiln. The saggers or cupboards should be well sprinkled with flint or quartzose sand, and a little of this material may at times be suitably placed on the goods themselves to prevent adhesion. In supporting articles by means of clay cubes or stilts, etc., attention should be paid as to where the marks formed by these supports will appear; carelessness in fixing these supports should on no account be tolerated.

CHAPTER VIII.

KILNS.

The construction of kilns is a subject which, like so many others, must be left largely in the hands of experts. At the same time the subject is one of the most important the clay-worker has to deal with, for, if his goods go wrong in the kiln, no amount of care afterwards will remedy the damage.

Many kilns are correctly constructed, but fail in actual use because their construction is not sufficiently understood by those using them. A kiln may, for instance, have too much draught, and so cause the heat to pass so rapidly through the flues that parts of the kiln never become properly heated until the speed is checked by the use of a damper or some other means of partially closing the flues. On the other hand, a flue is sometimes partially closed by the builder in such a manner that it may be opened out if more draught is found to be necessary; but unless this is known, the kiln may be condemned as useless owing to it not heating up properly.

The first thing, then, is to know the construction of the kiln, and by this is meant a practical knowledge as well as a theoretical one derived from books or from studying the builder's plans. Only in this way can serious losses be avoided when the kilns are not working quite satisfactorily, or when some part breaks down. In addition to this, a good knowledge of the construction of the kilns in use will not only enable the proprietor to realise the full value of the maxim that a stitch in time saves nine, but will often be the means of suggesting minor improvements in construction which, although small in themselves, are frequently the means of saving considerable sums of money in the course of time. Thus the saving of half a ton of coal a day represents a man's full wages at the end of the week.

The first consideration in erecting a kiln is the selection of the site, for if this is wrongly chosen it may be impossible to obtain good results from the firing. The prospective kiln-builder must watch carefully to see where the water runs and stands after rain, and must choose the dryest spot. If the kiln is in the vicinity of a river or of underground springs, it is necessary to ensure that these shall have no effect on the foundations. It is, in fact, essential that the kiln bottom be kept dry, and it must be well drained so as to remain so even in the wettest weather. More than one yard has failed as a commercial success for want of attention to this matter.

The depth to which a foundation must be taken to ensure dryness of the kiln floor depends, to a large extent, on the nature of the ground, but is usually much greater than is generally supposed ; and Bock states, as the result of a very long experience, that no kiln should be built on ground in which the water stands at a less depth than six feet in the subsoil, and, where floods are likely to arise, the floor should be raised above ground level and arrangements made for draining beneath the kiln. This matter of raised floors is also important in connection with kilns built near to the banks of a tidal river. Of the various materials used for rendering the floor of the kiln damp-proof, asphalt or bitumen is undesirable because it is affected by the heat, and concrete, although excellent when new, is apt to crack and is then useless. A simple yet effective foundation consists of a layer of moderate sized stones about 18 inches deep, well drained with pipes and covered with a layer of gravel, over which a bed of clay or loam is well rammed into place. A bed of sand may be added if desired, and the whole paved with hard-fired bricks. Where the ground is very wet properly built flues should take the place of the stones, these flues being connected so as to drain from one channel. Small wooden chimneys are also added in some cases to secure the proper ventilation of these flues, but if the chimney draught is strong enough the flues may be more conveniently connected to the chimney-stack.

Again, the outside masonry is often too thin, and the various dampers and caps fit so badly as to be almost useless. Such defects have all to be paid for by an excessive fuel consumption.

The strength of the arches is a matter often needing special care, for it must be remembered that the masonry must not only be sufficiently refractory to withstand the high temperatures, but must also be possessed of such resisting power that it can bear the strains set up by the continual expansion and contraction. Flattened arches are, therefore, to be avoided, as are also those with a very pronounced point. In almost every case the true semicircle is the best form of arch.

A good roof for protection from snow, rain, etc., is beneficial for permanent kilns, and their life will be increased, and the quality of the goods often improved, by extending the roof for some distance around, so as to keep the approaches to the kiln dry. Above all, care must be taken that the water draining from the roof is properly removed; it must on no account be allowed to soak into the masonry of the kiln. If goods are to be dried under this roof, some provision must be made for as much as possible of the heat of the kiln to be retained.

The dampers leading to the chimney flues require care to keep them air-tight. In the case of kilns of the Hoffmann type, this is best accomplished by having deep double rims and caps fitting into sand placed between them, so as to act after the manner of a water-seal, the sand taking the place of the water.

The collecting flue of a kiln should be sufficiently roomy for an ordinary man to easily get inside it for cleaning purposes, and should be provided with so many openings that, no matter which part of the kiln is under fire, the flues may be entered in the cooler parts direct from one of these manholes. The covers for these manholes must, of course, be kept air-tight—usually by means of sand, and a second cover often of wood.

The construction of the 'smoking apparatus' requires care; the walls are frequently far too thin, and the connection to the kiln is often badly made.

Chimneys are often too slightly built, and so lose heat and draught-producing power. Lined chimneys have a great advantage in this respect.

The second point to be considered is the nature of the goods to be fired. This influences the construction of the kiln in several ways, chiefly in regard to (*a*) the method of heating—whether the goods may be mixed with fuel or not, or if they must be completely protected by saggers or muffles; (*b*) the temperature to be reached, and its influence on the nature of the fuel and on the materials used in the construction of the kiln; (*c*) where two or more methods may be used, it is important to choose the one which will cost least in setting and discharging, and in fuel and in labour of firing.

In regard to the fuel but little need be said, as coal is almost exclusively used in this country, though producer-gas of various kinds may be used in certain cases, and the use of electricity has already met with some success. The solid fuel may be charged into special fireboxes or into flues left in setting the goods, and, in the case of some kinds of bricks, a certain proportion of sifted cinders ('breeze') is worked in with the clay so that the fire, once started, will continue burning, each brick forming a kind of fireball, and supplying the fuel necessary for its own baking. When coal is used, it should be kept under cover as much as possible, as this not only prevents a considerable waste of heat used in drying the coal, but prevents its disintegration to a large extent, so that it burns better and clearer than when it has been exposed to inclement weather. This is especially true of small coal. For further information on fuel, see page 41.

In considering the different ways in which the heat from the burning fuel may be applied, it is first necessary to decide whether the goods will be injuriously affected by the flame: if so, they must be protected by placing them in fireclay boxes called 'saggers,' or the kiln must have a protective lining or 'muffle' to prevent the flame obtaining access to the goods. Sometimes sufficient protection may be afforded by a special method of setting, as in the case of glazed bricks, which are so placed in the kiln that only the unglazed portions can possibly be attacked by the flame.

Although, from an academic standpoint, it would be more convenient to classify kilns according as the goods are directly or indirectly heated by the fuel, there is in practice no hard and fast line, and it is therefore more convenient to regard kilns as 'intermittent' or 'continuous'—the former term being applied to those which are lit, heated to the finishing point and are then allowed to cool completely before being emptied; and the latter being used for what is really a series of 'intermittent' kilns all connected in such a manner that, although some portions are at the full heat, others are heating, cooling, being filled or discharged, yet the fire is never allowed to go out from every part of the kiln.

Intermittent kilns are of three main types :—

(*a*) Top-draught, or Up-draught.
(*b*) Down-draught.
(*c*) Horizontal draught.

Up-draught Kilns are, on the whole, wasteful of fuel; the latter having but a short distance to travel before it reaches the goods, the flame is unduly cooled and smoke and incomplete combustion-products result. The fuel should have a sufficient space for a perfect flame to be formed before it comes in contact with anything to be heated, and this is more satisfactorily accomplished in a down-draught kiln on account of the greater distance the flame is able to travel.

In the down-draught kiln, also, the products of combustion have more opportunity of mixing with each other and so producing a more uniform heat than is possible in an up-draught kiln, and there is less tendency for the goods to be heated to a greater temperature at one part of the kiln than they are at another, a common fault of the up-draught type in which the bottom goods are almost always over-heated. Also, as they have to bear the weight of the goods above them, they are particularly liable to become twisted or crushed. 'Flashing' of the goods by the flame impinging directly on them is also much more serious in up-draught kilns. In spite of these disadvantages most of the earthenware made in this country is still fired in up-draught kilns, which have the advantage of simplicity of construction, are easy to repair, and, with sufficient care in placing the goods so as to suit the different heats in various portions of the kiln, give satisfactory results. By the nature of his trade the English potter is very loth to make changes in the construction of his kilns, and this, probably more than the question of efficiency, causes him to still use the up-draught kiln. There are a number of varieties of up-draught kiln, *e.g.* the 'Hovel,' in which the kiln proper stands inside a large cupola with just sufficient space left between them for the fireman to wheel his fuel and to stoke. The object of the cupola or hovel is to protect the kiln-mouths from the wind and outside air-currents, and it is very effective in this way; but the space for firing is usually so small that the fireman is much exposed, and, owing to the use of so small a chimney, the draught is often poor. A modified up-draught kiln, known as the 'Skeleton' oven, has become exceedingly popular of recent years, being simple in working, easy to repair, clean, and giving satisfactory results. The principle on which it is constructed is that of a stack supported round the oven proper by a series of arches, leaving between the shell or arches and the oven proper a space of 3 to 7 inches. Hence the lowest 3 feet of the oven and outside brickwork (*i.e.* up to the top of the mouths) are built solidly together, but above this point the oven proper is quite out of contact with the shell. The most suitable size for such a kiln is 18 feet for biscuit, and 14 feet 6 inches for glost ware (inside measurement). A kiln of this kind is very fully described by Sandemann in *The Manufacture of Earthenware.*

Down-draught Kilns have now largely superseded those with an up-draught for general purposes; apart from pottery proper and even for earthenware they have come largely into use for biscuit. Their chief advantages lie in the production of a more evenly distributed temperature and a greater economy of fuel. Down-draught kilns may be divided into four main classes, viz.:—

Rectangular kilns.
Round kilns.
Round kilns with an upper chamber; and
Round kilns with a lower chamber.

Rectangular Kilns.—The rectangular kiln consists of a rectangular chamber with fireplaces in the two sides and a false or perforated bottom connected to one or more chimneys. The doors for filling and discharging the kiln are placed at each end. These kilns are chiefly used for articles of rectangular shape which do not pack so conveniently into round kilns, but their use for pipes and other circular objects is increasing. The arrangement of chimney flues may be made as in round kilns with such alterations as are necessary to the difference in shape.

Round Kilns.—Circular down-draught kilns are now constructed of many patterns, but the main principle, that of allowing the flame and hot gases to first travel to the top of the kiln and then to be drawn down and away at the bottom, is the same in all. Strictly speaking, they should be termed 'up- and down-draught,' as the heat has a strong upward direction before it descends. It is this great length of travel which causes the efficiency of this kiln in the matter of fuel, and also helps very considerably in the production of a uniform temperature, as the air necessary for combustion becomes thoroughly mixed with the gases before they come into contact with the goods. A minor point is that the most strongly heated goods are at the top of the kiln, where, having no other goods placed above them, they are better able to retain their shape than in an up-draught kiln where the greatest heat is near the base. The placing of the goods in the kiln requires some care in order that the flame may not go direct to the flue without first passing round the goods. The number of openings in the false bottom of the kiln depends on the class of goods made: salt-glazed articles require a large number of relatively small openings, whilst for other goods the openings may be fewer and larger. These kilns vary in diameter from 11 to 26 feet, and in height from 6 feet (for salt glazing) to 23 feet. The medium sizes give the best results, but large kilns are more economical in fuel.

Additional chambers to the kilns are frequently added with a view to greater economy in fuel, and may be placed either above or below the original chamber. The heat they receive is, naturally, not so intense as that in the first chamber, but when suitable connecting flues are made it is more than sufficient for biscuiting the clay. Where a two-storeyed kiln is undesirable the two chambers may be built side by side, although there will be less economy of heat and fuel. A good pattern of down-draught kiln for bricks is fully described in Brown's *Hand-brickmaking.*

Horizontal Kilns are characterised by the use of a single fireplace, or (what is equivalent) are placed at one end of a rectangular chamber through which the gases are led, more or less horizontally, to the chimney. In this type of kiln, which is greatly used in the North of England, the floor may be solid or furnished with a perforated (false) bottom through which the gases may ascend or descend according to the design of the kiln. For firebrick-burning a solid bottom is most commonly used, the three openings to the chimney flue being placed near the floor at the back of the kiln. The goods are then placed so that the gases travel slowly round them in a horizontal direction and are gradually drawn downwards to these openings. If the setting of the kiln is properly carried out there should be no difficulty in getting the temperature evenly distributed, especially if sufficient loose bricks are left in the front wall of the kiln and are removed as the firing approaches the finishing-point so as to prevent the front tiers of goods being overheated. This class of kiln is far from economical, but, unless of great length, has the advantage of a particularly even distribution of temperature combined with a moderate first cost. It can, however, only be used for such goods as can be placed in the kiln in such a way as to secure an even distribution of the combustion gases, and its use must, therefore, be chiefly confined to the production of certain classes of bricks, tiles, and quarries. There seems to be no good reason why two or more such kilns should not be connected so that the hot gas from one might be utilised for heating the others; but experiments made in this direction do not appear to have been successful, although in single kilns of this type it is by no means uncommon to see flame in the flue at a distance of sixty feet and more from the kiln.

Continuous Kilns.—With the pursuit for economy in firing came the invention of the continuous kiln, in which a number of chambers are so connected to a system of flues that the heat from any one of them may be conveyed to the rest or not at pleasure. Hence it is possible to so work the kiln that various stages of the firing may be proceeding in different chambers at the same time.

The first kiln built on this principle was the famous 'Ringofen' designed by Hoffmann, and copies of this, more or less modified, are largely in use at the present time for the manufacture of terra-cotta, bricks, and roofing- or paving-tiles, as well as for the calcining of limestone and similar minerals. Since its first introduction, in 1856, many modifications have been made, and the number of varieties of Hoffmann kilns now in use is very large, but the underlying principle in all is to have a more or less ring-shaped tunnel in which the goods are set, the firing being so arranged that whilst part of the kiln is being fired, other parts may be filled or discharged, the kiln being divided up into a number of chambers by means of movable partitions.

In its most compact form the kiln is quite circular, but in the case of large kilns two parallel walls are terminated at each end by semicircular ones. Thus a 12-chamber kiln is usually circular, but with a greater number of chambers the diameter of the kiln remains the same while its 'length' is increased. Providing the ground will allow of it there does not appear to be any limit to the length to which such a kiln may be extended; but very long kilns, when used for clays which may be burned rapidly, are usually worked as though they formed two or more independent kilns. The capacity of the main chimney and its drawing power are the chief factors controlling the length of a continuous kiln.

Reduced to its simplest dimensions, the Hoffmann kiln may be represented as in figs. 4 and 5.

The kiln proper consists of a circular tunnel of any suitable section, which receives the goods to be fired through doors placed in the circumference or outside wall, and built up in the firing. The fuel is fed through apertures in the roof of the tunnel. Flues lead from the tunnel to the 'smoke collector,' which surrounds the base of the central chimney, the communication with which can be cut off by means of bell-shaped cast-iron covers. These flues may be at the base or near the top of the tunnel, according as the kiln is worked with an up- or down-draught. Immediately behind each flue a suitable opening is made for the insertion of a damper-plate, which forms, when in position, a complete partition across the kiln and so prevents the leakage of air or hot gases. As metal dampers are not perfect in this respect many firms now employ so-called 'paper shutters,' or large sheets of a specially made paper which are pasted on the inside of the kiln during the setting and are later burned down by contact with the travelling fire. These paper shutters do away with one of the great sources of air leakage, viz., through the damper-slots, and, although apparently expensive in maintenance, rapidly repay themselves in the amount of fuel saved. The paper used is a kind of coarse tissue-paper which is light and tough.

The fuel falls through vertical columns arranged by the setters in filling the kiln, and some skill is required in so arranging the goods that these columns, with their radiating channels, shall be properly constructed, for on this the success of the firing depends to a large extent. It is usually wise to fix 'setting laths' vertically in the kiln through the fire-holes, and to instruct the setters to use these as guides in the placing of the goods. The laths are removed through the fire-holes when the chamber is full.

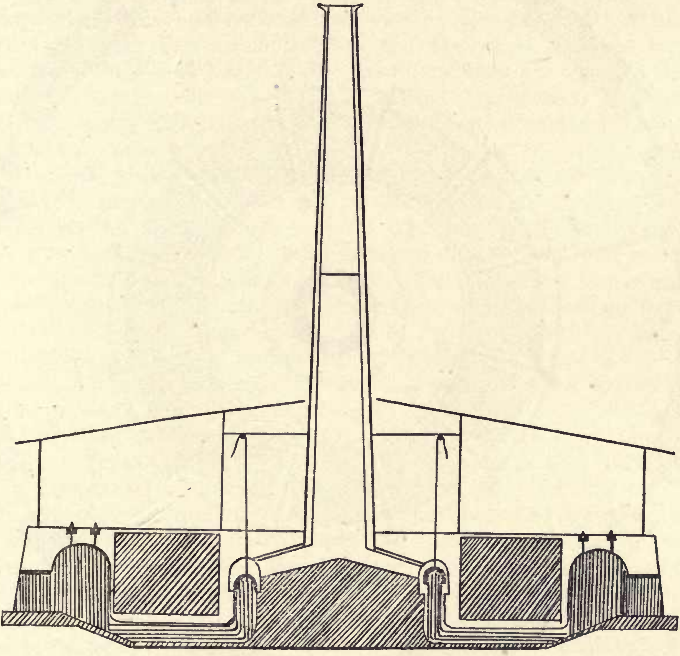


FIG. 4.—Vertical Section of Hoffmann Kiln.

The number of chambers in a kiln is, theoretically, of no importance, although in practice it should bear a definite relation to the time required for warming and burning the clay and to the desired output. If too many chambers are used the goods will be too long in the slow firing, whilst if too few chambers are employed (*i.e.* if the kiln is too short) sound goods cannot be obtained. It is essential that all the chambers should be in use, if the fullest economy of fuel is to be reached. Twelve chambers is a convenient number for most brickyards. Referring to fig. 5, it will be observed that all the chambers (numbered 1 to 12) are connected to each other by a free passage, but that a damper across the kiln prevents any passage between No. 11 and No. 12. Assuming that the kiln is in full operation, the doors in chambers

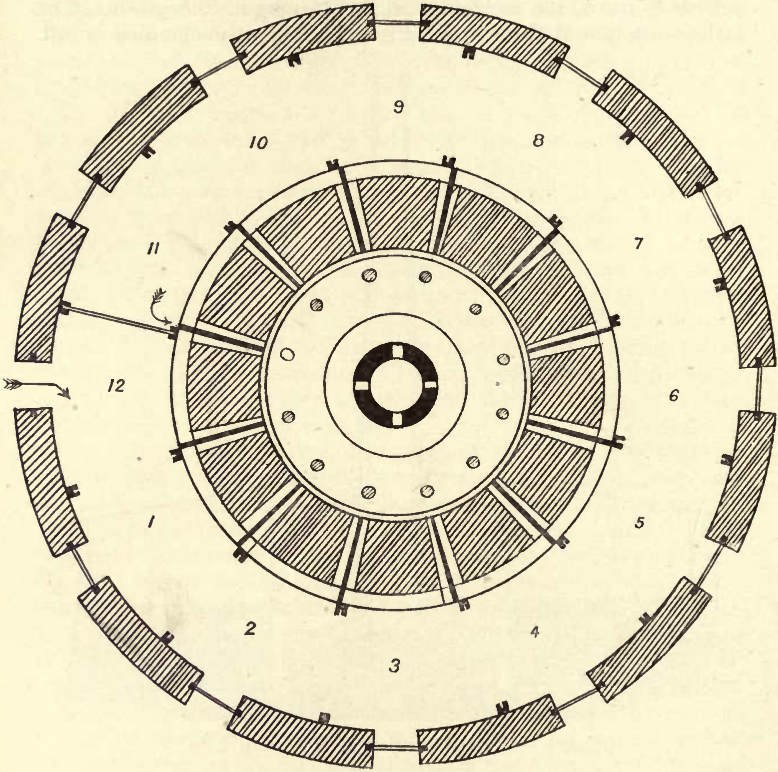


FIG. 5.—Plan of Hoffmann Kiln.

1 and 2 being open, No. 1 will serve for filling with the fresh goods and No. 2 for taking out those already burned. The chambers 3, 4, 5, and 6, which are already filled with burnt goods, are gradually cooling with the air which enters through the doors of 1 and 2, and this air as it passes on becomes warmer and warmer until at last it is as hot as the glowing ware, and conse-

quently the fires in the kiln are supplied with air almost as hot as the furnace itself.

In chamber No. 7 the fire is burning, and when its contents have reached the desired temperature those of No. 8 will have become so heated by the waste heat from No. 7 that the fuel fed into No. 8 after No. 7 is finished becomes instantly ignited. Chambers Nos. 9, 10, 11, and 12 will be dried off by the waste heat which passes through them, and the damper in No. 12 will turn the gases into the chimney through the small flue at a temperature only just sufficient to support the draught. When No. 1 chamber is filled and closed the damper is removed and placed between Nos. 1 and 2, the bell-shaped damper over No. 12 being lowered and the one over No. 1 lifted and lowered between Nos. 1 and 2. The contents of No. 3 will then become sufficiently cool to be drawn.

In some places a modification of this process of firing is employed, the air from the hot goods being used to dry those freshly set into the kiln and to warm them sufficiently to prevent any condensation products forming upon them when they come into contact with the burning gases. This is a very important matter with clays liable to scum from this cause, but some degree of loss of heat is experienced. This arrangement also offers additional facilities for lengthening or shortening the fire-space, as by the additional flues required the flue-gases may be led from almost any one chamber to any other.

When the 'flue-gases' are used to dry the freshly-set goods, there is a great danger of the sulphur compounds they contain being condensed on the cold, damp goods and so scumming them with a deposit of sulphates. This may be prevented by using a 'stove' in which air is heated before it enters the kiln, and the gases from the fuel in the main burning zone of the kiln are not used until the goods have become so heated that there is little or no danger of condensation occurring. The preliminary drying and warming generally referred to in this book as 'smoking' or 'smouldering' is sometimes known as 'stoving' from the use of this supplementary stove or air-heater (p. 181).

The use of a stove requires careful attention, or the difficulty of scumming will not be removed. The usual fault consists in allowing the stove to burn too low or not brightly enough; the amount of air heated is then very small, and as the products of combustion from the stove are mixed with the air used for drying, these very products may, if too concentrated, occasion the defect which the stove is expressly intended to avoid.

Many improvements have been suggested at one time or another, but up to the present the Hoffmann kiln in this country remains practically unaltered from its original form. At the same time it must be admitted that for some purposes an alteration is desirable, and in others the diminished cost of construction is sufficient to make the modification of the standard type well worth consideration. For example, Otto Bock has patented what is practically a Hoffmann kiln, the walls of which are of earth, the kiln being constructed by excavating out the main part of the kiln—the large circle or 'ring' which holds the goods—and building in the necessary flues in the central piece of ground. This kiln has, therefore, the top of its walls level with the ground, and in this way a considerable amount of heat, which would otherwise be lost by radiation, is preserved. The Bock kiln also differs from most other kilns in having no permanent roof, the 'roof' being composed of a layer of clay and another of sand or soil about 4 inches thick. To fill the kiln, the goods are slid down boards from the ground level to the men inside the kiln.

The *Zig-zag* kiln is another modification of the Hoffmann kiln, designed to avoid the great length of ground required by the original 'long' form brought out by Hoffmann, in 1870, as an improvement of the earlier circular form. In the Zig-zag kiln the main part forming the chambers is turned repeatedly on itself, as its name implies, so that the goods are loaded in through the ends instead of through the sides of the chamber. The Zig-zag is also one of the numerous varieties having permanent walls to divide the kiln up into a fixed number of chambers. It is specially used for small kilns where the ground is limited.

In order to overcome the difficulty of some of the goods (bricks) being damaged by the ashes from the fuel falling on them, permanent walls or fireboxes are sometimes erected. These undoubtedly serve the purpose, but at a considerable loss of economy in fuel. Still, for many classes of goods their use is quite unavoidable. In addition to this, the horizontal direction of the flame tends to prevent its proper and even distribution through each chamber. The simplest of these 'continuous chamber kilns' is obtained by building permanent 'flues' for the fuel to fall into when fired, as in the ordinary Hoffmann kiln; but this not being altogether satisfactory, it is more usual to build a complete partition to form each chamber, and to provide close to this a firebox or row of fireboxes to contain the fuel. It is advisable to leave plenty of holes in the lower part of the partition for the gases from the previous chamber to pass into the firebox of the succeeding one. These fireboxes then impart a strong upward tendency to the stream of gases which, being drawn from near the bottom of each chamber, has a much better chance of being diffused throughout the entire space than when the direction of the gases is more horizontal. In some forms of this class of kiln the bottom is perforated, and the gases passing through it are led to the firebox of the next kiln after having been mixed with a certain proportion of fresh (heated) air in order to maintain proper combustion.

One of the greatest advances in the construction of continuous kilns is that known as the *Staffordshire* kiln, patented by Dean and Hetherington. This must not be confused with the ordinary pottery kiln used in North Staffordshire, although such mistake is natural, considering the unfortunate title of the new kiln.

The means of supplying hot and cold air to different parts of the kiln are much more complete than in any kiln yet built, and, as only one face of fire is used in each chamber, this kiln is capable, under good management, of giving results equal to the best down-draught kilns with coal consumption as small as in continuous kilns. This is brought about by the combination, in a continuous kiln, of damper-controlled passages leading from the outer air to flues under the fire-grates in the bottom of the kiln in each chamber, as shown in the illustration, and of similar flues leading from the hot-air flues and from the outer air in such a way that, by appropriate connections, air of any desired temperature and in any desired volume may be admitted to any part of the kiln. The ordinary difficulties experienced in connection with warped dampers are also to a large extent eliminated by their position and shape.

By suitably working the dampers the following results may be obtained :—

(*a*) By opening dampers 11 and 18 the whole or part of the hot air from the finished or cooling chambers may be admitted to the chambers containing the freshly-set goods, and the steam resulting from the heating of these goods led away from the top through flues 7 and 3 to the chimney.

(*b*) By opening the dampers (16) of the flue (13) hot air from flue 5 may be led under the grates (14) to develop the highest possible temperature in the finishing chamber, or to distribute hot air uniformly from the hot-air flue (5) to a chamber containing green goods.

(*c*) The admission of cold air to a cooling chamber is kept under perfect control by means of dampers (18) and flues (17).

(*d*) The temperature of the hot air entering a hot chamber from one that is cooling may be perfectly regulated by the admission of air through flues 17 and 19.

(*e*) The volume of air admitted through the various flues allows of nice adjustment for reducing and oxidising atmospheres.

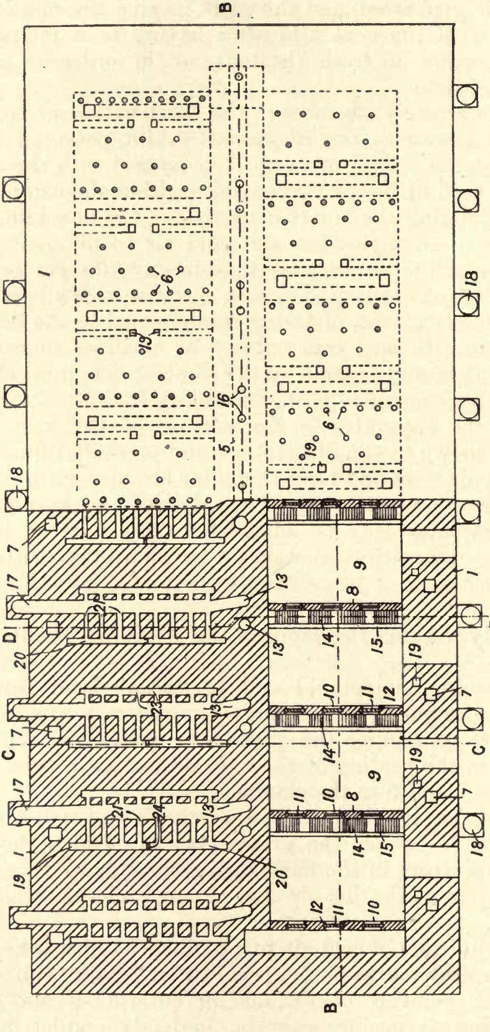


FIG. 6.—Plan of '*Staffordshire*' Kiln.

(*f*) The fire and hot gases may pass from chamber to chamber through openings (10), whilst cold air only is admitted to the under side of the grates (14) through flues (17).

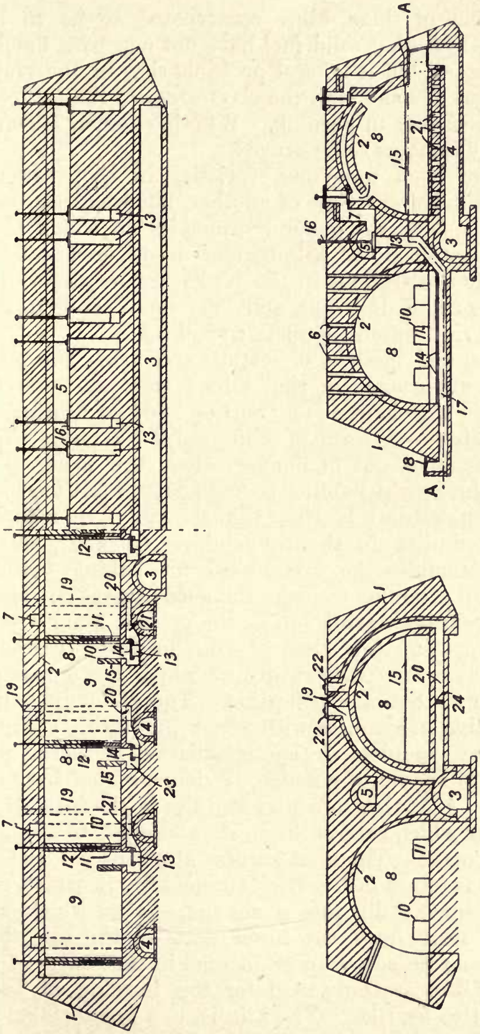


FIG. 7.—Sectional Views of '*Staffordshire*' Kiln.

(*g*) Any chamber can be completely sealed by closing all the dampers, thus allowing of good annealing. This arrangement is also of great value where the goods are liable to catch fire spontaneously.

Modifications of these kilns constructed so as to burn gas instead of coal or other solid fuel have not met with much success up to the present, but it is most probable that in the employment of producer-gas of some kind the clayworker of the future will find his greatest economy in burning. Whether much labour will be saved thereby remains to be proved.

There have been numerous varieties in shape proposed for continuous kilns at one time or another, but what has been stated will suffice to show the general principles on which they work. For details, a professional kiln-builder or designer must be consulted, for the illustrations in the books are invariably too small for use as working drawings, and very small errors in the size of the flues, etc., will often completely spoil a kiln.

The manner and method of setting and firing the goods is of the greatest importance in ring kilns; they are referred to in fuller detail in the chapters on 'Setting' and on 'Firing.'

Tunnel-kilns.—A form of kiln, useful for goods which must be rapidly removed out of danger when the firing is finished (because of their great liability to lose shape if left too long at the finishing temperature), is the 'tunnel' kiln. In many respects this kiln is similar to the tunnel-dryer (p. 134), and in some respects it resembles the ovens used for baking biscuits. For many years all attempts to make the goods travel on cars through the kilns were unsuccessful, but at the present time several firms in France are using this class of kiln for firing earths rich in felspar in which the temperature at which loss of shape occurs lies very near to that of vitrification. The chief difficulty lies in the comparative suddenness with which the heat is applied to the goods; a very complete drying installation is therefore needed, and the goods should, if possible, be delivered hot from the dryer to the kilns. A further difficulty also lies in the insulation of the waggon or car which carries the goods, and must, to a large extent, be made of metal. The most successful means yet discovered for this purpose is found in the Bock tunnel-kiln, in which projecting 'boards' of fireclay dip into a channel of sand which effectively deflects the heat from the lower parts of the car, the wheels of which run on rails in a lower channel in the centre of the kiln.

Clamp Kilns are only used for the burning of bricks and (less frequently) for tiles. The kiln is, to a great extent, built as the filling proceeds, an operation requiring considerable skill, and of which it is almost impossible to give a complete description.

Scarcely any two clamps are built exactly alike, the idiosyncrasies of the foreman as well as local conditions and customs having an important influence on the details. Usually a clamp consists of a number of walls or 'necks' 3 bricks or so thick, about 60 bricks long, and 24 to 30 bricks high. The ground on which the clamp is built is raised slightly at each side, so as to cause the bricks to lean slightly to the centre of the clamp and so form their own buttress. The centre of the clamp is practically upright, and is formed by building two 9-inch walls, about 45 feet apart, of burnt bricks laid on edge; these walls are about 4 feet 6 inches long, and 6 feet high. The ground between these walls is paved with burnt bricks on edge to keep off the moisture of the ground, and upon this paving two courses of bricks laid diagonally—about 2 inches apart for the lower course, and parallel to the ends of the clamp for the upper one. A 'live-hole' or flue is left about 7 inches wide down the centre of the whole length of the upright, and this is then filled with faggots up to the level of the second course of bricks. The whole of the surface is next covered with breeze or ashes to form a level bedding. The building of the raw bricks is then begun, these being laid on their edge and quite close. A 7-inch layer of breeze is placed over this first layer of raw bricks, the depth being increased at the ends of the uprights by padding the breeze with a few additional bricks. On this breeze is laid another row of raw bricks at right angles to those below, and covered with about 4 inches of breeze. Another course of bricks parallel to the first is now laid and covered with a 2-inch layer of breeze. This process of building is continued, the layer of breeze diminishing as the height of the clamp increases, except the top course, which has a moderately thick layer. The bricks must be carefully tied at the angles, as it is necessary to keep the upright perfectly firm. The necks or walls leaning against the upright are built in a similar manner, with the difference that they are parallel walls built alternately of headers and stretchers laid on edge, each stretcher course of one neck being opposite to a header course in the next. The clamp is completed by a casing of burnt bricks, the lower six courses being laid flat and the remainder on edge, roughly bonded together.

Live-holes must be built for every seven or eight necks, and the casing bricks are omitted when their employment would cover the holes.

The kiln is lighted by applying a coal fire to the mouths of the live-holes, and after the faggots are fully alight (which often takes twenty-four hours) the mouths of the holes are stopped up with bricks and clay.

No general rules can be laid down for the proportion of breeze required, as so much depends on the way in which the clamp is built. If too little is used, the bricks will be imperfectly burned, whilst an excess of breeze will tend to run the bricks to a slag. On this account it is desirable, in lighting a very large clamp, to begin with only a few live-holes and to light the others as the firing progresses. The time of firing varies from two to six weeks, according to the spacing of the flues.

Muffle Kilns are employed for burning glazed and other goods which it is essential should be kept entirely free from all contact with the flame or fuel. As is well known, they contain a lining of fireclay bricks which effectively keeps off all flame from the goods. The main difficulty in the construction of muffle kilns is obtaining a perfect distribution of heat around the top, sides, and bottom of the muffle, so that a regular and even heat is obtained inside it. Muffles are heated either by up-draughts or by down-draughts, the latter being preferable and more economical of fuel. As the material of the muffle has to be heated anew each time the kiln is fired, these kilns waste fuel when compared with others; but this cannot be altogether avoided. As there is only a very limited circulation of air inside the muffle, it is essential that it should be well filled with goods so that the radiation may be regular.

Muffle kilns are usually fired separately, but they may readily be coupled together so that the first may heat a second or even a third. The connected kilns are usually so arranged that glost goods are placed in the first, the waste heat from which is (if the flues are rightly constructed) sufficient to biscuit the second for most sanitary ware. For china and earthenware, the use of muffles has no particular advantage over saggers. The fires may be placed at the ends or along the sides of the kilns, the former being more economical and quite as satisfactory as the latter, and in addition they allow the kilns to be built in ranges of three and more, thus saving heat and material.

Gas-fired Kilns have been suggested in many forms, the Dunnachie and Mendheim patents being the best known in this country. When properly constructed they undoubtedly effect a saving in the cost of fuel, as a much lower grade will suffice. They are mostly worked by means of gas-generators which form a kind of producer-gas rich in carbon monoxide, but with a shorter flame than that from coal-gas. Regenerators are, therefore, used to reinforce the heating power and carry it further. The advantages of a gaseous over a solid fuel consist chiefly in the greater ease in regulating the heat, the greater cleanliness of the goods when fired in an open kiln, and the reduced labour, owing to the much smaller amount of clinker and ashes which are produced when coal is used in a producer as compared with an ordinary fire. Unfortunately, the majority of the gas-fired kilns which have been placed on the market have not been satisfactory in regard to the first of these conditions, especially in the larger sizes, although the Dunnachie kilns have proved excellent for many classes of work. As is to be expected, the most successful gas-fired kilns are all connected in series, so that the waste heat from one may be used by another.

Gas-kilns are specially suitable for heating in a reducing atmosphere, which is much more easily obtained with a kiln of this description than an oxidizing atmosphere, which necessarily requires more air.

On the whole, gas-fired kilns cannot be safely recommended to firms with a small capital; but larger ones will often be able to effect a considerable economy by their use, although at the cost of much experiment and labour in the earlier stages.

The Output of Kilns is a matter of very considerable importance in these days of great competition, and the question of how the output of a kiln can be increased is one which is occupying the minds of many clayworkers at the present time.

The output of single kilns cannot, as a rule, be increased to any notable extent, but with continuous kilns there is considerable possibility of this being done. The most direct way of doing so is to increase the rate of travel of the fire, and great progress has been made in this direction of recent years. For instance, the older kilns would not permit the fire safely to travel forward at more than 4 or 5 yards a day, but in the more recent continuous kilns a daily speed of 10 or 12 yards is by no means uncommon. This means that a modern kiln has about three times the output of an older one of similar capacity.

In many continuous kilns the capacity of the chimney is the factor which regulates the output, because, unless the chimney is large enough, it is impossible to add to the number of chambers without lessening the draught. It is a curious fact that whilst most boilers are fitted with an excessively large chimney, in most continuous kilns the opposite is the case.

A defective foundation of the kiln (easily recognisable by the arch and upper portions of the kiln becoming red before the bottom) is a frequent source of diminished output. The steam rising from a defective sole admitting damp to the bottom of the kiln occupies space in the chimney which should be occupied by flue gases, and the amount of heat required to volatilise this moistur prevents the kiln from heating as rapidly as it otherwise would do. Similarly, the capacity of a chimney is often seriously lessened by leaks in the kiln walls through which air is drawn in. This may be detected by means of a draught gauge applied to various parts of the kiln.

Wet fuel lessens the output of the kiln by taking longer to heat, partly because the water it contains has to be evaporated and partly because it lessens the speed of travel of the fire.

The efficiency of a kiln may be roughly calculated by assuming that for every inch of width of the kiln chamber (back to front) 160 bricks may be burned daily, though for some delicate clays only half this number must be used. Thus a kiln 10 feet wide (= 120 inches) may be expected to burn 120 × 160 = 19,200 bricks per day, although, with a specially delicate clay, only half this quantity (8600) may be possible.

Frit Kilns are used for melting materials for glazes, and are of well-known construction. They are mostly on the plan of a reverberatory furnace, though some are heated from below. The brickwork must be good and well laid; in other respects their construction presents no special difficulties to the potter's builder.

CHAPTER IX.

FIRING.

In many ways the firing of boilers resembles that of kilns; the reader is therefore referred to page 65 for information not contained in the present chapter.

In order that the firing may be efficiently carried out, and the kilns, or boiler, heated to the desired temperature with a minimum expenditure of fuel, it is necessary to consider the objects to be attained, and the changes undergone by the fuel in bringing these about.

Air Supply.—Taking coal as a typical fuel, the first change which it undergoes in burning is decomposition into a large volume of gas and a mass of practically non-flaming coke. The gas so produced will, in presence of sufficient air, take fire and burn with a brightly luminous or with a blue non-luminous flame, according to the proportion of air which has become mixed with it. The luminous flame is not possessed of such great heating powers as the blue flame, owing to its admixture with numerous particles of unburnt carbonaceous matter (soot) which are deposited on any cooler object which comes in contact with the flame.

Carbon on burning may form one of two compounds with the oxygen of the air—namely, carbon monoxide and carbon dioxide; but the greatest heat is only produced when the dioxide is formed, hence it is the object of the fireman to secure as plentiful a supply of air to the fuel as possible, at the same time avoiding such an excess as would waste heat by cooling the flame. As solid carbon when completely burned requires nearly three times its weight of pure oxygen, or twelve times its weight and 13,000 times its volume of air, it will be readily understood how large a volume of air is necessary for an ordinary fire. Yet seldom anything like this quantity of air is supplied to the fuel. As the gas is set free somewhat suddenly soon after the fuel is charged into the furnace, it follows that the greater part of this large volume of air will be required very shortly after the addition of fresh coal; and as the effective combustion of the gas depends upon each particle coming in contact with particles of air, it is equally clearly necessary that the air and gas must be well mixed before combustion can effectively take place. In the ordinary furnace it is not possible to mix the air and fuel-gas as intimately as might be desired, as they cannot be sufficiently long in contact with each other for diffusion to take place completely; hence the advisability of dividing the air supply into as many fine jets as possible. This may be accomplished in a manner suggested many years ago by C. W. Williams, viz., by boring numerous holes of about half an inch diameter in the door and front of the furnace, the total area of these holes being not less than half the area of the grate. If too many holes are bored, it is easy to close some by an iron plate; but in practice it will seldom be found necessary to do this, as if the firehole has a cross-section of a foot, and the firebox holds a cwt. of coal, the air needed for its combustion would form a column of the same area as the firehole and one mile long! It is quite impossible for the air and coal-gas to be properly mixed by the common practice of opening the furnace door of a boiler, or if the mouth of the fire is filled with coal, as in many kilns at the present day. It is not so easy to supply sufficient air to kilns as to boilers, and reliance is generally placed on the flues, which are presumably made of such a length as to supply sufficient air for the complete combustion of the fuel before it passes into the chimney.

The coke remaining on the bars after the gas has been driven off from the coal being solid, it is clear that the mixture with air can only take place at the surface of the fuel in contact with the air—that is, near the grate-bars. If these are unduly choked with clinker, the fuel cannot burn for lack of air; if, on the other hand, the fuel lies unevenly on the bars, and in some places does not cover them, air will rush through the uncovered portions and into the flues without properly oxidizing the fuel. It is therefore necessary to see that the bars are as evenly covered with fuel as possible; but the layer must not be too thick, or the air will be unable to penetrate it and incomplete combustion will result; about 7 inches of glowing fuel is usually sufficient if the coal is fed on to alternate sides of the firebox, and the layer kept as level as possible.

The efficiency of the combustion can only be completely ascertained by a periodical analysis of the flue gases (see 'Tests'), as carbon monoxide (the chief product of incompletely burnt coal) is invisible, and the absence of soot or smoke does not necessarily imply perfect combustion of the fuel. The presence of coloured smoke always indicates that some of the fuel has escaped burning, and is, to that extent, wasted. To prevent this waste, the following conditions must be secured:—

1. A sufficient air supply. If the fuel is not supplied with sufficient air, the gases will act as reducing agents, *i.e.* they will take oxygen from any coloured oxides present in the glaze and so spoil its colour, or the carbonaceous matter will not be burned out, owing to the lack of oxygen in the gases, and any iron compounds will be more or less deprived of their oxygen, and will produce slag-spots.

2. Thorough admixture of the air and gases from the fuel.

3. A continuous high temperature in the firebox so as to ensure the ignition of the gases.

4. As the solid portion of the fuel requires time for its combustion, sufficient grate area and flue space must be provided. The coal layer must be porous to allow the air to penetrate, yet no part of the grate must be left uncovered, and the fresh charges should be frequent and small or the fuel on the bars will be cooled too much. For a similar reason the fuel should be disturbed as little as possible, although with clinkering coals care must be taken that the supply of air through the grate-bars is not stopped.

5. The flame should be about ten yards long with good coal; it should never be thin and short, nor wavering like a flag in the breeze, as this last implies that the grate is not evenly covered. It should be highly luminous, as, if dark and dull, an insufficiency of air is indicated. Whenever possible, sight-holes should be arranged so that the nature of the flame may be frequently observed.

6. Clinker must be removed before the bars are too much choked; but its removal requires care, or much smoke may be produced in addition to the cooling effect of masses of air passing through the uncovered bars. When the addition of sand or other material will render the clinker infusible without seriously lowering the heating power of the fuel, such an addition should be made, as the time and trouble saved in cleaning will soon compensate for the slight loss of heat used in heating the material. The easiest way of mixing such material with the coal is to make it into a thin cream with water, and to sprinkle this over the coal some time before use. It is, unfortunately, only possible to raise the fusing point of the clinker in a very few cases, so

that the best way is to use coal with as small a percentage of ash as possible.

From the foregoing remarks, it will be seen that the operation of fixing a kiln or boiler *efficiently* is a matter of some skill and care; and a manager who considers it a job to be given to any man who is strong enough to handle a shovel, will sooner or later find his mistake cost him dear in the deterioration in the quality of his goods or in a waste of fuel.

Draught may be produced by the difference in weight of the air in the kiln and chimney and that outside (natural draught), or it may be produced artificially by means of an air-pump or fan.

In the case of a chimney, the velocity of the air passing through it is proportionate to its height and to the temperature of the air inside the chimney. It should not be below 5 feet per second.

As the density of air decreases rapidly with increasing temperature, and as it is the weight of air passing through the chimney, and not its volume, that is of value, the drawing power of the chimney is greatest when its *mean* temperature inside is double the external temperature + 273, if the temperatures are measured in ° C. This is calculated for three typical temperatures in the following table:—

TABLE OF MAXIMUM DRAWING POWER OF A CHIMNEY.

Inside Temperature.		Outside Temperature.	
° C.	° F.	° C.	° F.
323	613	25	77
305	581	16	60
273	523	0	32 (freezing)

The actual draught, measured in inches of water, may be calculated from the formula

$$d = h\left(\frac{7{\cdot}6}{a} - \frac{7{\cdot}9}{b}\right)$$

when d = draught in inches of water;
h = height of chimney in feet;
a = absolute temperature of external air (= ° F. + 491);
b = absolute temperature of internal air (= ° F. + 491).

If the internal gases are at a temperature of 600° F. and the external air at 60° F.

$$d = h \times \cdot 007$$

The following table, due to Kershaw, shows the height of chimney required to produce a given draught:—

Height of Chimney in feet.	Suction at Base of Chimney in inches of water, with exit gases at 600° F.
50	0·350
75	0·525
100	0·700
150	1·050
200	1·400
250	1·750
300	2·100

The effective draught at a boiler or kiln-furnace fire is always 35 per cent. to 40 per cent. less than the suction at the base of the chimney, and depends upon the length and area of the intervening flues, and the state of the brickwork as regards leakage.

For a boiler, the area of the chimney above the level of the firebars is commonly taken as

$$\text{Area in square feet} = \frac{\cdot 06 \times \text{lbs. of coal burned per hour}}{\text{Height of chimney}};$$

but this must be taken as a minimum, and, if the flues are over 100 feet in length, a greater area will be necessary to overcome the increased friction. For kilns, the results of this calculation must be at least doubled, as a much sharper draught is required.

For kiln-firing, however, the height is usually of more importance than the area of the chimney. Thus whilst for a boiler in a fairly open position consuming 1 cwt. of coal per hour a height of 50 feet will usually be sufficient, and, for a fuel consumption of 1 ton per hour, 150 feet is ample for the chimney, these figures are quite erroneous when a kiln chimney is under consideration; and as the construction of kilns, even of the same type, varies so much, it does not seem possible at the present time to state definitely the minimum height permissible for a kiln chimney.

A chimney which is too low or too wide will not produce a sufficient draught; it may often be remedied by placing an iron plate with a square or cross-shaped opening on the top of the chimney, the area of the opening being varied according to the draught required. If this does not prove to be satisfactory, auxiliary draught by means of a fan will probably have to be employed.

One great cause of loss of heat in the chimney is owing to careless opening of the furnace doors of boilers, and to allowing parts of the firebars to become uncovered with fuel both in boilers and kilns; the result is that an excessive quantity of air rushes through the flues, becomes heated, and then passes up the chimney. It is almost impossible, even with the most carefully fired kilns, to avoid using once and a half, or even twice, the necessary (theoretical) quantity of air for the combustion of the fuel, and it frequently happens in practice that ten times the proper amount of air passes through the flues without the loss this entails being suspected. It cannot, in fact, be determined or controlled without frequent and periodical analyses of the flue-gases (see p. 263). If the fires are properly managed, the flue-gases should contain 18 to 19 per cent. of carbon dioxide with traces only of the monoxide.

If the fireman has no means of getting his flue-gases regularly tested, he must take especial care that the colour of his flame is right, and that it is never allowed to have a dull, smoky hue or show any other sign of an insufficient supply of air; on the other hand, he must keep a sharp lookout lest air rushes in through cracks and crevices in the masonry, impairing the draught and causing waste of fuel in the heating up of so much unnecessary air. For this purpose a draught measurer is often employed (see p. 254). Careful measurements with one of these instruments have shown that whilst the draught produced is proportional to the height and to the difference in temperature of the inside and outside of the chimney, yet the actual weight of gases passing up a chimney per minute is practically the same for all temperatures above 300° F., and that there is, therefore, no advantage to be gained by exceeding that temperature.

In many forms of kiln it is essential that the goods should be 'set' in such a manner as to create an even draught throughout the kiln, as otherwise the temperatures attained will vary too greatly in different parts; it is here that skilful and careful setting is of importance, even for some common goods.

As leaky kilns cause loss of draught, all cracks should be stopped with clay and dampers should be kept in good condition.

For a similar reason the trial-holes should be opened as little as possible: a sheet of mica used as a window to the kiln will allow of the inside being seen without any cold air entering the kiln.

The regulation of the draught is chiefly made by dampers working in either a vertical or a horizontal direction (for some reasons the latter are to be preferred, as being better fitting). The proper use and value of dampers is not to be understood without a considerable amount of thought, study, and practice; far too many firemen look upon them simply as a means of closing the kilns when the firing has been finished (a curious idea!) or when a kiln is out of use. A careful and observant fireman will occasionally increase the heat in his kiln by partially closing the damper, although as a general rule the wider the damper is open the greater the draught and the more intense the heat in the kiln.

It is always advisable to have some form of draught measurer in order that the supply of air to the fuel may be kept right. This is too often left to chance, with the result that fuel is often wasted or the goods are discoloured by reducing gases.

If too much draught is allowed the burner will have hard work to keep a sufficient heat in the kiln, as it flies to the chimney shaft at once. It is not the heat in the fireboxes, but that in the kilns, that effects the burning of the goods, and the burner must alter his dampers until the proper degree of heat can be reached without unnecessary waste of labour and fuel.

Too little draught, on the other hand, will sometimes result in one part of the kiln being raised almost to white heat, whilst other parts are almost black. If cleaning the firebars does not mend matters the damper should be raised, or, if it be already drawn out to its fullest extent, it probably means that the flues at the bottom of the kiln are filled with sand or that the goods are set so closely together that no draught is possible between them. If the chimney shaft is only short, it is often possible to increase it temporarily and so obtain a greater draught; but with a long shaft it is cheaper to allow the kiln to cool, examine it thoroughly, and, if necessary, re-set it.

It is not possible to give figures showing the actual air-pressure (draught) which should be maintained in all cases, as so much depends on the class of clay and goods in the kilns that the only way is for the clayworker to find out for himself by actual experiment how much air is necessary.

A similar remark applies to the temperatures to be reached in the burning. Seger has, however, given the following figures as approximately correct:—

Goods.	Seger Cone.	Temperature in ° C.
Porcelain colours and lustres, .	022 to 010	590 to 950
Clays rich in lime and iron, .	015 to 01	800 to 1130
Brick clays, clinkers, paviours, .	1 to 10	1150 to 1330
Stoneware with salt- or slip-glaze,	5 to 10	1230 to 1330
White-ware biscuit, . . .	3 to 10	1190 to 1330
White-ware glost, . . .	010 to 10	950 to 1330
Fireclay and porcelain, . .	7 to 20	1270 to 1530
For determining the refractoriness of clays, . . .	26 to 39	1650 to 1900

The figures in the last column are only approximate, and it is always desirable to refer to the number of the cone rather than to the degree of temperature, especially with the higher numbers.

In most cases of clay-burning the exact temperature reached is of less importance than the length of time the goods are exposed to a certain temperature—*e.g.* whether the maximum temperature is 1250° or 1300° C. matters less than the *time* of exposure at 1250°. The essential question is—"Has the heat been acting for a sufficiently long time?"

The Waste of Heat from the fuel may arise chiefly from: (*a*) Loss of heat by radiation from the top and sides of the kiln or boiler. This loss is greatest when the kilns are built quite separately, and least when they are arranged *en bloc* as in a continuous kiln or a battery of boilers. To a certain extent the loss of heat from this source may, in the case of kilns, be reduced by building a drying-room over the kilns. The actual loss from this cause may be reckoned as about 10 per cent. of the total loss, though the actual proportion varies greatly with different forms of kilns; with well-covered boilers it ought not to exceed 7 per cent. of the total loss.

(*b*) Loss of heat retained by the ashes and clinker, which is practically negligible so long as the ashes contain no unburnt fuel, as it seldom exceeds one-fifth of one per cent. of the total heating power of the coal. If, however, unburnt fuel finds its way into the ashes, the loss may be increased indefinitely—sometimes amounting, when very small coal is used and the fires badly cleaned, to nearly half the heating value of the coal. With continuous kilns this may be due to stoking a new row of fire-holes before the kiln is hot enough, or to putting too much fuel into the fire-holes just before finishing, or to the use of too little air. In each of these cases coke will be found among the ash.

(*c*) Loss of heat carried by the flue-gases up the chimney. Many erroneous ideas exist as to the temperature at which the gases should enter the chimney, especially since the introduction of fans for producing draught.

In the first place it is clear that, as the efficiency of a chimney depends upon the difference in temperature and density of the flue gases and that of the outside air, the flue gases must be hotter than the air outside; the exact difference in temperature will depend on the temperature required in the furnace and on the amount of heat which is allowed to escape. As a general rule it may be understood that a temperature of 250° to 300° F. is amply sufficient, with a well-constructed chimney, to secure a good draught, and any considerable excess of temperature over this should, if possible, have the attention of an expert who will endeavour to make use of the heat thus being wasted. So much depends on the nature and state of the kilns and furnaces, and their positions relative to the chimney, that it is almost impossible to suggest the best means of utilising this excess of heat without being on the spot; the heating of drying-rooms or of the feed-water for the boilers are the commonest applications of the waste heat, but great care is required in the former that no leakage occurs, or the draught of the kiln may fail at a critical moment.

For successful firing it is necessary to consider what goes on inside the kilns, and to know something of the changes which take place in the constitution of the goods placed therein. These changes may be grouped under four main heads :—

1. Drying.
2. Eliminating volatile and combustible matter.
3. Burning proper.
4. Glazing.

Drying.—The greater part of the water should, of course, have been dried out of the clay before the goods are placed in the kilns; but even when the goods are 'bone dry' they still contain up to 15 per cent. of water, which can only be removed by heating for some time to a temperature approaching a dull red heat. This water appears to be combined with the clay in some way, as after it has once been removed the clay can no longer be made plastic by the further addition of water as is the case if the goods are merely dried in the ordinary way at a low temperature.

Eliminating Volatile Matter.—The ordinary fireman never seems to realise how much water there is in the goods in a kiln; 300 lbs. per ton of goods is by no means an uncommon quantity, and as each pound of water forms roughly 27 cubic feet of steam, this means that over 8100 cubic feet of steam must be driven out of each ton of goods before the firing proper can commence! Hence the necessity for ample ventilation (especially with muffle-kilns) inside the kilns, and for sufficient time being allowed to effect the evaporation of the water without causing it to boil and so spoil the surface of the goods. It is on this account that a 'smoky' fire is used at the commencement of the firing.

Whilst, generally speaking, damp goods should never be placed in the kiln, it may sometimes be necessary to break this rule. In such a case the damp goods should be placed as near the top of the kiln as possible. Even then there is considerable risk of the goods being spoiled.

It is not always easy to tell how long to keep on the 'smoking,' the usual English practice of putting a cold bar of iron into the kiln and noticing whether any moisture condenses on it being a very rough and by no means satisfactory test. When it can be managed the temperature should be measured by means of a thermometer; it should increase steadily from the start, and the 'smoking' should not be stopped before the goods have reached a temperature of 120° C. (or 250° F.). If it is possible to draw a weighed 'trial' or two occasionally and to continue the drying until these cease to lose weight, more satisfactory results are likely to be obtained; and if the proper length of time of drying has once been found for a particular class of goods, the trial-pieces may be omitted, though the use of a thermometer is always desirable.

Much of the splitting of so-called delicate clays is due to a lack of sufficient care in the drying, or 'smoking,' so that the outside of the goods is dried too quickly, with the result that internal strains are set up in proportion to the 'closeness' or density of the clay, its thickness, and the rate of drying.

In continuous kilns especial care must be taken with the smoking, as there is a tendency to unduly hurry this operation with such kilns. It is only in exceptional cases that goods can be efficiently dried (smoked) in less than 48 hours.

If the smoking is ineffectively carried out the goods are apt to 'fly,' or unpleasant condensation products are formed on them, no matter how carefully they may be covered. If the steam from the goods were to condense as pure water, no further damage would result than that caused by the softening of the goods; unfortunately, the water thus condensed on the goods is never pure, but is of a strongly acid nature, chiefly owing to the sulphuric acid produced by the oxidation of the sulphur in the coal. (A test recently made showed that this condensed water contained nearly 30 grains of sulphuric acid per gallon.) Alkaline sulphates, hydrochloric acid, and ammonium chloride are also frequently present, and tend to cause discoloration or scum.

As it is the air passing through the kiln during the smoking which really carries off the steam and other volatile matters, it is necessary to allow it sufficient passage; the damper the goods the more air will be required. As soon as the goods have reached a dull red heat the draught may be adjusted to secure the most economical burning of the fuel.

It is scarcely necessary to point out that the increase in heat during the smoking should be as regular as possible. A thermometer attached to a light chain or rod can be conveniently used to ascertain the temperature up to 300° C. (570° F.).

All secret methods for carrying out the earlier stages of firing continuous kilns safely have the same objects, viz., the separation of the period of 'smoking' from that of true firing, and the removal of the water-vapour from the goods through special openings in the kiln. As the contraction of the air through loss of heat (due to the evaporation of this water) is greater than its expansion (due to the addition of the vapour), the air used for smoking becomes specifically heavier than it was when first introduced, and its natural way of travel is downwards, but it is usually expelled through pipes in the arch of the kiln.

The two most important methods of 'smoking' goods are :—

(1) The use of a special stove ('stoving').

(2) The use of pure air drawn over hot goods in the kilns with a view of cooling them.

The second method is preferable so far as it is applicable, because the air is simply heated by contact with the hot goods and therefore undergoes no contamination by flue gases, etc. It is merely necessary to exercise care that the gases are not too hot when they are turned on to the newly-set goods or the latter would crack. The difficulty of applying this method lies in the fact that in many kilns the supply of clean hot air is not sufficient for the proper heating of the new goods to 120° or 130° C., and it must therefore be supplemented by the first method. It should, however, always be possible to heat the goods to 45° C. (112° F.) with pure air so as to avoid all chance of discoloration during the stoving.

Briefly, true 'stoving' consists of the use of a portable stove (of iron) burning coal or coke, and in this way heating a large supply of air which can be drawn into the kiln through the fireholes or through special openings in the kiln. As already suggested, the objection to using this method directly the goods are set is that the products of the combustion of the fuel in the stove are mixed with the hot air, and that, consequently, great care is required to prevent acid condensation products forming on the goods and discolouring them. This is one of the chief reasons why waste kiln gases cannot be used at such an early stage of the burning; they contain too much water and too much acid. It has been calculated that a cubic yard of kiln gases saturated at 212° F. and cooled to 194° F. will deposit no less than six ounces of water.

The stove should be so constructed that not all the air is heated by passing through the fuel, but that some of it is heated indirectly so as to keep it free from combustion products. The exact proportions of fuel and air required for the 'smoking' varies with the temperature of the goods in the kiln when the 'stoving' is begun and with the skill of the firemen, for it must not be forgotten that this early stage of firing requires just as careful attention as the later stages of the firing.

The following example will indicate how the minimum quantities of air and fuel may be calculated; but it must be borne in mind that the figures obtained by calculation are the very lowest possible, and that in practice they will probably have to be increased by at least half their value.

Assuming that one chamber holds 10,000 bricks, each weighing 7 lbs. and containing $\frac{1}{2}$ lb. of water, it will be necessary, in the present instance, to heat 65,000 lbs. of clay and 5000 lbs. of water to 212° F., a rise of 152° F., and also to evaporate this water. For driving off the water two quantities of heat are necessary—(1) for raising its temperature to 212° F., $5000 \times 152 = 760{,}000$ B.T.U.; and (2) for converting it into steam (latent heat), $5000 \times 967 = 4{,}835{,}000$ B.T.U. The bricks will require $65{,}000 \times 152 \times 0{\cdot}2 = 1{,}976{,}000$ B.T.U. for heating the clay to 212° F. (the sp. heat of clay being 0·2), and the total amount of heat needed will be *at least*—

760,000	B.T.U.	for heating the water,
4,835,000	,,	,, latent heat,
1,976,000	,,	,, heating the clay;
7,571,000	,,	

which is equivalent to 5 cwt. of coal, or 56 lbs. of coal per thousand.

If, in passing through the chamber, the air falls 100° F. in temperature, the amount of air needed will be at least 7,571,000 $\div (100 \times 0{\cdot}24) = 315{,}500$ lbs. of air; which, if the smoking take 48 hours, represents 6572 lbs. of air per hour or nearly 1500 cubic feet per minute.

If the goods had been raised to 112° F. by hot air from the cooling kilns and a proportional quantity of water had been evaporated, only 350 lbs. of fuel would have been needed.

Towards the end of the smoking the organic matter in the clay, together with any gelatin, or gum, which may have been used in the slips, will commence to burn, but these substances are usually present in such small proportions that no special care is needed. With clay containing much coal or peaty matter, however, the case is different, and unless the kiln is very carefully managed the goods may 'catch fire' and get overheated. With such clays it is necessary to keep the temperature as low as possible during the smoking, and to largely exclude air at the earlier stages of the burning so as to keep the temperature well under control. With clays of this kind great care and experience are essential to success, as too little air-supply will cause loss of heat, whilst too much may result in over-firing.

Burning.—There should be no sudden rise in the temperature of a kiln, yet the object of the firing changes somewhat as soon as the goods have reached a dull red heat. In this later stage of firing the nature of the gases inside the kiln becomes of importance, as some clays, particularly those rich in sulphur compounds, require to be first heated in a reducing and then in an oxidizing atmosphere; whilst with others the operations of oxidizing and reduction must be carried out in the reverse order. This is obviously a matter which each manufacturer must determine for himself, as the most suitable for his particular class of work; and, having once determined his best method of working, he should see that it is carried out, and that carelessness on the part of the fireman does not cause him to have a smoky fire when a clear oxidizing one is required, or *vice versâ*. In the case of boilers it is particularly necessary to avoid a reducing fire, as this causes rapid deterioration of the plates; a little excess of air matters little, but a deficiency may do great harm.

Regularity of heating and a careful regulation of the air-supply are likewise necessary if the best results are to be obtained. Even when the fire-holes are in good repair the fires may still work irregularly if the stoking is unskilfully done. Many goods are spoiled through the firebars not being kept properly covered, especially with a caking coal on a windy day. It is always best to stoke lightly, frequently, and evenly, and the fireman should give his fires constant attention without wasting fuel by too much poking.

The temperature to which goods must be heated in the kilns naturally varies with the different kinds of clay and glaze, but to obtain ware of the maximum strength and durability the clay must be heated until a certain proportion of the constituents have fused sufficiently to cement the more refractory particles together; but the temperature must not be so great as to allow the article to lose its shape, and the glaze must be heated sufficiently to cause its complete fusion. At the same time it must remain fused sufficiently long for any bubbles which may have been formed in it to escape. In order to determine the temperature to which a clay must be heated to attain its maximum durability, which is, usually, the point of incipient vitrification, see p. 145.

For goods which have to bear repeated heating and cooling (as firebricks and retorts) it is desirable to have a certain lack of homogeneity of structure, in order that the mass may have as few points as possible from which chemical action (which leads to fusion) may proceed.

In most cases the appearance of a freshly-broken piece of fired ware will enable the clayworker to judge of the correctness or otherwise of the firing. Bricks and fireclay ware should be porous yet not too spongy; earthenware should give a fracture not unlike that of a piece of freshly-cut cheese, with a slight yet noticeable gloss; while porcelain is only very slightly porous and the glossiness of the fracture is more pronounced than that of earthenware. From what has already been said, it will be clear that after the water and combustible matters have been driven from the clay by the smoking and the earliest stages of firing, there is little to be gained by a slow heating of the clay to the maximum temperature desired. Some firemen consider that a more or less lengthy 'soaking' is necessary at one or more stages of the 'full fire,' but experiments have shown that, in most instances, this is not correct, provided that the combustible and volatile matter has been completely removed from the clay, and that once this has been accomplished 'soaking' is not only a waste of fuel but is liable to damage the goods, and, in the case of goods baked and glazed in one firing, to deaden or dim the glaze seriously.

There is, however, in clays containing much organic matter, a great need of prolonged heating below 1000° C. in order that this matter may be removed before the firing is allowed to reach a further stage, as otherwise black cores will be obtained.

In biscuit-firing three points are important, viz.:—

(*a*) From the start to 120° C. (smoking) the heating must be very slow and regular, so that the water cannot boil out of the goods, and the goods themselves may not fly or crack.

(*b*) The biscuiting proper, when the heating may be much more rapid (provided that the clay does not contain much combustible matter, in which case the earlier stages must be slower). At this stage of the firing it is equally necessary that the heat shall increase regularly, with no 'set back' due to neglect in the stoking, and that the nature of the flue gases shall be of the right kind, as some classes of ware require to be heated entirely by an oxidizing flame, others by a reducing, and others first by one and then by the other. (See p. 8 *et seq.*)

The rapidity of the heating at this stage is also, to some extent, dependent on the amount of shrinkage undergone by the clay. This varies greatly with different clays, but is generally small at first and increases rapidly with increasing temperature until the point of vitrification has been reached. This may occur at as low as 700° C. if the proportion of alkalies in the clay is large, but, in the case of fireclays practically free from alkalies, a temperature of 1200° C. or over must be reached before any vitrification can be detected.

With the diminution of volume the clay increases in density; but these two changes are not directly connected with each other in every case, as the formation of air-spaces in the clay, whilst not appreciably affecting the volume, has a noticeable effect on the density, so that certain clays (kaolins, for example) at high temperatures lose both in volume and in density.

The question of density or porosity of the clay ware is especially important in the manufacture of large articles which have to withstand rapid changes of temperature. In such cases the most porous clay obtainable must be used, so that, when the goods are heated, the air-spaces between the particles will allow of their free movement without the article being split owing to internal strains. Sometimes sawdust, graphite, or other combustible material is added to the clay before use, so that, after firing, a very porous or 'open' product may be produced. Porosity may also be increased in many cases by the use of a less finely ground clay or by the addition of coarser fragments of burnt clay (sagger).

(*c*) In the finishing of the kiln-firing much skill is required. Some workers prefer to close all the mouths of the kiln completely as soon as the desired temperature has been reached, and to allow any subsequent increase in temperature to effect the maturing of the glaze and the cementation of the refractory particles of the biscuit. It will be seen that this method of working has a large element of chance in it, as the increase in temperature so obtained by closing up the kiln will vary with the amount of fuel on the bars, with the draught, and with the speed at which the temperature has been increasing prior to the closing. At the same time this method has the advantage of allowing the kiln to be left at a much earlier time than with other methods of finishing, but it is obviously only suited for a somewhat rough class of work.

Other workers insist that all fires should be drawn as soon as the necessary temperature is attained, and argue that, by closing the fireboxes whilst much fuel is in them, a reducing atmosphere is produced inside the kilns, owing to the fuel not having a sufficiency of air for its proper combustion. With some classes of goods such a reducing atmosphere undoubtedly does harm: on the other hand, too rapid a withdrawing of the fires may lead to cracking of the goods. It will generally be found best to so regulate the firing that when the desired temperature has been obtained it may be kept up for as long as may be necessary for the maturing of the glaze or the cementation of the biscuit, as the case may be, and then to let the fires die down somewhat before the fireboxes are closed. In this way the liability of the kiln to draw in air may be avoided, and the chance of a reducing atmosphere appearing when it is not needed is lessened.

Too many firemen fail in their work because they will insist on firing at too long intervals and putting on too much fuel at a time. By so doing, perfect control over the temperature of the kiln is lost, and trouble is sure to ensue sooner or later.

Glazing.—Firing glazed goods may be carried out on either green or biscuit-goods. On principle, one single firing is better than separate firings for biscuit and for glaze; it should be chosen when possible (1) on account of its economy, and (2) because a single firing ensures the use of an engobe and glaze of such a nature as to make their union with the body of the ware more complete than where different firings are employed. The case of glazed bricks appears to be an exception to this general rule, as, owing to the difficulty of disposing of second and third qualities of these goods, it is necessary to select the bricks for glazing with great care, and this can in many cases be done more effectively after the bricks have been fired once.

Considered apart from the firing of the ware itself the burning of glazed goods requires little explanation. Its chief difficulties lie in the production of a steadily increased temperature and in maintaining it for as long as may be necessary for the proper development or maturing of the glaze, and the maintaining of the correct atmosphere (reducing or oxidizing) inside the kiln. This question of the atmosphere is especially important in the case of coloured glazes, for many substances used as glaze-stains are profoundly modified in colour by the nature of the atmosphere in which they are heated. Thus chromium compounds are green in a reducing atmosphere, but red or buff in an oxidizing one; lead glazes may be blackened in a reducing atmosphere, and manganese and cobalt compounds form bubbles of oxygen in the glaze heated too long in an oxidizing one. Hence it is impossible to fire all kinds of colours at one time in a kiln.

The remarks about the closing of the kilns apply equally to glost as to biscuit ovens, but the evil results of a bad 'finish' are far more noticeable in the former than in the latter.

As so much depends on the nature of the glazes used no general details can be given as to the best way to fire a glost kiln, except that it is often well to follow Seger's advice when using coloured glazes and to commence the firing with a reducing or smoky flame up to a temperature corresponding to Cone 1, and in this way to remove the evil effect of any sulphates which may be present, but to employ an oxidizing flame before the glaze begins to melt and to continue this to the end of the firing. This rule will not, however, apply to all cases. It is also well to remember that in the majority of glazes the more rapidly they are fired the better will be the result, as prolonged heating dulls the lustre of the glaze.

Some of the results arising from improper firing will be found under the head of 'Defects' (p. 191 *et seq.*), and some of the principal characteristics of Glazes and Engobes will be found enumerated on pages 19 and 138; but it must always be remembered that the greater part of successful firing depends on the watchfulness, care, and skill of the fireman. A good burner is a treasure not lightly to be discharged; a bad one is an unmitigated evil. A first-class burner is one who is able to get his kiln heated evenly throughout, or who in pottery kiln-firing can get the different parts heated to just the right points; can detect any notable change in the draught or heat of the kiln by observation, and handle his fire accordingly; and, lastly, who knows when to stop firing and how to close down.

Cooling.

The essential point in cooling the goods in the kiln is to secure speed with safety. If too rapidly cooled, the goods will dunt or crack; if the cooling be unduly prolonged, time will be lost. It is for each clayworker to determine for himself what is the minimum time in which his kilns can be safely cooled. It is as necessary to take precautions for the regular cooling of the goods as it is for their regular heating; draughts in particular are to be avoided. Many workers cool their kilns carefully at first, but unduly hasten the later stages, with consequent loss of goods; for it is when the goods have cooled to below a red heat that cracking mostly occurs, sometimes owing to opening the kiln too soon, and at others by withdrawing the goods before they are sufficiently cold. It is a good plan not to pull down all the doorway at once but to take out the top quarter first, and leave the rest until the following day.

CHAPTER X.

DISCHARGING, SORTING, PACKING, AND DESPATCHING.

Discharging.

Is the last operation in the manufacture of goods, and is one which presents no special difficulty to men used to the work. The bricks composing the doorway should be piled neatly on one side for future use.

The goods should be sorted roughly as they come from the kiln and should be so arranged that the sorters may handle them as little as possible, for handling costs money. After being sorted, the defective goods should be placed in groups according to their faults and charged to the men responsible for them.

As the goods from the kiln are in many cases 'finished articles,' the greatest care should be taken in discharging, as carelessness at this stage causes greater loss than at almost any other. This is particularly the case with glost goods which have been through two or more kilns, according to the colours they carry. In bricks and roofing tiles a lamentable degree of carelessness is often shown in handling the finished goods, and much loss is thereby accounted for. The damaged arrises so frequently seen are often due to the bricks being discharged too hot for the men to handle them properly, but insufficient supervision is also a prominent source of loss in this department.

In many cases the saggers are difficult to separate; it is better to give them a sharp blow with a hammer rather than to attempt to prize them asunder by means of a chisel. The latter may be usefully employed in removing small pieces of clay, etc., adhering to the goods. Before refilling, the kiln must be thoroughly cleaned out.

Sorting, Packing, and Despatching.

Sorters should be carefully chosen and well paid, as carelessness on their part is often troublesome to remedy and a fertile cause of annoyance to customers.

Sorting bricks, tiles, and terra-cotta generally should be done with the aid of a gauge in order that articles of different sizes may not be sent to the same job. Coloured goods should be compared with a standard colour, so that, in the event of any enquiry, the sorter cannot plead 'misunderstanding of instructions.' In any case the manager of the works should frequently visit the sorters to see that they are working properly, and should take care that they are not kept too long at one colour or they are bound to work badly owing to their eyes becoming fatigued to that colour and so less able to detect small variations from it.

No goods must ever be allowed to rest on ashes or cinders. If they are glazed, they are too valuable to run the risk of scratching by pieces of clinker in the ash; whilst if unglazed, they are extremely likely to 'scum' if they absorb any salts from the ash. For a similar reason it is inadvisable to expose bricks and similar goods unnecessarily to the weather.

The sorting room should be of ample size and well lighted, preferably from the north. Changes in the stock should be accurately noted as they occur, so that the stock sheet shows the actual goods on hand at the close of each day. An occasional checking by actual count is desirable, but it must only be a check and must not take the place of accurate record-keeping.

Packing requires more or less skill according to the nature of the goods. The tendency to waste packing material should be strongly discouraged, but undue 'economy' will result in breakages in transit. Speed in packing and despatch is greatly facilitated by a well-constructed shed into which the carts or trucks can be run and loaded, the floor of the shed being at the most convenient elevation for this purpose. It pays to have this shed protected from the weather so that the packers are kept dry, and not, as in some places, have to work in a mass of wet straw and slop.

Packers are paid on either time or piece; the latter is preferable where it can be arranged, though it is often difficult to fix a price which shall be equally fair to master and man.

CHAPTER XI.

DEFECTS.

The following list contains the different defects more commonly met with, but by the nature of the case it cannot be complete. The defects are placed in alphabetical order for facility of reference.

Absorption of the glaze by the body of the goods being too porous is usually the result of insufficient firing in the biscuit-kiln. If an insufficiently thick coating of glaze be applied, a similar result will be obtained. Excessively prolonged heating of the goods in the glost-kiln will cause a partial volatilisation of the glaze, whilst if the ware be placed too near unglazed pieces (*e.g.* the walls of the kiln), the glazed goods will be 'dry,' or, as is sometimes said, the body will have 'sucked in' the glaze.

Blinding of the glaze, though differing somewhat from mere turbidity, is largely produced by the same causes; the term, however, is usually confined to a peculiar turbidity brought about by the formation of minute crystals on the outer surface of the glaze, so that the latter has a curious 'matt' appearance. Certain leadless glazes containing a large proportion of chalk or whiting and a small proportion of alumina are especially liable to this defect, if they are kept too long at a temperature above their melting-point. The remedy consists in the addition of clay to the glaze, and a considerable shortening of the time of 'maturing' of the glaze.

The use of wet saggers, or of damp fuel, after the glaze has begun to melt, will also tend to blind the glaze.

Blisters or **Blebs** are commonly the result of too high a temperature in the kilns, and, less frequently, of air confined in the clay (due to excessive or insufficient pugging), which expands with the heat and raises a small lump or blister. Glazes heavily charged with metallic oxides (for colouring) will often 'boil' or blister if placed near to a mass of unglazed ware. If, towards the end of the firing, the temperature of the kiln be allowed to drop and be then suddenly raised, blisters are often formed, especially in coloured ware.

Blistered bricks are but seldom the result of putting damp goods into the kiln, as is so often supposed, but are usually due to the fatty nature of the clay or to vegetable matter it may contain. Lean, short clays, when put into the kilns in a damp condition, do not blister, but crack or fall to pieces. It has been frequently found that the addition of leaner clay will remedy the evil.

Blotches of colour on the goods may be produced in a variety of ways. With *unglazed* goods, they are usually due to the use of a reducing fire, or to an insufficient supply of air to the kilns (see 'Firing'), or to an excessive proportion of iron pyrites in the clay. Highly carboniferous shales require prolonged heating, with an abundant supply of air, to prevent their discoloration. Copper or iron oxides, or similar compounds which have coloured silicates, will also discolour clay, as will various kinds of dirt introduced by the carelessness of the workmen.

With *glazed* goods, blotches of colour may also be produced by the reducing action of the fire, by insufficient oxidation of the iron in the clay, by the defective mixing of a coloured glaze, by the careless application of colour to the goods, or by perspiration (or oil) getting on to the goods, and preventing the even distribution of the glaze. In such cases, the cause having once been found, the remedy is obvious.

Some colours are easily volatilised in the kilns; these should not be placed near to white ware or ware of very delicate colours, or the condensation products may form ugly blotches of colour on the goods. See also 'Discoloration.'

Blowholes, in either baked clay without glaze, or in glazed ware which has been glazed in the green state, are mainly the result of insufficient pugging or wedging of the clay, so that the air contained in the wet clay has not been expelled before the goods entered the kiln. In this case the blowhole will be clean; if discoloured, it has probably been caused by carbonaceous matter in the clay (tiny particles of coal or dust are a common cause), which burns away, leaving a hollow place, the edges of which are often partially vitrified by the mineral matter present in the impurity. If the blowhole is almost black in colour, it is probable that the clay has been badly picked, so that the ironstone has not been completely removed. Metal filings caused by the men sharpening their tools at the bench will often produce a similar effect.

Too rapid heating of damp clay will sometimes cause blowholes by the sudden formation of steam in the interstices of the clay, and to its escape with explosive violence. Common clays, containing much iron as pyrites, unless heated sufficiently slowly, will occasionally show the same defect.

Blowholes forming in the finished goods on exposure are generally attributed to the formation of quicklime in the goods from the chalk contained in the clay. The simplest remedy is to increase the temperature of the kilns, so that the lime may combine with the clay; if this is not feasible, the fired goods may be dipped into water so as to completely slake the lime, or the clay may be washed free from some of its chalk before use; this latter method is, however, generally too expensive.

Blushing is a term used to denote two entirely different defects; it sometimes refers to a very slight discoloration suffused over a large part of the surface of the ware, usually due to an article of light colour being fired too close to others of much darker shade; but it is also used to denote peeling or scaling of the glaze, and in this case the causes will be found under these headings.

Brittleness in glazes, or in bodies of partially vitrified clay, is one of the results of too rapid a cooling of the kilns, especially at the commencement, whereby the material is not properly annealed. China ware containing an excessive proportion of bone ash is especially liable to be brittle.

Bubbles are often the result of too suddenly raising the temperature of the kiln to a point considerably above the melting point of the glaze, and to allowing the glaze insufficient time to 'mature.' At the same time, excessively prolonged heating of the goods at the melting point of the glaze must be avoided, as it tends to cause a rearrangement of the molecules and to dull the glaze. No definite rule can be laid down, as the time required for the proper development of the glaze varies with the materials of which the latter is composed.

Certain materials used as glaze stains evolve oxygen and other gases when heated, and if this takes place whilst the glaze is in a partially melted condition, the gases may be retained in the form of tiny bubbles. If maintaining the temperature of the kiln for a rather longer time does not cure this defect, it may be necessary to use a reducing fire for finishing the firing, or to discard the use of the bubble-forming material.

Air bubbles are occasionally found as the result of the materials having been so finely ground that the air is imprisoned: this defect is a rare one, and the remedy is obviously to be found in the use of coarser materials.

Chipping off of the glaze or engobe is due to the same causes as 'peeling,' which see.

Cooling the kilns improperly is a fruitful source of many defects, especially 'crazing,' 'cracks,' 'dunts,' and 'feathering,' or crystallisation, and the more important defects will be found treated under one or more of these heads.

Cracks are of two main kinds—those in the clay or body of the ware, and those in the glaze. These latter are known as 'crazes.'

Cracks in the goods before going to the kilns may be due to faulty designing, but this may to some extent be remedied by very careful attention to the manner in which the goods are supported, both in the drying room and in the kiln. In the case of machine-pressed goods, what, from an engineer's point of view, may appear a trifling defect in the machine, will sometimes make it impossible to turn out sound goods: a little unevenness in the pressure, or a slight misfit in a die, or even a slight roughness of the metal face will sometimes cause the goods to crack.

Another very common source of cracks during the drying of the goods is due to this process being carried out carelessly, so that certain parts are dried more rapidly than the rest, a dangerous process at any time, but especially so with jointed goods, or with those having great variations in the thickness of their various parts.

The use of too plastic a clay, or of one too finely ground, is a prominent source of cracks in sanitary ware, especially in large tanks and baths. The remedy consists in the use of a leaner (more sandy) clay, or in the addition of silica in some form to the plastic clay. Some clays which are not excessively plastic also crack because they are too rich in silica; such clays may be cured by admixture with an appropriate proportion of bauxite.

Faulty pugging of the clay, whereby some portions of it are drier than others, will also cause cracks to appear, owing to the unequal contraction in drying.

Sometimes cracks are produced, in spite of the greatest care being taken to make the clay paste thoroughly homogeneous, if an unsuitable die is used, or, in the case of wire cuts, if the mouthpiece of the pug mill be not carefully adjusted to the clay in use. It is essential that the clay shall press equally against every part of the die or mouthpiece; especially must this be the case with regard to the corners, as otherwise the piece will have a soft place when it comes from the press, or the central portion of the clay strip will leave the pug mill mouthpiece before the sides, and the strains thus set up will cause the clay strip to crack.

In this latter case it sometimes happens that the narrower sides of the strip leave the mouthpiece before the broader ones, so that when cut the bricks have a tendency to curl slightly.

The friction in the mouthpiece depends on the slope of the inner surfaces of the latter (being least when the slope is least), and on the area of the sides of the strip of clay, so that the narrower sides have less friction than the wider ones. It is, therefore, advantageous to make the narrower sides of the mouthpiece slope rather more than the others in order that the different portions of the strip may all travel forward at precisely the same rate.

The most friction occurs at the corners of the mouthpiece, with the result that the edges are held fast whilst the remainder of the strip travels forward, and the edges, no longer able to withstand the strain, tear away in the form of the so-called 'dragon's teeth.' These 'teeth' are also formed when dry clay remains in the mouthpiece of the mill. If an alteration of the slope of the faces of the mouthpiece and a rounding of the corners does not effect the desired result, as may happen with an excessively 'short' clay, it is best, if the composition of the clay cannot be altered, to use a mouthpiece with water lubrication. The water forms a cushion between the clay and the metal, and so, by reducing friction, prevents the tearing of the former, but it has, at the same time, the tendency—owing to the 'slip' which the water forms with the clay—to cover up small surface cracks which would have been visible if no water had been used, and which, though covered, seriously lessen the strength of the bricks.

In the kilns cracks may be produced by a variety of causes, such as faulty setting, kiln leakage, or bad firing. Under the first of these comes the cracks produced by the goods having been set without any regard to the strength of their relative parts or to their not having been set solidly, so that the movement resulting from their contraction causes them to fall or at least to crack. Setting bricks on a floor on which there are fragments of brick which get under one end of the goods and tilt them slightly, this irregularity increasing as the courses rise, with the result that the bottom brick cannot stand the irregular strain, and cracks, is a by no means uncommon experience. Goods which are too dry when set are often very brittle, and so crack in the setting.

Kiln leakage may be due to a faulty site, to the kiln not being drained, to faulty construction, or to lack of repairs. This latter may also cause cracks by allowing the kiln to 'leak air'; too much draught will do the same. In ordinary brick kilns care should be taken that the 'screen' (when one is used) in the kiln is made of good materials with as thin joints as possible, or the cement ('daub') used may shrink unduly and allow air which has not been properly warmed by the fire to leak in and crack the goods. For a similar reason, holes at the bottom of the screen are not to be recommended, though they are frequently used with a view to inducing some of the fire to enter them and so save fuel. In muffle kilns, or those in which the goods are placed in saggers, the danger of cracks from cold air is reduced to a minimum.

Cracks due to the firing are often caused by raising the temperature too rapidly at the commencement; the goods are thus heated unequally and cannot stand the strain put upon them, or the steam may not have all escaped from the kiln and may force its way out of the goods with explosive violence; or, if the steam is allowed to remain too long in the kiln, it may condense on the goods, soften them, and then when the heat is raised rapidly it may crack them, just as would be the case if the goods were first soaked in water and then dried rapidly on a hot stove. If a thermometer cannot be used in the earlier stages of firing the kiln, some arrangement should be made whereby a trial may be withdrawn to see that it is free from steam; sometimes a large cold poker or crowbar is put through the trial hole and left for a few minutes; if it is damp on being withdrawn the kiln is not free from steam; the bar must be quite cold on insertion. Steamed goods are commonly the fault of a fireman who does not work his dampers properly.

Cracks may be also formed in certain classes of kilns by careless stoking, so that cold air is allowed to rush through holes made in the clinker and fuel; hence it is not advisable to clean out all the fires at the same time.

In cooling the kilns, goods may easily be cracked. They must be cooled slowly just as they are heated slowly. Especial care is required to prevent cold air from spoiling the goods directly after 'burning off,' as may easily happen if the closing of the fireholes is proceeded with too leisurely. A good plan is to lower the damper *slightly* as soon as the last charge of coal has completely stopped flaming.

When goods are insufficiently fired and are not glazed they are liable to crack on exposure to the weather; this is often the case with red bricks which are heated just sufficiently to develop the desired colour without any regard being paid to their durability.

Cracking of the Engobe is commonly due to its having a different expansibility to that of the clay of which the goods are made. If so, the remedy depends largely on which contracts or expands the most. This can only be accurately determined by actual measurement (see p. 249), but much may be learned from an examination of the crack. If it be a clean one with the engobe adhering well to the body on each side, the former will be improved by having its contractibility lessened by the addition of a little flint, quartz, or fine sand; unless the engobe is already very rich in silica, when rather less of this ingredient should be used. If, on the other hand, the engobe rises up from the body with a blister-like formation, a cure must be sought in the addition of a greater proportion of flux to the engobe or in increasing its fusibility and contraction.

Sometimes cracks in the engobe are due to the use of gum or other materials intended to make the slip adhere better to the goods; or to the use of acid salts or materials which coagulate or decompose the slip, such as alum, sulphate of copper, etc. These latter may often be cured by the addition of a sufficient quantity of soda solution to just neutralise their effects; this will not, in most cases, materially affect the fusibility of the engobe. For the rest there is no cure except a discontinuance of their use.

The use of a too coarsely ground engobe will sometimes cause it to crack; in this case the remedy is obvious.

Crawling of a glaze (especially of a stoneware glaze of the Bristol class) may be due to too high a percentage of alumina or to excessive zinc oxide, but is more frequently due to too thick a coating of glaze. If the ware is dusty it is sure to crawl.

Other causes are imperfect ventilation in the kilns, bad firing, and even careless setting. The addition of a little extra flux to the glaze will often cure it (see also 'Peeling,' p. 206).

Crazing or cracking of the glaze is exceedingly difficult to prevent as it is almost, if not entirely, due to the glaze and clay expanding to different extents for the same change in temperature. In coloured glazes, especially, it is difficult, when altering the expansibility of a glaze, to avoid changing the colour, and consequently many of the cheaper articles on the market craze badly as they grow older. It is, in fact, one of the difficulties in connection with this defect that it does not always show itself before the goods have been sold.

If crazing occurs suddenly in a glaze which is generally free from this defect, and the firing, and especially the cooling, of the kilns has been properly carried out, it is likely to be due to an unnoticed variation in the composition of the felspar or Cornwall stone used in the glaze. Thus a stoneware glaze which ordinarily is particularly free from crazing will often craze badly if 5 per cent. of soda be added to it; yet such a variation in the percentage of alkali in the felspar and stone is by no means uncommon.

Crazing may also be due to change in the methods of work, such as applying the glaze to green instead of to biscuit goods and *vice versâ*, or to applying too thick a coating of glaze to the goods. As, however, the clay and glaze always tend to exchange some of their constituents, there is continually a chemical action going on whilst the goods are at a high temperature, with the result that on prolonged heating the glaze tends to become less fusible and the clay more so; and as the reaction is to a large extent dependent on the relative masses and surfaces of the two, it follows that the thinner the glaze the better chance will it have of attaining to a composition more like the body on which it is placed. For this reason a prolonged firing, or an increase in the temperature of the finishing point of the kiln, will often prove an efficient remedy for crazing if the defect be not too pronounced; in the former treatment the partial volatilisation of the alkalies in the glaze may also help.

Seger has studied the causes of crazing exhaustively, and recommends the following as the best remedies:—

(*a*) Use a smaller proportion of plastic material in the body, and increase the proportion of flint or quartz.

(*b*) Grind the body more finely, especially the siliceous portion.

(*c*) In non-vitrified bodies increase the amount of fluxing materials; but if the bodies are vitrifiable, as in porcelain, use a smaller proportion of flux, especially of felspar.

(*d*) Prolong the heating of the kilns.

Instead of altering the composition of the body it is often easier to alter that of the glaze, in which case Seger recommends:—

(*e*) Increase the proportion of flint or quartz in the glaze, taking care that there are never more than three molecules of silica to each molecule of alkali in the glaze; in this instance assuming that one molecule of alumina is equivalent to three molecules of alkali.

(*f*) Substitution of part or all the silica in the glaze by boric acid; this also lowers the melting-point of the glaze.

(*g*) Replace some or all of the alkali in the glaze by others of a lower molecular weight (see later for Table of Molecular Weights). This is equivalent to increasing the proportion of silica. Thus the use of zinc oxide as an 'anti-craze" depends on the fact that its power of combining with silica is to the power similarly possessed by lead oxide, in the proportion of the molecular weights of these oxides, viz. 79 : 223; so that if a glaze containing 55 per cent. PbO and 45 per cent. SiO_2 were found to craze under certain conditions, it might perhaps be cured by the substitution of zinc oxide equivalent to half the lead oxide present. This would produce a glaze containing 33 per cent. PbO, 12 per cent. ZnO, and 54 per cent silica; that is to say, the percentage of silica would be increased nearly 10 per cent. by this means. Such a great change in composition would, however, seldom be made in actual practice.

When a glaze on a vitrifiable body crazes through the body being over-fired, it is really due to the glaze not being able to absorb sufficient silica from the body. The addition of a little flint to the glaze will often effect a cure.

Crazing is most likely to occur on bodies with low flint, high clay, and more than 30 per cent. of felspar.

Crooked Ware may be caused by lack of sufficient support in drying, by irregular drying, by careless placing of the goods in the kilns, by too great a heat in the kilns so that the ware is partly fused, or by an error in the mixing of the body so that too much fusible matter (or, conversely, too little infusible matter) has been introduced into the mixing. From whatever cause, except in the most complex shaped vessels, the production of crooked or warped ware is preventible.

Crystals in glaze are due to the formation of silicates which are soluble in the remainder of the glaze, and which separate out in the form of crystals when the glaze is cooled sufficiently slowly. When regarded as a defect (see 'Blinding'), the formation of crystals may be prevented by rapid cooling of the glaze, by applying a thinner coating of the glaze to the goods, or by such an alteration in the composition of the glaze that mono- and bi-silicates and not tri-silicates are formed.

Curving or warping of the ware is treated under 'Crooked Ware.'

Dimness, or lack of lustre, in glazed ware is usually due to faulty firing of the kilns. Other causes are mentioned under 'Dullness.'

Dirt has been aptly defined as 'matter in the wrong place,' and its occurrence is generally due to carelessness or ignorance. Some remedies may be found under 'Spots,' 'Discoloration,' etc., according to the appearance given to the ware; in most other cases the nature of the dirt will give a clue to the best means of preventing its occurrence in future, such as greater cleanliness in the workshops, kilns, and yards, inspection of saggers for loose pieces of clay or dust, arrangements for preventing dust from blowing on to the goods, and so on, not omitting watchfulness over the men lest by the thoughtless sharpening of their tools at the working bench they introduce metallic filings into the clay, or by lack of personal cleanliness, especially when making coloured slips or glazes.

Discoloration may occur on either the unbaked, the biscuit or the glazed goods. In the first case it may be due to impurities in the clay forming a kind of 'scum' (which see), or to dirty, careless workmanship or improper storage.

If the discoloration is formed on the baked ware it may be due, in addition to the causes just named, to (1) improper placing in the kilns so that the flame licks the goods and so discolours them; (2) to insufficient air in the kilns, so that the combustible matter in the clay is not completely consumed, or (3) the iron incompletely oxidised. Some clays contain so much vegetable matter that, unless very slowly heated, they catch fire and the goods are drawn out black from the kiln. The only remedy is to limit the supply of air at the commencement of the heating, so that only a small proportion of the material can burn at once, and to prolong the heating at a dull red heat until all the coal or other combustible matter in the clay has been completely removed.

In the manufacture of goods in which the colour of the baked clay plays an important part, as in red bricks and some terracotta, discoloration is commonly due to improper firing. This subject is a complex one, and many points in it are by no means fully understood as yet: some useful hints will, however, be found under the heading 'Colouration' (p. 6).

Discoloration of glazed goods may be caused by the impurities in the clay or glazes used, or by 'dirt,' 'scum,' or 'steam,' or, in the case of certain coloured glazes, by the colouring materials volatilising and condensing on other goods placed near. This is particularly the case with glazes containing copper or cobalt.

Where lead glazes are employed a blackening of the goods in the kilns may often be due to the use of a reducing fire by which the lead compounds are reduced, sometimes with the production of sulphur compounds; in this case, a remedy should be sought in the supply of more air to the fuel.

Where fires are badly supplied with air and the temperatures of the kilns increased with great rapidity, black particles of soot or carbonaceous matter may be deposited on the goods and become surrounded by the melted glaze in such a way that the air is unable to burn out the carbon. For this there is no direct remedy other than prevention, which is always better than cure.

Most coloured glazes are very sensitive to temperature change when near their melting-point, and still more so to the composition of the atmosphere in which they are heated: thus copper in an alkaline glaze at a moderate temperature, and with a plentiful air supply, will produce a blue colour; with a siliceous glaze under similar conditions this will be turned to green; whilst if heated in a strongly reducing atmosphere so that cuprous compounds are formed, red glazes will result; or if the atmosphere varies and is at one time oxidizing and at another reducing, a combination of these colours will be formed. Chrome compounds under powerfully oxidizing conditions tend to form characteristic buff compounds instead of the usual green ones.

Discolorations due to uneven coating of the goods with a coloured glaze, or to not making a sufficient allowance for the run of the glazes, suggest their own remedies.

Other forms of discoloration are treated under the headings 'Blotches,' 'Spots,' 'Sulphur,' etc.

Iron spots (pyrites) may often be removed by a finer grinding of the clay whereby the blotches are converted into black 'pin-points,' but in many works it is more satisfactory to clean the grinding mill off twice daily and to throw away the sweepings; these will contain most of the pyrites, which, on account of its hardness, will not grind so easily as the clay.

Buff-burning bricks are often discoloured with faulty burning and with defective preparation of the clay. In clays of this class containing both lime and iron a red surface discoloration may be due to the sulphuric acid from the flue gases decomposing the iron-lime compound, and so allowing the iron to give its natural red colour in places.

Much discoloration of unglazed goods is external and due to flue gases, etc. This class of defect is referred to under 'Scum.' Other forms of discoloration are due to sulphur in the fuel, and these can often only be avoided by substituting wood for coal, when very sensitive colours are being fired, though for most purposes the use of a purer coal will bring about a cessation of the defect.

Dryness and **Dullness** of the glaze is generally due to one or more of the following:—

(*a*) Too little glaze on the goods.

(*b*) A too infusible glaze which does not mature properly at the temperature of the kilns.

(*c*) An error in the firing of the kilns.

(*d*) Placing the goods too near unglazed surfaces, or to the use of unglazed saggers.

(*e*) To the biscuit being so hard fired that it does not absorb sufficient glaze when the goods are 'dipped.'

Dunting is a variety of 'cracking' of the clay goods due to either too rapid heating, or too rapid or irregular cooling; but the expression is often used to denote cracks from other causes. If the crack shows an opening at the edge, too rapid firing at the commencement may be suspected; though carelessness in the making or in the placing may be the cause, as considerable experience is required in the allocation of such defects to their true sources.

If the dunt is produced in the cooling it will usually show no opening at the edge of the crack, and if broken, the edges of the crack will be quite smooth; if the crack was in existence before firing commenced, the fracture will generally be much rougher.

Glazed ware which has been removed from the kilns before it was sufficiently cooled will often make a series of noises like small pistol shots; if the ware be then carefully examined, each of these reports will be found to be represented by a crack.

Efflorescence is a variety of 'scum' (p. 210) produced by salts in the material which gradually crystallise out on the surface of the goods. If this occurs during the drying of the goods in the clay state it may sometimes be prevented by adding baryta or barium carbonate to the clay in the pug mill in quantity sufficient to decompose the salts present; this can only be done when these salts form insoluble compounds with the baryta. Painting the goods with starch paste or with oil or tar is often useful as a preventative, or in some cases an increase in the temperature of the kilns will afford the desired freedom by causing the salts to combine with the clay.

When the efflorescence is produced some time after the goods have been in use (as in certain kinds of bricks which turn white in places after a time), the cause may usually be found in the mortar used or in the position of the goods, which have been so placed that they absorb water heavily laden with mineral matters which are deposited as the bricks dry. A gentle sponging of the goods with very weak hydrochloric acid will often remove the deposit.

This subject is more fully dealt with under the general heading of 'Scum.'

Feathering is a species of crystallization which sometimes occurs in glazed goods, and is due to unsteady heating or to draughts during the cooling of the kilns. Some glazes are more liable to this defect than others, especially if they are capable of forming a definite compound (silicate) with part of the constituents of the glaze which is soluble in the remaining portion of the glaze. Leadless glazes containing a large proportion of lime often do so.

Flashing is a term used to denote the effect of a luminous flame on clay goods whereby the latter are changed in colour and 'scorched.' Goods so discoloured cannot as a rule be cleaned; it is therefore necessary to prevent the access of flame to the goods either by placing them in properly luted saggers, or, in the case of commoner goods, of placing them where the flame cannot reach them.

Flowing is a process of glazing by vaporisation, in which a volatile compound of the colouring matter is produced and deposited on the surface of the ware. Blue is the commonest colour applied in this way, though greens are produced from copper compounds. The usual material for producing the volatility is a chloride, the particular chloride selected being dependent on the nature of the ware; lead chloride or a mixture of salt and saltpetre or bleaching powder are frequently used, generally in the form of small pellets which are placed in the saggers along with the vessels to be decorated, the colour itself being applied to the ware. If the saggers are properly luted, and the other conditions suitable, the chlorinated atmosphere will cause the colour to spread from the design on to the surrounding white body in the form of a kind of halo, the extent to which this takes place depending on the amount of colouring matter on the goods, and on the length of exposure to the chloride.

When flowing exists as a defect, it is usually due to the presence of a chloride and some metallic oxide which the chloride can volatilise.

Frost is at once the great friend and enemy of the clayworker according as he uses, or misuses, its effects.

As a means of breaking up the raw clay no means devised by man have proved so effective as frost, and, in spite of the great advance in machinery, many of the most skilful clayworkers prefer to weather their materials, whilst many of the smaller works would be closed were it not for the beneficent influence of this agent.

Frost acts chiefly by converting the moisture of the clay into ice, which occupies a larger volume than the original water and so causes the disintegration of the mass. On this account it is necessary that the clay should be exposed as much as possible, and that it be kept sufficiently moist.

On the other hand, all goods exposed to frost are liable to suffer damage, though many withstand its influence for a long time. Better class goods should always be protected.

Glossiness in the glaze is sometimes difficult to obtain with leadless glazes. It appears to be in some way connected with the molecular weight of the fluxes used, but the exact relationship has not been determined. Ware which is kept too long in the kilns at the melting-point of the glaze will often lose its gloss, which may, however, often be restored by a relatively rapid heating and cooling. Under-firing, or an insufficient thickness of glaze, will also cause a lack of lustre; whilst goods placed too near unglazed surfaces in the kilns will often suffer from the same defect.

Heating of the drying rooms and kilns is to be considered as most important if successful manufacture is desired. The great point to be remembered is that all heat must be applied *steadily*, as irregular temperatures will prevent best work being done. It is therefore advisable to have some means of controlling the firemen in order to prevent their firing irregularly, especially at night, and various appliances for this purpose are described under 'Tests.'

The effects of too much or too little heat are dealt with under the headings 'Over-firing' and 'Under-firing,' but it must be borne in mind that goods may be spoiled by too slow or too rapid heating, although the actual temperature attained when the kiln is at its maximum may be correct. Too rapid heating will sometimes give a result similar to over-firing, whilst it is almost certain to crack the goods; too slow a heating, on the other hand, wastes fuel, and, especially near the finishing point of the glost kiln, is apt to produce goods insufficiently glossy or 'dry.'

Holes or **Hollows** in the surface of the goods are produced when a piece of combustible matter has got into the clay. When the goods come out of the kilns this matter has been burned out, and a hollow place results. This defect is most frequently due to carelessness, either on the part of the clay-picker, who has not done his work properly, or on the part of other workmen who have carelessly allowed pieces of paper, food, coal, or similar material to become mixed with the clay. Air imprisoned in the clay also 'blows' or 'blisters' in the kiln.

'Pinholes' on the surface of the glaze are discussed on p. 207.

Lime, or chalk in moderate-sized pieces, sometimes produces holes, but may be prevented by a finer grinding of the clay.

Iron causes various defects. See pp. 8, 53, 192, 200, etc.

Laminations are frequent in wares made by compression, and are often extremely difficult to avoid. They are commonly produced by a lack of pressure in the machine, or to the pressure being unequally distributed. As comparatively slight errors in adjustment will cause a serious loss of strength in the goods due to the lamellar structure of the same, the services of an expert had better be requisitioned, or the matter put into the hands of the machine makers.

Limey Clays, unless crushed very fine, will 'blow' when burned. Washing is preferable to crushing very fine, but is somewhat more expensive.

Lumps on the surface of the goods as they come from the kilns may be due to the ironstone contained in the original clay, which has not been removed by the picker, or to pieces of material (sagger, dust, or ashes) falling on the goods whilst in the kilns. If the goods are heated too rapidly, the contained moisture or gases produced from the combustible matter in the clay may not be able to escape without lifting up a portion of the surface of the goods, very much like a miniature volcano; in this case the remedy is obviously to heat more slowly.

Moisture in the kilns is often unsuspected; yet, when present, is a source of great trouble to the clayworker. In some cases the site of the kilns renders it extremely difficult to keep the kilns dry, but this must be done if successful work is to be carried on.

Moisture in the goods can scarcely be termed a defect; its removal is treated of in the section on Drying.

Moisture in raw materials, especially those used for glazes, is often excessive. The best firms of dealers will supply on a guaranteed basis of moisture (commonly 10 per cent.); but even then it is very desirable that each purchaser should test his own goods, or he may easily buy water at the price of felspar or lead. (See p. 246.)

Oil on goods will prevent them taking the glaze until it has been removed by firing. It is, therefore, important that all butter or other fatty goods as well as lubricants should be rigidly excluded from places where they can spoil the goods. Even where oil is legitimately used in a clayworks, care should be taken as to its quality, as the author once had considerable difficulty in tracing the source of some very objectionable iron spots until the oil was found to be the cause. When oil is required for lubricating clay goods which are afterwards to be glazed without previous firing, paraffin may often be employed; care must, however, be taken that it is free from non-volatile oils, which would prevent the glaze from adhering to the goods.

Over-firing is one of the chief sources of loss in most clayworks; it is brought about by a variety of causes of which the greater number are due to carelessness. Unless the fault be excessive, this defect is not of so much consequence in terra-cotta works or in those where only white or transparent glazed goods are produced; but, in the case of coloured ware, the colour of the article may often be ruined by the fireman's carelessness in this respect.

The chief characteristics of over-fired ware are distortion of shape or design, running of the glaze, and improper colour of the goods. These can only be avoided by the clayworker determining exactly the conditions necessary for successful firing for his particular goods, and insisting on these being maintained, using such instruments as are available for the determination of the temperature, draught, etc., so as to afford an efficient control.

Paleness of colours may be due to faulty making of the material, to the colouring matter being adulterated, or to the presence of interfering substances; these, however, are matters for the professional chemist and analyst. If the firing of the kilns be unduly prolonged, some colours, being more or less volatile, will become light; or through faults in the application of the colour to the goods, the latter may not receive sufficient colour. This is particularly the case where the colours are applied in the form of a slip in which the goods are dipped, as the colouring matter, being often very 'heavy,' settles rapidly to the bottom of the dipping-tub.

Parting of the glaze is a common fault of leadless glazes which contain too large a proportion of felspar; but it also occurs in other glazes excessively rich in fluxes. The surface tension of the melted glaze is so much greater than the force with which it adheres to the clay that the glaze gathers itself into globules of varying size. As porcelain bodies have a composition much more nearly allied to that of the glaze than have other bodies, it follows that parting but seldom occurs in this branch of the trade, whilst it is not unfrequently met with in the application of new glazes or colours to bodies of refractory clay. The most appropriate remedy consists in the addition of some infusible material, such as flint or clay, to the glaze; but where this is not practicable, the difficulty may often be overcome by adding lime, chalk, or other flux to the clay of which the goods are made. In the case of cheap or large goods, it is more economical to cover them with a slip composed of the clay of which they are made mixed with the flux, and then to glaze in the usual way.

Peeling or 'scaling' of the engobe, or of the glaze from the body of the ware, is generally due to a difference in the relative expansibility of the materials used. In this respect it may be regarded as the complement of 'crazing.' Seger has recommended that the following alterations be made in the *body*:—

(*a*) Reduce the proportion of silica (flint) and increase the proportion of plastic clay.

(*b*) Substitute kaolin or china-clay for the more plastic clay.

(*c*) Increase the proportion of felspar.

(*d*) Use less finely ground materials, especially flint.

(*e*) Fire the kilns at a slightly lower temperature.

He also recommends that in the *glaze*

(1) The proportion of alumina and silica be reduced or the fluxes increased.

(2) Part of the silica be replaced by boric acid.

(3) Part of the alkali or alkaline earth meals be replaced by others of higher atomic weight (p. 198); thus sodium carbonate might be replaced by whiting (calcium carbonate), or whiting by barytes.

(4) A shorter time of exposure to the maximum temperature of the kiln, or heating the goods to a lower temperature, as over-firing tends to produce peeled goods. Thus on firing a piece of glazed ware normally it may give a good result, yet, if under-fired, may craze, and, if over-fired, may peel.

It is, of course, to be understood that this alteration in either body or glaze is to be made systematically, and only one of the above suggestions carried out at once in order that its effect may be determined. The prevention of peeling and crazing is one of the greatest difficulties of the potter's art, and it can only be solved by careful and often prolonged trials.

Other causes of peeling are:—

(*a*) Oil or grease on the surface of the goods.

(*b*) Too high a polish on the surface of the clay if the goods are glazed in the green state.

(*c*) Dust on the goods; this and the superlative polish are best removed by passing a clean damp sponge lightly over the goods just before glazing.

(*d*) Stones in the clay of which the goods are made will often cause peeling by their shrinkage on heating; in this case the clay must be more finely ground before use. The same treatment must be used if the peeling is the result of an insufficiently homogeneous mixture, if a fat and lean clay is employed, special attention being paid to the pugging or mixing of the clays.

Perspiration being often of a greasy nature acts very much like oil when it gets on the goods; special care must therefore be taken to prevent ware which is to be glazed from being fingered more than is necessary.

Pinched Ware. See 'Crooked Ware' and 'Warped Ware.'

Pinholes are produced in various ways, the commonest of which is the use of too hard a glaze or of insufficient firing. Another frequent cause of pinholes is dust on the ware before glazing, or falling on the goods whilst the glaze is still sufficiently damp for it to partly sink in. If the glaze gives off tiny bubbles of gas when near its fusing point, or after it has fused, these may rise to the surface and then break, leaving a small depression on the surface of the glaze.

Whilst the remedy must necessarily depend to a large extent on the cause of the pinholes it will generally be found that by softening the glaze somewhat, by the addition of a small proportion of flux, or by slightly increasing the temperature of firing, the defect may be prevented. Ware which is pinholed may often be cured in this way by re-glazing with a somewhat softer glaze; but if the defect is due to dust of such a nature that it will not 'take' the glaze, this treatment will not be effective.

Pinholing is often said to be due to air-bubbles in the glaze or glaze slip; but experiments made by the author, in which air and various gases were purposely worked into the glaze before use, failed to produce this defect.

Pitting is commonly due in unglazed ware to the presence of organic or combustible matter in the clay, which burns out in the kilns and so leaves pit-marks. These may sometimes be removed by a polishing wheel of hard earthenware, or by filling them up with a paste of finely-ground pitchers, clay and water, and passing the goods a second time through the kilns; but the only satisfactory remedy is to be found in a more careful preparation of the clay.

Pitting in glazed ware may be treated as under the head of 'Pinholing.'

Plucked Ware, or ware which has had pieces pulled out of it in removing it from the stilts or from the kilns, is usually due to the use of improper supports, or of using them in an improper manner; but it may also be due to over-glazing, so that the glaze runs down and cements the support to the ware itself. Inefficient cleaning of the glaze from the bottoms of the goods will produce the same defect. If goods are so badly placed that they fall over and so touch other pieces, or if the kiln is so over-fired that the same result happens, the placers or burners may be justly blamed, though with ware of entirely new and unaccustomed shape some little allowance may have to be made in this respect.

Porosity is a special characteristic rather than a defect in ware. It may be increased in dense-burning wares by mixing the clay with fine sawdust or other combustible material before use, which will burn out in the kiln; or it may be diminished by adding more easily fusible clay or some natural flux to the clay, but in this case it must be remembered that the total refractory power of the clay is reduced in proportion as its porosity is diminished. When it is desired to make clay goods entirely non-porous, they are usually glazed both inside and out.

The firing of clay which contains a notable proportion of coal, sawdust, or other combustible matter is often difficult and requires the greatest care, or the kiln will catch fire and the goods be spoiled.

The determination of the relative porosity of different clays is referred to on page 288.

Porosity may be reduced by mixing the clay with a low-melting clay, felspar, or stone, but this treatment often presents difficulties in the working of the clay.

Roughness of the surface of goods coming out of the kilns may be due to lack of care or skill on the part of the maker, to an excessively rapid heating of the kiln in the earlier part of the firing, or to impurities, especially pyrites, in the clay if the goods are unglazed, whilst roughness of the glazed surface is one of the commonest signs of under-firing, though a particular kind of roughness (blisters) may be due to too much heat, or to placing the goods too near an unglazed surface.

Roughness is a defect of so general a nature that it is almost impossible to treat it efficiently without seeing the goods; a little care and patience will, however, generally elicit the cause and discover a remedy.

Running of the glaze is most frequently, if not invariably, due to its being too fluid at the temperature of the kilns, so that if the latter cannot be altered, the glaze must be rendered less fusible by the addition of hardening materials, such as flint and clay. In coloured glazes, however, the shade is affected by this treatment, so that the clayworker is placed in a dilemma, the only feasible remedy then being to arrange the thickness of the glaze in such a way that as little of it as possible shall actually drop off the goods.

Where the colour of the glaze is of secondary importance running may usually be prevented by a careful addition of alumina, either pure or in the form of clay, taking care to keep the ratio of acid oxides to basic oxides within the limits necessary for a satisfactory glaze.

Salts and **Saltpetre** show as a whitish incrustation or efflorescence on the surface of the goods either before or after firing. The term 'saltpetre' is generally incorrect when used in this connection, as the incrustation is not often due to this substance, but to sulphate of lime. For further particulars, see 'Efflorescence' and 'Scum.'

Scratches, chiefly on glazed goods, are invariably preventible;

they are caused by some hard substance coming in contact with the goods.

Scum is a term used for a variety of defects of the surface of the goods. It is applied indifferently to the exudations from the goods and to various deposits which exist entirely on the surface, such as condensations of various kinds and crystalline deposits. It is therefore necessary to ascertain, as completely as possible, the nature of the scum, which can to some extent be accomplished by breaking the scummed article and endeavouring by means of a powerful lens to ascertain whether the 'scum' has penetrated below the surface. An examination of the physical state of the scum—as to whether it is amorphous or crystalline, its colour, etc.—is also important.

Broadly speaking, the causes of scum may be found in the materials employed, and in the absence of sufficient care in keeping the goods clean either in the drying house or in the kilns, or, less frequently, in the faulty storage of the finished goods.

By the nature of the case, different branches of the clayworking industry suffer in very different ways from this defect: fine pottery, for example, is seldom or never troubled by scum due to the materials themselves; whilst in bricks and terra-cotta this is the most usual source of trouble, consequently they may be considered first.

Scumming due to the materials used may show themselves as more or less white crystalline deposits, penetrating slightly into the article, and observable either when the goods are dry or when they have been fired and exposed to damp air. In the former case the scum is almost invariably due to soluble salts in the clay or in the water used, the most important of these salts being the sulphates of sodium, magnesium, and calcium (lime). The corresponding chlorides and nitrates are only very occasionally the cause of scum, which is fortunate, as these latter are particularly difficult to remove. If the cause lies in the water used being impure, especially if it contains much oxidized sewage matter, the supply will probably have to be changed unless only low-class goods are being made. If, however, the water is merely contaminated with sulphates, it may be used, and the effects of the impurity neutralised by the addition of baryta, barium chloride, or barium carbonate (see below).

In the majority of cases the scum caused by salts is due to these impurities being in the clay and not in the water, though they are also occasionally formed during the firing, owing to the sulphur in the fuel combining with the bases in the clay to form sulphates. Various attempts have been made to remove these scum-forming salts from the clay by wintering or washing the clay before use; these methods have not, however, proved very successful, and in some cases, as in a clay containing pyrites, the proportion of soluble salts may actually be increased by this treatment.

The state of the goods when the scum is first observable must regulate the treatment most likely to effect a cure. Thus, if the scum is noticed on the goods in the drying room it may happen that it is due to sodium compounds, which will combine easily with the clay at the temperature of the kilns and so cause no further trouble. If, on the other hand, it is due to lime salts, these may not combine with the clay, and the goods will be scummed on drawing them from the kilns.

What is sometimes regarded as a brown scum is due to soluble iron salts, formed by the oxidation of pyrites in the clay; this is often very difficult to prevent, though the use of carbonate of barytes is frequently of service.

In the manufacture of bricks, the oil used not infrequently contains soap: this will occasionally produce an alkaline scum which leaves patches of glazed surface on the fired goods. It can only be prevented by the use of an oil free from this impurity.

The methods which have been proposed for preventing the formation of scum formed during the drying of the goods are chiefly of two classes: those which endeavour to convert the scum-forming salts into harmless substances, and those which consist in covering the goods with a colloid material which will absorb the salts and will fall off when the goods are removed from the kiln.

The first of these classes of 'cures' is represented by the use of some baryta compound (usually the carbonate) which is added to the clay when it is being worked up with water into the plastic state. Barium *chloride* must not be used in presence of much *calcium* sulphate, as the formation of the highly soluble calcium chloride actually increases the amount of scum. The baryta compound converts the greater part of the soluble sulphates into the insoluble barium sulphate, which cannot then rise to the surface of the goods, and hence can form no scum. It is often advisable with some of the better-class goods to use a little chloride of barium in addition to the carbonate, especially if soluble iron salts are present. In all cases it is necessary to add the chemical in fairly accurate proportions, as an excess may produce the very defect it is sought to avoid. A method for determining how much baryta will be required is described later. This determination should be made at fairly frequent intervals as the proportion of scum-forming salts in the clay is apt to vary considerably. The material is best added by making it into a cream with water and applying it to the clay by means of a watering-can; the clay is then thoroughly well mixed, as it is essential that the baryta be as evenly distributed throughout the mass as possible.

The second class of 'cures' usually consists in painting the goods with tar, or with a starch or flour paste, or even with oil, the object being to cover the goods with a material which shall be sufficiently porous for the goods to dry rapidly and at the same time to allow the scum-forming material to be produced in or on this outer covering instead of on the surface of the goods. The advantage which such a coating also possesses is that it prevents, to some extent, flashing of the goods by the flame in the kilns; but its disadvantages are that the mass is apt to putrefy if made of starch or flour, and is in any case somewhat expensive in application. In this connection it is interesting to note that M. Perkiewicz has patented the use of a mixture of flour and gelatin applied in a special manner, practically without cost to the goods, which appears to overcome several of the greater disadvantages of this method of scum prevention. The method has been greatly praised in some parts of the Continent, but it has not been tried on any large scale in this country.

Certain varieties of scum are formed on the goods whilst they are in the kilns owing to unsuitable firing, or to the use of a highly sulphureous fuel. Condensation of steam on the goods during the preliminary 'smoking' or 'stoving' is also responsible in some cases, as flashes of flame are in others. Some clayworkers employ sheets of paper for covering the exposed surfaces of their goods during the preliminary heating, but great care has to be taken not to use a paper with any considerable proportion of flux in its ash, or the goods will be vitrified in places. Though undoubtedly useful in a few cases, this method is not of any general application.

When goods (especially bricks) *which have been in use* for some time show signs of scumming, this is generally due to one of three causes:—

(*a*) To salts contained in the place where the goods are stored, as when they are piled on a foundation of ashes or slag.

(*b*) To the use of unsuitable mortar.

(*c*) To unsuitable firing.

In the first of these cases the goods draw up moisture more or less saturated with salts, which are carried to the surface of the goods as the water evaporates and there remain as a scum.

Clearly the only remedy in this instance is to take care that this absorption of salts cannot take place, by altering the material on which the goods are laid.

If mortar containing a considerable proportion of soluble matter is used the bricks will show a similar effect to that just mentioned, except that in this instance the scum will be more evenly distributed over the surface of the wall, whilst in the former one the greatest amount of scum will be but a few feet from the ground. Scrubbing the scummed surface with hydrochloric acid diluted with about ten times its volume of water will often effectually remove this class of scum, but care must be taken not to allow the acid to come in contact with the mortar.

If goods scum during use owing to improper firing they cannot, of course, be cured. E. Cramer has pointed out that a reducing fire is often helpful in such cases, as the sulphates are decomposed by this means; but great care is required, or the use of a reducing fire will be found productive of almost innumerable difficulties.

According to Dr. Mäckler's researches it would appear that in the case of finished (fired) goods the amount of scum formed bears no definite relation to the proportion of soluble salts they contain, but that there is a pretty definite connection between the amount of magnesium and sodium sulphates and that of scum. The porosity of the material also seems to be of little influence, but the capillarity (or power of the material to lift liquids through its pores) is very marked. This capillarity is greater the smaller the diameter of each individual pore, hence partially vitrified bricks seldom show any scum. The heating of the goods to the point of incipient vitrification is, in fact, the best remedy for scum, as in this way the salts combine with the alumina and silica of the clay. This is, however, impracticable in many cases as the colour of the goods would be thereby spoiled.

There is no rapid method of determining whether a particular batch of goods will scum or not during use; but Dr. Mäckler has found that the method described on page 296 gives excellent results, and is, in fact, so delicate that it will produce a noticeable scum in cases where the same goods under less severe conditions would be free.

In those cases where the use of baryta in any form would be too expensive it is usual to cover the scum-forming clay with an engobe of superior clay, which may or may not contain baryta compounds. The use of such an engobe is, however, attended with so many difficulties that its employment should be avoided whenever possible. The Perkiewicz patent coating, made at the Ludwigsberg Moschin Clayworks, in Germany, will often afford help when other means have failed.

Settling of the glaze-slip is to be strenuously avoided, as if it is allowed to occur the fusibility of the glaze will be altered owing to the lighter constituents being removed in the dipping, whilst if the glaze is a stained or coloured one the colouring material will be applied unevenly to the goods. The only way to prevent this is to keep the glaze well stirred up whilst in use, though the addition of a very small quantity of finely-powdered alum to the slip will sometimes be found to be of value in keeping the heavier particles of material longer in suspension.

Shelling or peeling of the engobe or of the glaze is due to the glaze and body not being properly adapted to each other, and so not expanding or contracting to the same extent when the temperature of the goods is changed. This lack of agreement may be owing to the use of a glaze of unsuitable composition, or of an engobe containing too much plastic clay; or it may be that the heating of the kilns has not been so arranged as to give the materials the desired composition; that is to say, the molecules may not have had an opportunity to arrange themselves in such a way as to produce the desired compound, even though the recipe has been closely followed in making up the engobe or glaze.

This defect is largely produced by causes of an opposite nature to those producing crazed ware; further information as to these causes will be found under 'Peeling.'

Shrinkage of clay goods on firing is not in itself a defect, but when the change in volume takes place irregularly so that the goods lose their symmetrical shape and 'warp,' there is something abnormal. This will generally be found to be due to carelessness or lack of skill in the drying or placing of the goods in the kiln, or to attempts at mending damaged or incomplete pieces with clay of unsuitable stiffness. It is less frequently due to some other class of clay having become accidentally mixed with the bulk of clay used.

When the body is covered with a clay engobe, the latter, if it shrinks more than the former, will tear or peel, and this must be remedied by the addition of more siliceous matter in the form of sand, quartz, or flint, or by replacing some of the clay in the engobe by one of a more refractory nature.

Excessive over-firing will raise the temperature of the clay too near to its softening point and so cause the goods to shrink unduly.

Smoked Ware is really a misnomer, as the appearance which characterises it is not due to smoke, but to the reduction of the lead in the glaze. The name is presumably derived from the curious discoloured appearance of the ware, sometimes resembling smoked glass. It is commonly caused by allowing the grate-bars to become choked with clinkers so that the kiln fires are not supplied with sufficient air, though it may also, in some measure, be due to the use of inferior fuel. This latter may produce a large proportion of clinker, especially if it contain much pyrites, and so render it difficult for the fireman to keep his bars clear. The remedy is to use a fuel as free from fusible ash (clinker) as possible and to allow the fires to burn quite clear before stoking and charging with fresh fuel, at the same time taking care that they do not burn so low as to actually lose heat in the kiln. Great care must also be taken that sufficient air is supplied to the fuel, particularly at the finishing of the firing, and on the introduction of each fresh charge of fuel. If, in spite of such precautions, the ware is still found to be smoked, the flue gases from the kilns should be analysed to determine whether they contain reducing gases; if so, the air supply will have to be still further increased. True 'smoking' cannot occur in leadless glazes, unless they contain colouring matters which form dark-coloured compounds when heated in a reducing atmosphere: defects of this kind are usually more of the nature of 'discolorations' (which see).

Soluble Glaze is a matter with which some potters have had difficulty. The solubility may apply to the glaze as a whole, or it may only refer to the presence of lead in a form in which it can be extracted by water or weak acids. This latter difficulty has been made prominent by the action of the Government in restricting the use of lead in glazing. It is, of course, important that pottery used for domestic purposes should not yield lead to the fruit juices or other substances used for food, and for certain technical purposes it is necessary that the glaze should be capable of resisting the action of relatively strong acids, such as vitriol. Professor Thorpe has found that if all the bases in the frit are calculated as PbO and all the acid radicles as SiO_2, and the ratio of these two results is not greater than 1·45 : 1, the frit will yield practically no lead to acid of the nature and strength proposed as a Government standard (see p. 283). Hence frits can be made with a considerable proportion (up to 59 per cent. PbO) and yet be quite insoluble under the conditions of the test.

Lack of resisting power and solubility in a glaze are usually connected with its fusibility, the more highly refractory glazes being the most resistant. This is to some extent due to the fact that in these latter glazes silica (flint) takes the place of the borax used in the ordinary glazes; hence the replacement of boric acid by silica, or of borax by soda (or lime) and silica, will usually bring about the desired insolubility, but at the same time the fusing-point of the glaze is materially increased. In our present state of knowledge it is not possible to combine high resisting power to chemicals with low melting-point in a glaze.

Spitting-out may, like blowholes, be caused by the goods being placed in the kiln whilst too damp, the result being that the steam produced by the evaporation of the moisture forms a miniature volcano as it leaves the clay. Pyrites and similar materials will also cause 'spitting'; they indicate that the clay has not been sufficiently carefully picked over before grinding. If the spitting is due to the presence of organic (combustible) matter on the surface of the clay (particles of bread from the workers' meals are not uncommon in certain works), greater care must be exercised in the superintendence of the works in order to find at which stage this particular impurity is introduced. Air-bubbles in the clay due to insufficient pugging will also cause this defect.

Splitting of the body of the goods is generally due to lack of care or skill in the making of the goods, faulty jointing, etc., but it may also be caused by the goods being improperly dried (one part being allowed to dry too rapidly), to draughts, or to unsuitable placing in the kiln (not setting the goods level, not supporting them properly, or piling them too high upon each other). This last is one of the commonest causes of this defect in bricks.

Lack of sufficient support to projecting pieces during the drying of elaborately shaped articles, the use of too plastic a clay which is, consequently, dried too rapidly, and slight, yet important, defects in the mouthpieces of machine presses, are other frequent causes of this troublesome defect.

Spots may be due to a great variety of causes. If coloured, they may be a species of 'discoloration' (which see). They are chiefly of two kinds, according as they are due to impurities in the material itself or to external influences.

If the spots are on the terra-cotta, or biscuit, they may be caused by pyrites existing in a finely divided state in the clay, indicating imperfect sorting or 'picking' of the clay. Iron in other forms will also produce black or red-brown spots, the exact source of the iron being often very difficult to determine. Sometimes it may be traced to the workmen filing their tools at the bench where the clay goods are made; at other times the cause of the spots may be found to exist in the iron-containing oil used for lubricating the machinery getting into the clay or on to the goods; or, again, it may be traced to the use of dirty sand in the saggers so that it gets on to the goods when the saggers are being placed in the kilns. The remedies in such cases are obvious, but the substitution of sawdust on the knocking-out block in the last case deserves special mention. White spots on unglazed ware are usually due to the crystallisable salts in the clay being carried to the surface of the clay during the drying, and showing themselves later in the form of white spots or 'scum' (p. 210).

Yellow spots are often due to soluble iron compounds in conjunction with lime in the clay.

Raised spots are usually the result of dust or sand falling on the goods in the kiln; sometimes this happens when one sagger is being placed on another.

Spots in the glaze may be due to the workman allowing tiny drops of slip to fall on to the ware, to the glaze not being completely melted, or to its being imperfectly mixed, or to its being insufficiently finely ground or sieved. Dust falling on the goods will also produce raised spots more or less covered with glaze, whilst most of the causes of 'spitting' will cause the formation of 'spots' of various sizes which are raised somewhat above the general level of the glaze. Coloured spots in the glaze are mostly due to accidental impurity, a few grains of some 'stain' having got into the glaze (see 'Discoloration').

Stains may be in masses or in spots. See 'Discoloration' and 'Spots.'

Starving may be caused by stopping up the mouths of the kilns with fuel, thus lessening or even stopping the draught. As a result of the insufficiency of air thus caused, the fires at the back of the mouths may almost die out and so may admit cold air into the flues and make successful firing impossible. 'Starving' is also a result of not pushing the firebars well on to the brickwork supports at the back of the fireboxes; air can therefore leak into the flues behind the bars without being properly heated by the fuel, and so will not only diminish the draught but may also keep certain parts of the kiln constantly at a very low temperature, so that the glaze is never properly fluxed.

'Starving,' in other words, is almost invariably due to lack of sufficient air at the fire-grate, and it may, consequently, be remedied by arranging for a better or larger air supply to the fuel.

Streakiness in glazed goods may be caused by the fineness or coarseness of the glaze itself, or to unskilful application. In vessels with very uneven surfaces the glaze is apt to collect more thickly in the hollows and to run off the higher portions. When this is the case, the glaze will have to be 'touched up' before the goods are placed in the kiln so that these tendencies may be counteracted. In some cases very pretty effects are produced by allowing the glaze to run in certain directions. As a general rule, when ware is dipped it is best to have the glaze finely ground, as it dries more slowly in this condition, and so allows a more even distribution of the glaze on the surface of the goods.

Stripping off of the glaze or engobe is due to these not having a similar contractibility to the body of the ware. It is a special difficulty in the case of white enamels which contain tin as an opacifying medium, particularly when this substance is present in large proportions, *e.g.* over 20 per cent. Being due to the oxide of tin itself, this defect can only be remedied by a series of extremely careful experiments in altering the composition of the enamel without losing its opacity and gloss.

When stripping is due to the incompatibility of the body and engobe or glaze, it may generally be remedied in the way described under 'Peeling.'

Stunting. See 'Cracks.'

Sulphates, whether in the clay or in the water used, are apt to cause the formation of an efflorescence or scum on the goods. This is best prevented by the use of baryta compounds or by covering the goods with an engobe (see 'Efflorescence' and 'Scum').

Sulphates are also apt to cause turbidity in the glaze, as they may, under certain conditions, liberate free silica. By the use of a reducing fire at an early stage of the firing the sulphates will be decomposed and their turbidity-producing power destroyed.

Sulphur occurs to a notable extent in poor coal and produces a characteristic effect on glaze, especially when the latter is coloured. This effect can only occur when there is insufficient air in the kilns and fires, as, except in the case of the very worst fuels, the sulphur dioxide produced from the fuel should be carried off before it can affect the goods. As it does not usually pay to attempt to purify the fuel, care should be taken that the coal used is reasonably free from sulphur compounds.

Sweating or running of the glaze is referred to under this latter heading.

Swelling of the glaze is often noticed when a kiln has been seriously under-fired, so that the glaze has just begun to melt but still remains porous and dull; on further heating to the necessary temperature the swelling will disappear and a normal result will be obtained, provided that the glaze has not lost too much of its more volatile constituents by prolonged exposure to heat.

Swelling of unglazed goods is usually due to their having been placed in the kiln in a very damp condition, and then having been so rapidly heated that the moisture could not escape without the exercise of considerable force.

Temperature being of the highest importance in the firing of the kilns, as well as in the drying of the goods, great care should be taken in regard to its measurement and regulation, as errors in the temperature of the goods at various stages of the manufacture may prove to be a source of enormous loss.

Thinness of the goods themselves is a matter for which the designer and maker are responsible. As goods alter in shape in the kilns in proportion to their thinness, care is required to adjust this to the purposes for which the articles are required.

Thinness in the glaze on the surface of the goods drawn from the kiln is due to an insufficiently thick coating of glaze. This may be caused by the glaze slip being too watery, to its having settled somewhat, to its not having been properly stirred up before use, or to the dipping having been done too rapidly. When other methods of applying the glaze are in use, the defect will be found in the majority of cases to be due to an insufficient coating of glaze material on the goods.

It occasionally happens that if a piece of glazed ware is placed too near to an unglazed surface in the kiln that the latter will 'rob' the former without getting glossy itself. The cause of this curious action is by no means fully understood.

Turbidity in a glaze is most frequently the result of underfiring, the glaze not being properly fused. Sometimes the accidental admixture of some infusible matter, particularly clay slip, will be the cause, and, less frequently, an error in the proportions of the different materials used in the compounding of the glaze. When the defect is very pronounced a curious egg-shell appearance is produced which, on re-firing at a somewhat higher temperature, will be converted into an ordinary transparent glaze.

Minute bubbles of air or gas which have not been able to escape, owing to insufficient time being allowed for the glaze to mature, are occasionally observed, particularly when the glaze contains compounds which evolve oxygen at high temperatures.

Prolonged heating of the glaze at temperatures below its melting-point is apt to produce turbidity owing to some of the alkali (flux) in the glaze being volatilised. This may be remedied by a more rapid heating at the earlier stages, or by the addition of as much more alkali to the glaze before use as will counteract that lost in the kiln; great care is, however, necessary, as too much alkali will make the glaze 'trickle' or 'run' and will often be the cause of its crazing.

When the turbidity of a glaze is due to sulphur compounds the quality of the coal used needs attention; but even with good coal and a highly reducing atmosphere, insufficient air supply to the fires will cause turbidity. When large proportions of sulphates are present in the glaze, free silica will sometimes be formed and so cause turbidity; this may be prevented by the use of a slightly reducing atmosphere in the kilns up to just past dull red heat, and an oxidizing one for the remainder of the firing. In this way the sulphates will be decomposed before they have time to liberate the silica. Great care is required with reducing fires that no soot is formed on the surface of the goods, as this would become surrounded later by the melted glaze and no amount of heating would then cause its oxidation.

Twisted Ware. See 'Crooked Ware' and 'Warped Ware.'

Under-firing is one of the great troubles of the clayworker. As a general rule, it is far better to over-fire than to underdo it, as in the former case probably only a few goods will be spoiled, whilst in the latter case none of the goods will be worth much. The whole question of firing requires careful study on the part of both masters and men. Some further details will be found on page 170.

Unevenness in the glaze or engobe may be due to careless application, but it is not infrequently due to the running of the glaze. This latter is especially the case with ornamental ware in high relief. If the glaze is too soft or fusible it will tend to collect in masses in the hollower surfaces of the goods, whilst if it be too hard and infusible it will not flow evenly over the surface.

Raw glazes containing soluble matters will usually produce an uneven surface, as these matters are carried to the surface in the drying of the glaze. The remedy is to frit such glazes.

Some glazes settle rapidly, and so an even mixture of their components cannot be applied to the goods. In such a case the addition of a little powdered alum is sometimes useful, or the addition of 2 or 3 per cent. of gelatin to the slip (the gelatin being previously dissolved in about four times its weight of nearly boiling water), will convert the slip into a stiff blancmange-like mass, which can be applied to the goods like a paint. Being solid, the material has the advantage that raw and unfritted colouring materials can be added to the glaze with the certainty that, so long as the gelatin does not melt, the colour must be applied evenly, no matter what is its relative density.

Unevenness in colour is chiefly due to 'settling' of the colouring matter in the glaze, to careless application, or to firing. In the first case, the use of some denser medium for carrying the colour is necessary (the use of gelatin, as just described, being suitable in stained glazes), whilst in the two latter more careful superintendence of the workers is necessary. If it is necessary to have a number of goods of exactly the same shade, it is desirable not only to have them coloured at the same time and with one mixing of material, but to fire them in approximately the same positions and all in one kiln. If this is not done, the many factors which can influence the shade of ware will render it almost impossible to obtain a perfect match.

Vitrified Ware, in the sense of defective ware, is the result of fluxing material in or on the goods. It is sometimes produced when non-porous unglazed ware is made of clay which has been very badly mixed, so that the flux occurs in pieces instead of being properly distributed throughout the mass.

Patches of vitrified matter are generally the result of drops or splashes of glaze falling on to the goods. If the goods are fired at too high a temperature the material may partially melt or vitrify. Attempts have been made to utilise this effect in the production of self-glazed articles.

Warped Ware (see also 'Crooked Ware') is chiefly due to bad placing in the drying shops or kilns, to over-firing, whereby the materials are partially melted, or to faulty workmanship on the part of the maker.

White Patches or spots on coloured ware are usually due to accidental splashes of clay or engobe, or to the glaze being only partially fused. In the former case the defect is scarcely to be removed, though it may perhaps be painted over; in the latter, re-firing, possibly at a slightly higher temperature, will often effect a cure. See also 'Turbidity.'

Wrinkled Faces on bricks have sometimes been met with on the Continent in cases where the firing of the kiln has been erratic, and where a strong reducing atmosphere has made it possible for some silica to volatilise and to be deposited on the goods. This siliceous deposit may, apparently, be formed at a comparatively low temperature, and as it will not shrink with the contraction of the clay, wrinkles are formed. This is only a suggestion as to the cause: the cure consists in keeping a watch on the air supply to the fuel.

CHAPTER XII.

WASTE.

The subject of waste, though treated separately here, is only dealt with briefly, because many defects of working and management which produce waste have been pointed out in other sections, and the subject is too complicated to be compressed into a few words.

Waste may be considered in relation to goods, materials, power, and management, but, in whichever department of the works or offices it occurs, it is invariably included in the profit and loss account, though its identity is often hidden. In other words, the money value of waste is that by which it must be judged, for if this is not taken into account waste of one kind may be prevented, but a more serious loss of money may result from the 'cure' than was caused by the 'disease.'

Waste of Goods may be due to (1) over-production, so that the goods spoil, get damaged, or become out-of-date and, therefore, valueless; (2) carelessness in handling, whereby the goods become damaged or broken or dirty. Under this heading must be included faulty picking of the clay, or carelessness of the workmen in allowing food, paper, or other foreign matter to become mixed with the clay, and of the dippers, artists, etc. who get colour or glaze on the wrong parts; (3) so-called 'unforeseen' damage due to defective warehousing, draughty or leaky workshops, resulting in warped, cracked, or spoilt goods.

Most of the above defects and loss may be remedied by careful and thorough foremanship and management, ever remembering that 'a patch in time saves nine' when tiles come off the roof or a window-pane gets broken.

The question of dirt getting into the goods is a more serious difficulty in some works. It is so generally imagined that the cost of keeping the works clean is so much waste money, yet this is by no means always the case. In how many sanitary works, for instance, is the clay allowed to be trodden under the feet of the makers until the parts of the floor not actually used for goods become noticeably higher than the rest? This clay is cleaned out when it becomes too much of a nuisance, and, being so dirty, it must be thrown away, whereas the use of boxes or tubs in which the workmen might throw the scraps of clay would entirely prevent this waste by enabling the clay to be returned to the mill and worked in with the fresh clay. In addition to this, it is always found that the workers do more and better work when the place is kept clean, and the management is rendered easier, for in a clean works untidiness and dirt are readily detected and stopped. There is also the influence of the big customer who now and again wants a glance through the works, and who is much more likely to place his orders in a clean and tidy works with a business-like appearance than with one of the tumble-down affairs so frequently seen, in which an architect fears to enter lest a building collapse and break his neck, or the state of the yard is so bad that he risks spraining his ankle. In the more delicate branches of clayworking this cleanliness is adequately observed, but a visit to some of the Continental brickyards would astonish some of our British foremen.

In a pottery using, say, three kinds of clay, much liability to confusion may be easily avoided by staining two kinds with aniline dyes, such as methylene blue or magenta, or one of the stronger greens. These colours will burn out completely in the kiln, and the amount added need be so small that the porosity of the clay is not affected. This method is particularly applicable to clay made up from scraps which is not to be used for best work, and for which the plan now generally used of setting bits of coal, clay, or stilts on special boards of special ware is far from satisfactory, as these bits are so liable to be lost.

Another effective way of keeping the clayhouse clean is to have one man to do all the transport, instead of a lot of lads or girls larking around the clayhouse as is often the case at present. The difficulty that 'the makers provide these young people' can be easily got over with a little tact, and the additional cleanliness of the clayhouse or sliphouse will rapidly repay the trouble of making the change.

Intimately connected with the question of dirt in the works is the question of drainage, for, if this is not properly arranged and maintained in order, the works can never be really clean. In most works the difficulty is not so much how to obtain water, as how to get rid of it when it has entered the works in the form of rain or snow. Yet on the successful solution of this problem depends one of the first means of clean, and to this extent economical, working. The clayworker should, therefore, see that the drains are attended to at fairly frequent intervals, especially during the wet season.

Waste due to careless handling of the goods should be very thoroughly gone into, and the offender charged with some or all of the loss. (Care must be taken not to break the Truck Acts in making these deductions from the men's wages.) By keeping a careful account of each maker's stock and checking this at frequent intervals, most of the waste due to breakage in handling may be eliminated.

Waste of Materials is a more difficult matter to control than the loss of goods made in the works. Under this heading are included raw and finished materials (clays, fuel, glaze materials, colours, etc., as well as tools and machinery). Wastage of materials is chiefly due to improper use, to improper materials or slow and out-of-date machinery, or to a direct 'throwing away' of the materials.

Under 'improper use' is to be included the ignorant or careless waste of fuel in the kilns or boilers; the employment of a needlessly expensive glaze, clay, or fuel comes under the term 'improper materials,' as does also the use of needlessly heavy machinery or of blunt tools. At the same time the opposite extreme must be avoided, for if an excessively cheap fuel, for instance, is purchased, its heating value may be so small that it may prove dearer in the long run than a more expensive one. The only correct way of valuing fuels is to determine their calorific power, or, if a less accurate criterion is sufficient, the amount of combustible material per pound of fuel, and to calculate the costs of such weights of the fuel as will furnish a given number of heat units or of pounds of combustible matter. Tests of this kind will rapidly show the best kind of fuel for the purposes of the clayworker, and will also show the necessity of proper storage, for the calorific power of wet fuel is much lower than that of the same fuel when dry.

The chief waste of fuel occurs in the firing of boilers and kilns, for if too much or too little air be supplied to the fuel, loss will occur (see pp. 65, 171, and 182).

Wastage of clay and glazing materials, when not due to carelessness on the part of the users or makers, is often difficult to detect. In many works difficulties and loss arise through the desire to economise by buying 'cheap' lines, which are seldom satisfactory unless there is someone on the works who can thoroughly test the materials and ascertain their correct strength and value. Felspar, to take only one instance, is frequently sold of a very different composition to that of normal spar, and yet the price is but little lower than that of the best felspar.

The composition of glazes and engobes is a matter which the proprietor knows little about, as a rule; but care should always be taken, when a change is made on the score of economy, that a real saving is effected and not a loss incurred, as in a recent case, where a minute proportion of zinc oxide in a glaze rich in Cornish stone being considered extravagant, a glaze containing over 50 per cent. of felspar was substituted, with the result that the cost was increased over 30 per cent.

If sufficient material can be stocked at one time, or if the composition of the material may be relied on, considerable sums may often be saved by the use of substitutes for some of the ordinary glaze materials; but, the use of these being to some extent experimental, and the composition of the raw materials being subject to considerable variation, it is useless to attempt this line of economy unless very considerable stocks can be held so that a new supply may be thoroughly tested before the old is finished. With the better known glaze materials this testing is not nearly so essential, though it is always advisable.

By far the larger proportion of waste in clay and glaze is due to carelessness, or to want of proper provision for scraps. The result of this is that in the course of a year an amount of material is thrown away as dirty or useless which might, in the majority of cases, have been utilised for a cheaper line of goods or for some portion of the goods less readily seen; whilst much of the clay now allowed to pass away as dirty might, with suitable provision on the part of the management, have been kept clean enough to only require working up again for use. This is especially the case in the sanitary (fireclay) trade.

The utilisation of *waste products*, such as broken pots (sherds) and old plaster moulds, is a more difficult problem. Beyond mixing a certain proportion of the finely-ground sherds with the raw clay in order to lessen its rate of contraction and make it firmer in the kiln, or to reduce the plasticity when the clay is too strong (though sand is generally employed for this purpose), there are but few uses for the sherds. Some experiment in the bacterial purification of sewage would lead one to suppose them to be superior to coke for filling the beds, but the cost of carriage would probably prevent their extensive use outside the potteries. Attempts to use ground potsherds and cement have not been successful in the preparation of artificial stone, as sand has proved cheaper owing to its being already in a powdery state.

Many attempts have been made from time to time to re-burn old plaster moulds, but this has never been commercially successful; and endeavours to include ground moulds in the plaster mixture used for new ones have resulted in a loss rather than a gain, as the moulds thus made wear out more rapidly and deliver less easily than those made from new plaster. These two sources of loss, serious though they are, are at present unavoidable. This does not mean that they will ever remain thus, for a fortune awaits the man who can find a profitable use for them on a large scale.

Saggers are another item in which a considerable waste occurs, part of which is certainly avoidable, being due to making the saggers of improperly-ground clay. The sizes of the grains in saggers and other goods which have to withstand repeated heating and cooling, are both very numerous and highly variable in their relative proportions; and manufacturers would be wise in experimenting in this direction. The proportions differ so greatly with the different kilns used, as well as with the sizes of the saggers, that general details would be useless. Suffice it to say that a satisfactory, or reasonably satisfactory, sagger-clay having once been obtained as the result of careful experiments and trials, this clay should be carefully sifted (before firing) through variously sized sieves and the proportion remaining on each carefully noted for future use. As a rule, the greater the proportion of fine clay in the sagger the shorter will be its life; a certain proportion is, however, necessary in order to bind the larger particles together.

The waste in products (goods) due to damage in manufacture is, unfortunately, usually great, but it may be kept within exceedingly narrow limits by a wise yet vigilant and strict oversight. The difficulty mainly lies in ascertaining who is responsible for the damage, and in many instances the men must be given the benefit of the doubt. If, however, the sense of responsibility is maintained at a sufficiently high standard, this difficulty will be to a very considerable extent removed by sufficient and impartial inspection.

The Waste of Tools, machinery, barrows, timber, etc., through not being properly put away or cared for, is one which should be avoided. There is no excuse for tools (in the fullest sense of the word) lying about to rot or rust when a little care on the part of the users might secure their maintenance in good condition. The same remark applies to crates, bags, barrels, and other objects used in the conveyance of goods into the factory. A place for everything, and everything in its place, is the best waste preventer yet discovered.

Waste of Lubricants is very common in clayworking. Very few potteries or brickworks take the trouble to collect and filter their oil so that it may be used over again, yet an oil-filter is not an expensive appliance, and its use makes the engineman less anxious to screw out the lubricant to danger point, for he knows that any excess will be collected and re-used with the addition of a little fresh oil to make up for loss.

As all lubricants clarify more easily when warm, it is a good plan to have a spiral tube in the oil-purifier through which a little exhaust steam may be passed; or, as this is apt to put some back-pressure on to the engine, the discharge of the steam traps may be allowed to pass through the spiral pipe.

A rough-and-ready filter consists of two pails, one of which is used to contain the unpurified oil, while the other has a pad of flannel placed over it through which the oil skimmed off the contents of the first bucket is allowed to filter. Meat-cloths or waste may be used instead of the flannel. It is often convenient to fit them on to a coarse metal sieve, which keeps the cloth or waste flat and so enables the filtration to proceed more rapidly.

In collecting the oil care must be taken not to mix different kinds together. Separate tanks should be used, and, where there is a danger of splashing, baffle plates should be used to prevent two or more kinds of lubricants from becoming mixed.

Waste in Machinery, both running and standing, is often very much greater than is usually supposed, and the usual allowance of 10 per cent. per annum for depreciation by no means always covers the case.

The actual daily expense of machinery is made up of three parts: (1) Depreciation and interest charges; (2) cost of power; (3) cost of repairs.

Of these the first is also expected to include, either directly or indirectly, a proportionate charge for rent of space occupied by the machinery, but this is a matter which will depend on the way in which rent and rates are distributed amongst the different departments of the works. Suffice it to say that these charges remain pretty constant whether the machinery is running or disused; it is, therefore, a 'waste' or dead charge whenever the machinery is unnecessarily idle.

The cost of power to a machine will depend on four conditions: (*a*) the machinery is not in use and is motionless; (*b*) the machinery is not in use, but is running on the loose pulley or clutch; (*c*) the machinery is running, but not at full power; (*d*) the machinery is running at full (but not excessive) power and quite satisfactorily.

If the machinery is not in use and is not moving, as in (*a*), the expense of power may be *nil*, except in so far as the boiler or other source of power may have to be kept in readiness for an immediate demand, when the cost of this must be included, just as in the more wasteful (though often with present plant unavoidable) machinery of class (*b*). The only way in which the waste in these sections can be avoided is to keep the machinery constantly at work; or, if it is not intended to use it further, to write it off the books. Where the nature of the machine is such that it cannot be continually kept at work (as in the case of a hauling engine or a pump), the times of idleness must be reduced as much as possible or the expenses of this particular part of the plant will be excessive.

If the machinery is not running at full power (class *c*), it is important to find out the reason for this defect. If the plant is too powerful for the amount of work it has to do, it is a question as to whether more work cannot be given it by a rearrangement of plans; for machinery which is not doing its full work costs nearly as much to run as when fully occupied. Not only so, but most clayworking machinery works more smoothly and satisfactorily when at its proper load than when running light, and the wear and tear is proportionately less. If the cause of waste of power is due to defects in the adjustment of the plant, or to actual defects in construction, it will generally be found that repairs and adjustment will rapidly repay their cost. If it is a question of antiquated plant (as, for instance, an old boiler which the insurance company will not allow to be worked at full pressure), it is often cheaper in the long run to replace it with more modern or, at any rate, more efficient machinery.

It is only when machinery is working at normal speed, with normal output and full time, that it can be regarded as satisfactory; other conditions involve waste which, however caused, is nevertheless waste, and must be regarded as such without any attempt at 'glossing it over' if economical working is to be secured. The sight of machinery running 'loose' is so common in clayworking, that little or no notice is taken of it; it is considered to be on a level with 'breakages,' 'bad kilns,' etc.—that is, as losses which cannot be avoided. Needless to say, a little study on the part of the manager will rapidly convince him that this is by no means the whole truth. What is true of machinery is equally so of steam used for heating purposes; the amount of this commodity wasted annually in most clayworks is simply astounding.

Waste at the Boiler may usually be checked by a careful watch on the coal-book, or by a small bonus to the fireman if he can reduce the amount of fuel burned and yet keep up the steam. At the presses and mills it may usually be reduced by a system of piecework, accompanied with various encouragements to the men to work as rapidly as possible consistent with good work. This will ensure the full use of the machines when in use, but will not always prevent their running 'loose' unless there is abundant work for the men. A study of the lines of shafting will also indicate whether greater economy cannot be secured by using clutches so as to minimise the amount of idle shafting in motion.

Some machines are so clumsy, and require so much unnecessary power to drive them compared with the work they have to do, that their use involves a continual waste of power. Sometimes this waste cannot be avoided, because two or more classes of goods are made on the same machine; but even then it will often be more economical to obtain a smaller machine for the lighter work, the increased output being utilised in selling the goods at a slightly cheaper rate and still making a greater profit per annum. It is a matter of relative cost.

Waste of Power in Transport is another serious loss in many clayworks, few engines used for this purpose being worked at anything like their greatest efficiency. In most cases it is the result of bad management, by which a succession of small loads at fairly frequent intervals occurs instead of larger ones at longer intervals. The waste here is not only in the power, but also in the labour involved in driving the engine (or ponies), which might, under better arrangement, be employed on other jobs. This does not mean that a cheese-paring policy will be successful, but that in many clayworks a rearrangement of the transport will often result in one man's or lad's labour being available for other work during a considerable portion of the day. This is clearly not a case where generalities will be of use: each works must be considered in the light of its own circumstances and conditions.

Waste Steam is chiefly due to carelessness on the part of the workmen in not turning off cocks when the steam is not required; or in using more steam than is necessary for a particular purpose (this is especially true in drying sheds); or in allowing the machinery to run without working. On this account it is very desirable that the control of all steam-cocks should be in the hands of the foremen only and not in those of the individual workers. Leaks in the piping or in the engine, boiler, or other part of the machinery should be under the responsibility of the engineer, and some means should be adopted to see that he keeps the plant under his charge in efficient condition. This may readily be done by means of occasional indicator readings of the engines and dynamometer readings of the machines. In fact, it is a good investment to attach some simple form of register to each machine of which the output is not paid for by the piece, in order to ascertain how many hours per day it runs idly or with only partial work.

One of the great advantages of electricity as a source of power is the readiness with which it may be measured, as a simple watt-meter on each machine will register the total power consumed, and a careful study of these records ensures such electrically-driven machinery being worked to the fullest advantage. This information is not so readily obtained for steam-driven plant, but where it can be obtained it almost invariably results in more economical working and reduced running expenses. Unfortunately, so long as steam is so useful and economical a heat-transporter it is hardly likely that electricity will make much headway in many classes of clayworking; but there is little doubt that where heat can be economically obtained from fuel directly, or in those parts of the works where power, but not steam, is required, that electricity will sooner or later be adopted, not only on account of the advantages it possesses as a form of energy, but also from the ease of measurement which enables its exact cost to be so readily obtained. This factor of cost is likely to become increasingly important with increasing competition in the future.

Waste of Heat is, in some respects, the most serious and most difficult of prevention of any waste in a clayworks. Whether the heat is lost in the form of steam or actual heat from fuel matters little; in either case the money it absorbs per annum is immense.

Waste heat from kilns and furnaces (including boilers and dryer- and shed-fires) is a serious matter, yet but little real attention is paid to it. Some aspects of this question have been dealt with in the chapter on 'Firing' (p. 171) and need not be repeated here.

The chief loss is undoubtedly due to unskilled stoking, and to the resultant use of too much or too little air. As a consequence of this either a large amount of heat is wasted in heating air to no purpose, or the combustion of the fuel is incomplete and the full amount of heat is not obtained from it. If only three times the theoretical amount of air is used in firing (a by no means uncommon proportion), not less than 40 per cent. of the fuel used will be wasted in heating this unnecessary excess of air.

The only true control of the stoking which can in any way be regarded as complete, is that which results from a study of the composition of the flue gases (p. 263) and the temperature at which they enter the chimney. For many purposes it is sufficient to determine how much coal is required per gallon of water evaporated per day, as the results of these tests, when the boiler is worked under the best conditions, and to insist on the fireman not using more than (say) 10 per cent. more than this in order to avoid the trouble and expense of testing the flue gases regularly; but for kiln-firing this cannot so readily be done, since, whilst a careful study of the amount of coal consumed by each chamber or kiln is of value, variations in climate, etc., have much more influence on kilns than on boilers, so that a hard and fast rule as to the amount of coal to be consumed in the kilns cannot well be laid down. With sufficient care, however, the amounts can be fixed very closely without any hardship to the firemen.

Faulty construction of the kilns is often a source of loss of heat, as it allows the gases to enter the chimney too soon and at too high a temperature. With a continuous kiln this may be remedied by increasing the number of chambers; but with single kilns it is to a large extent unavoidable, though in some cases by leading the flues through a drying shed the heat may be better utilised. In this case care must be taken not to unduly lessen the draught; if the chimney is too small, the substitution of a fan will often effect an economy. These fans require but little power to run them, and in most cases are cheaper than a chimney of the same capacity.

The utilisation of waste heat from kilns is a matter requiring considerable special knowledge. The flue gases can seldom be turned directly into the shed containing the bricks or other goods, partly because the temperature is too high and partly because of the impurities (notably sulphur compounds) which they contain. As a rule, they are passed into a flue under the floor of the dryer, this floor being frequently made of iron so as to conduct the heat more readily to the bricks or goods, which are then frequently placed on waggons or cars to keep them from actual contact with the hot metal. These cars also serve as a convenient means of transport for the goods through the dryers, which are preferably of a tunnel form (p. 134).

Further particulars regarding the prevention of waste, or of reducing it when it cannot be entirely prevented, will be found in the chapters on 'Tests' and 'Defects,' and under the various operations under which waste may occur.

CHAPTER XIII.

TESTS, ANALYSIS, AND CONTROL.

The following suggestions for tests, and other means of controlling an economical and efficient production, are intended for the manufacturer and for the practical clayworker and not for the clayworks expert. Detailed descriptions of complex methods which have, of necessity, to be employed in the more accurate testing made by the latter are, therefore, omitted, and the reader is referred to the standard works on the subject when such information is required. For convenience of reference the headings are arranged alphabetically.

Anemometer.—An instrument for measuring the volume of air passing through a chimney or flue. It consists of a small wheel with relatively large vanes attached, and is so constructed that the slightest movement of the air sets it in motion. A counter is attached in order to register the number of revolutions. This number multiplied by the area of the opening of the flue or chimney through which the air passes gives the number of volumes (cubic feet) of air passing per minute.

Absorption.—The power of unglazed clay to absorb water is of great importance for certain purposes, particularly in the brick trade. The test is best carried out by accurately weighing one or more of the articles, immersing them almost, but not quite completely, in water for a short time, and, when partially saturated in this manner with water, to complete the immersion by covering them with the water and allowing them to remain covered for some hours. They are then taken out, their surfaces wiped dry, and the articles re-weighed. The increase in weight gives their absorption capacity. Thus, if a brick weighing 120 ozs. when dry was found to weigh 132 ozs. after immersion and wiping dry, as just described, its absorption capacity would be $132 - 120 = 12$, which $\div$ 120 (the dry weight of the brick) gives 10 per cent. The reason for not immersing the article completely at first is to allow the air contained in the pores to escape; if the article is completely covered from the first, the water surrounding it prevents the escape of some of the air and so gives too low a result. See also 'Porosity' (p. 288).

It is thought by many clayworkers that the more water a brick will absorb the more easily will it be damaged by frost, but recent experiments at the Royal Testing Station, Berlin, disprove this.

Analysis.—The details of the various methods of analysis of the materials employed by clayworkers are of so complicated a nature, and require so high a degree of manipulative skill in their execution, that they cannot profitably be dealt with here. Readers who wish to experiment in this direction cannot do better than study the little work, *How to Analyse Clay*, by H. M. Ashby; but they must not be disappointed if, even after many attempts, they do not obtain such accurate results as they desire. At the same time it is important that those responsible for the production of the goods should be able to understand and make use of the information contained in an analytical report, and the following notes may be made of use in this connection.

Clays consist, as is well known, of silica, alumina, and water, together with various substances such as soda, potash, lime, iron oxide, etc., and the percentage of each of these constituents is set out in the results of analysis, which, if quite correct and complete, would total up to exactly 100. As, however, there are usually slight errors, and sometimes trifling amounts of substances present which have not been determined, it is seldom that the results add up to 100·00 exactly. Indeed, it is generally wise not to accept published figures which total so exactly without some investigation, as, in all probability, one of the constituents has been estimated by difference, *i.e.* several constituents have been 'determined' and the sum of these deducted from 100 to yield the remaining one. Analyses in which this mode of obtaining a result has been adopted should be avoided, as they may be more liable to contain serious errors than one in which the figures add up to *nearly* but not exactly 100·00.

It is not, however, sufficient to know the total amount of each constituent of a clay. Information is required as to the various combinations in which these constituents occur, the fusing-point of the clay, its contraction on heating, etc. It is, therefore, desirable to have a 'mechanical analysis' of the clay showing the proportions of 'clay,' 'silt,' 'dust sand,' 'fine sand,' and coarse particles in the clay. These are obtained by washing the clay with great care in a special apparatus devised by Schoene.

It is also desirable to ascertain the nature of the different minerals in the clay, and to have the results of what Seger has called a 'rational analysis,' which shows the proportion of 'clay substance,' felspar, and quartz or sand, in the sample.

The chief value of ordinary chemical analysis is to indicate the presence or absence of deleterious substances, such as iron compounds in a china clay, or of soluble salts in brick clay, or a large proportion of alkalies in fireclay. A 'rational' analysis shows rather more clearly how the different constituents are combined into the three constituent minerals of clay, spar, and quartz, while a 'mechanical' analysis indicates the state of fineness of the sample, and, if the different portions into which the clay has been separated by this means are analysed, a further series of clues as to the advantages to be gained by washing the clay before use is obtained. Thus, the free silica (quartz or sand) present in clays only acts as a flux when it is in so fine a state that it will pass through a sieve with at least 600 meshes per linear inch, and is then so fine that it cannot be separated from the clay itself by washing. Coarser particles of silica act as refractory agents to the clay. This accounts for the curious results sometimes noticed on the addition of quartz or flint to clay; sometimes the clay is rendered more refractory and at others it is rendered more fusible. Seger, who has studied this subject thoroughly, found that if finely-divided silica is added, in gradually increasing quantities, to pure kaolin (which he regards as typical 'clay substance'), the fusing-point of the mixture is gradually lowered until the mixture containing one molecule of kaolin to seventeen molecules of silica is reached; after this, the addition of more silica increases the refractory nature of the mixture until pure quartz is reached, when it is found to have practically the same fusing-point as pure clay (kaolin). Hence, if the analysis be made on a clay which has been passed through a No. 80 sieve, the higher the percentage of 'clay substance' the more refractory the clay. The presence of notable quantities of alkalies or of metallic compounds will, however, modify this condition in proportion to the amount of such fluxes, which (in the rational analysis) will be found under the head of 'Felspar.'

It must always be remembered that 'felspar' in this sense is not a single chemical compound, but is a type of mineral with many varieties of similar mineralogical composition. Thus the ordinary felspar of the clayworker is a potassium felspar known as 'orthoclase,' but the potassium may be partially, or entirely, replaced by one of several other metals such as sodium, calcium, etc., and in each case the new mineral retains its family name of felspar. All felspars have, however, this in common, that their composition may be represented by the formula $RO,Al_2O_36SiO_2$ where Al_2O_3 represents one molecule of alumina, $6SiO_2$ represents six molecules of silica, and RO represents one molecule of any oxide similar to potash, soda, or lime, or any proportions of such oxides as will together make up exactly one molecule. As 'felspar' is a flux and yet contains nearly two-thirds of its weight of silica, it does not follow that a clay with a high silica content must necessarily be refractory. As stated above, the whole question turns upon the state in which the silica exists. If it is combined with an RO base, or if it is so finely divided that it can readily combine with the kaolin in the clay, it will act as a flux; if, on the other hand, it is in comparatively coarse particles, it will make the clay refractory. As an ordinary analysis does not show this difference of state, the importance of a rational analysis is obvious.

Clay substance was a term devised by Seger to represent 'pure clay,' consisting of the finest particles that can be separated by washing the clay, separated from any finely-divided silica by treatment with hot sulphuric acid. As the result of many analyses of different kinds of clays, Seger found that all contained a substance of slightly varying composition, yet always corresponding to $Al_2O_32SiO_2 + 2H_2O$, which is also the formula for the typical kaolins or china clay. Plasticity apparently depends more on the state of division of the clay than on the chemical composition. This 'clay substance' is highly refractory (Cone 36); its presence in large proportions indicates, therefore, a refractory clay. If much felspar, or quartz, is also present the fusion-point of the material will be lowered correspondingly, as already explained. The exact fusing-point must be determined experimentally (see p. 269).

Glazes may be regarded as clays containing an inordinately large proportion of flux or base. They are analysed in a similar manner to clays, and the results of the analyses are best stated in the same way. Further information on the composition of glazes and other engobes will be found on page 19.

Flue gases should be analysed at frequent intervals in order to ensure that fuel is not being wasted. See page 263.

The *water*, *oil*, store materials such as bone dust, etc., used in a clayworks should be constantly tested. Usually a complete analysis is unnecessary, although advisable, when buying fresh lots of clay or glazing materials. Certain tests as to the purity of the materials in use should, however, never be omitted from the works routine. If carefully attended to, many pounds might be saved during the year.

Special questions arise from time to time which can only be answered after various analyses have been made. As a general rule in such cases it is best to secure the services of an expert, as the results obtained by amateurs are not often worth the time spent in obtaining them.

Baryta has, for some years past, been successfully used to prevent certain varieties of 'scum,' due to the presence of soluble sulphates in clay. In order to determine the quantity of baryta or of barium carbonate to be added, the following experiment should be made and repeated with every fresh batch of clay, as the proportions of soluble sulphates vary considerably and a large excess of the baryta compound is to be avoided.

Into each of half a dozen bottles, exactly 4 oz. of the dry clay in the form of fine powder is placed, together with about half a pint of water. The bottles should then be about three-quarters full. The clay and water are well shaken, any lumps of clay carefully broken up, and measured volumes of a 1 per cent. solution of barium chloride solution added. This is usually done by means of a burette, graduated in cubic centimetres, and obtainable from any scientific apparatus dealer. One cubic centimetre is placed in the first bottle, 2 in the second, and so on up to the last, which would receive 6 cubic centimetres. The bottles are shaken up vigorously at intervals of an hour for twelve hours, after which about 4 oz. of the clear liquid (filtered, if not quite clear, through filter-paper) is placed in a clear glass and a few drops of dilute sulphuric acid added. If sufficient barium chloride solution to precipitate the soluble sulphates has not been added, the solution will remain clear; but if too much has been added, the sulphuric acid will produce a white turbidity. The bottle containing the liquid with which the least turbidity is produced is the one which contains the most correct proportions of baryta and clay. Suppose it was No. 4 (No. 3 bottle remaining clear may have exactly the correct amount added, or it may not have had sufficient, so that it is best to take the one showing a slight turbidity as correct). Then No. 4 will have had (say) 4 cubic centimetres of the barium solution to 4 oz. of clay. As this solution contains 1 per cent. of its weight of barium chloride (cryst.), each 4 oz. of clay will need the addition of $4 \times {\cdot}01$ grammes of barium chloride, or each ton of clay will need $4 \times 3\frac{1}{4} = 13$ oz. of barium chloride; or, as 1 lb. of the chloride corresponds to $\frac{5}{6}$th lb. of the carbonate, 11 oz. of the latter may be substituted. If 100 grammes of clay be used instead of 4 oz., each cubic centimetre of barium chloride solution will correspond to 100 grammes of the solid per ton of clay. If a clay should contain so large a proportion of sulphate that 6 cubic centimetres of the barium solution are not sufficient to precipitate it, a fresh test must be made, using more of the solution for each bottle.

Binding-power of clay is often determined as a check on the correct working of the mixing and pugging machines. Although a skilled worker can tell immediately by the 'feel' of the clay whether it has been properly worked, it is often handy when special mixtures are in use to determine the force required to pull a strip of the plastic clay apart. The test cannot be usefully made on the dry clay as it is often so brittle as to be untrustworthy. It is best carried out while the clay is still damp but after the contraction has largely ceased, though tests of the clay straight from the mill are of great value. The test is most conveniently made with an apparatus similar to that used for the testing of Portland cement by tension: a piece of the plastic clay being formed into a rough resemblance to a figure 8 in a brass mould, a light scale-pan attached, and the whole hung from a convenient beam or stand. Shot is then allowed to trickle at a standard rate into the scale-pan until rupture takes place, when the combined weight of shot and pan is determined. If the test piece has an area of one square inch at the point of fracture, the weight in pounds per square inch required is found without calculation. It is convenient to mark two small dots exactly two inches apart on the test piece before breaking and to measure the percentage of increase in length brought about by the tension of the weight (shot). The results obtained vary greatly for different kinds of clay; a very plastic clay will have a breaking strain of some 50 lbs. per square inch, whilst other clays will break under a strain of a few ounces. (8 lbs. is a fair average for ordinary brick clay.)

It is also useful to observe the length of a piece of clay which can be pressed through a $\frac{3}{8}$-inch hole in a vertical plate before appreciable bending of the clay takes place.

In order to determine how much lean clay or other non-plastic material can be added to a clay without unduly destroying its value for moulding into shape, the two materials are mixed in various proportions and the same measured quantity of water added to each. The pastes are then rolled into small balls as equal in size as possible and allowed to dry. They are then rubbed gently between the finger and thumb or with a small 'camel-hair' brush. The mixture which just resists the action of the rubbing may be taken as the standard. Some authorities make up small balls of mixture in this way and then notice to what length a cylinder can be rolled from each without cracking.

F. F. Grout concludes, as the result of numerous experiments, that plasticity is proportional to the product of two factors—viz., the load required to sink a Vicat needle a definite depth into the mass of clay, and, secondly, the deformation of the clay under stress, which he measures by the increase in area of a clay cylinder produced by the load which just causes cracks to appear. If these two factors are separately observed for a given clay tempered with different quantities of water, it is found that the products obtained by multiplying each set of corresponding factors together lie on a smooth curve which has a well-defined maximum for some particular proportion of tempering water. He finds, moreover, that whilst fine grinding generally improves the plasticity of a clay, this is not invariably the case. The addition of sand or crushed quartz impairs the plasticity, though the effect only begins to be marked when the amount added is appreciable.

Boilers (see p. 60).—The actual testing of boilers is usually, and most satisfactorily, carried out by the inspectors appointed by the various Boiler Insurance Companies; their reports and suggestions should be carefully attended to.

Bone, or, more correctly, Bone Ash, is the residue left on calcining the bones of animals until all the combustible matter has been driven oft. It consists chiefly of calcium phosphate, and is used in clayworking partly as a flux and partly for rendering the body more transparent and translucent. It is also used in the manufacture of china to prevent crazing, to increase the whiteness of the material, and to prevent distortion through over-firing.

As calcium phosphate is the chief ingredient, the material should be assayed for this substance, and samples containing less than 75 per cent. should not, as a rule, be used. The assay of phosphates should be made by a properly trained chemist. The chief impurity in bone ash is chalk or calcium carbonate, which occurs naturally to the extent of about 15 per cent., but it is also occasionally added as 'filling.' It is a particularly unprofitable adulterant to the potter as it unduly softens his bodies. It may be determined by the method described in the assay of chalk (p. 242).

Burners, or firemen, require constant supervision if the very best results are to be obtained, as their work is hard and the temptations to shirk it are exceedingly great. On this account it is good practice to pay the firemen partly by wage and partly by bonus on the articles from kiln. Various means now exist for checking the firemen's work, such as pyrometers, etc., which register the temperature of the kilns, and various kinds of 'watchman's clocks' are also in use to ensure that the fireman does not fall asleep at his work. The great defect of most of these appliances, however, is that they do not give the warning until it is too late to repair the damage which has been done through the fireman's neglect of his work. What is really wanted for this purpose is an arrangement which shall inform the burner when it is time to put on more fuel or to attend to his fires, and if he does not attend to his work, to warn the foreman, manager, or some other responsible person. To a limited extent this is accomplished by the Stöcker clock, which rings an electric bell at the kiln every fifteen minutes or so; if a press-button is not pressed within, say, three minutes, another bell in the foreman's or manager's room (or bedroom, if at night) is set ringing. In this way a suitable person is warned immediately the burner neglects his work, whether from illness or other cause, and little or no harm is done to the goods in the kilns, whereas by the ordinary kind of registering warner the manager is not aware until the next morning that anything has gone wrong.

A somewhat cheaper, though less satisfactory, warner consists of a telephone at which the manager can listen and so hear the noise made by the fireman when firing; this plan, however, is tedious for the manager, and is of but little use if he has gone to bed and the fireman has gone to sleep at his post.

One of the most promising 'warners' is an attachment to a Callendar pyrometer (p. 316) whereby, the instrument having been set to certain limits of temperature, any increase above or decrease below these limits causes a bell to ring at the kiln and so warns the fireman, whilst if this warning is not attended to and the temperature brought within the proper limits within a reasonable time, a second bell in the manager's or foreman's bedroom is set ringing. Unfortunately, electrical pyrometers are not very durable at the high temperatures used in most clayworks, and require such frequent standardising as to be unsuitable for general use except by a specially trained man.

Calorimeters are instruments for determining the amount of heat held, given up, or gained by any substance. They differ from thermometers and pyrometers in that they measure actual heat and not changes in temperature. The unit of heat is the amount required to bring about a change of temperature of one degree in a unit weight of water at a given temperature. There are three units at present in general use, viz., the 'calorie,' which is the amount of heat expended in raising the temperature of one gramme of water 1° C. (strictly, from 4° C. to 5° C.). As, however, the 'calorie' is too small for ordinary purposes, it is usual to employ a unit one thousand times as large—*i.e.* the amount of heat required to raise the temperature of one kilogramme of water 1° C. This larger unit is termed the 'major Calorie,' but in writing it is usual to term it 'Calorie,' distinguishing it from the smaller unit by writing its name with a capital C.

The third unit is the British thermal unit (B.T.U.), which is the quantity of heat required to raise the temperature of one avoirdupois pound of water from 60° to 61° F.

Calorimeters are chiefly of use in clayworks in testing the *calorific power* of fuel. Two forms of calorimeter are most in demand: one a comparatively simple instrument, devised by Lewis Thompson; and the other a more complicated and somewhat more accurate instrument, known as the 'bomb' calorimeter.

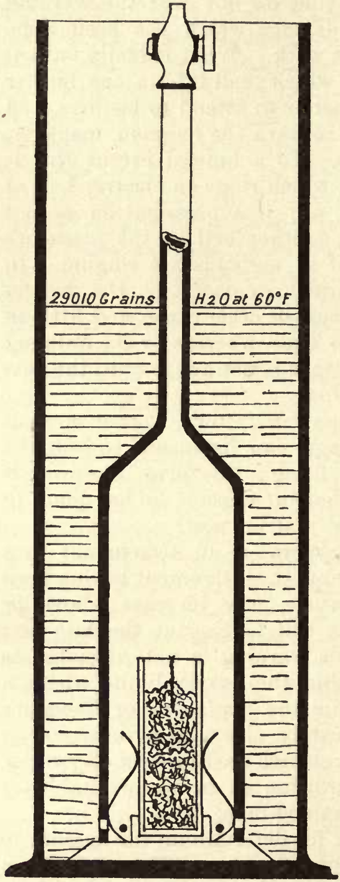


FIG. 8.

The Thompson calorimeter (fig. 8) consists of (*a*) a large glass cylinder marked to contain, when rather more than half-full, 29,010 grains of water at 60° F.; (*b*) a copper tube, or 'furnace,' fitting into a recess of a perforated stand, over the spring clips of which fits a combustion vessel consisting of a copper cylinder perforated round its lower edge, and provided with a long pipe and stop-cock at its upper end. There is also a thermometer (*c*) which must be capable of being read to at least $\frac{1}{3}$° F. The test is carried out by mixing 30 grains of the dry and finely-powdered fuel with about 300 grains of a 'combustion mixture' composed of 3 parts by weight of pure potassium chlorate and 1 part of pure nitre. Both these substances must be finely powdered, dry, and well mixed before use. The dryness of all materials used in calorimetry is important, and it is best to dry them *separately* at 100° C. immediately before use. The mixture of fuel and combustion mixture is placed in the copper furnace-tube, and a small fuse, made by soaking a couple of strands of thick cotton in a strong solution of nitre and allowing them to dry thoroughly, placed half-way into the mixture. The fuse should be about 1 inch in length. The glass vessel having been filled to the mark with water, the temperature of which has been accurately ascertained by the thermometer, the fuse is lighted, the 'combustion vessel' fitted into the clips, the stop-cock closed, and the whole arrangement lowered carefully into the water with as little delay as possible. If the combustion mixture has been properly made and the materials are dry, the fuel will be set on fire and will take up the oxygen necessary for its combustion from the mixture; white smoke will be given off through the perforations in the copper vessel, and bubbles of carbon dioxide and other gases will rise through the water with such violence as to upset the apparatus unless the copper vessel is held in place. As soon as the bubbles have ceased and it is judged that the combustion is over, the stop-cock is opened and the copper vessel used to stir the water and so render it of an even temperature throughout. When this is accomplished the temperature of the water is again read by means of the thermometer, and the rise in temperature is noted. It is usual to add one-tenth of the increase in temperature to the result in order to compensate for losses by radiation, etc., and heat absorbed by the instrument. As the latent heat of steam is 967, and 30 grains of fuel are used, the rise in temperature in ° F. plus 10 per cent. gives directly the number of pounds of water which will be evaporated by one pound of fuel: thus if the rise in temperature was found to be 11° F., the number of pounds of water at 212° F. which would be converted into steam by one pound of the fuel would be $11 + 1{\cdot}1 = 12{\cdot}1$ lbs.

The 'calorific power' may be found by multiplying the rise in temperature (duly corrected as above) by 967. Thus, in the example given, $12{\cdot}1 \times 967 = 11{,}700$ B.T.U.

The 'bomb' calorimeter works on a similar principle to the above, but, instead of the somewhat unsatisfactory 'combustion mixture,' the fuel is burned in an atmosphere of compressed oxygen, the combustion being carried out in a block of cast steel in which a suitable cavity, fitted with a screw cap, has been bored.

In either case it is necessary to examine the contents of the apparatus on completion of the test, in order to ascertain that no particles of unburnt fuel still remain.

Although this test is one which can be carried out quite satisfactorily with ordinary care and attention to details, there are numerous sources of error, and it is always advisable to repeat the test several times and to take the average of the results obtained. Various modifications of the apparatus—employing electrical firing, using sodium peroxide instead of oxygen, etc.—have also been put on the market. In skilful hands excellent results are obtainable, but special training in scientific work is necessary before good results are reached. As the value of a fuel depends almost entirely on its heating power, *i.e.* on its calorific power, the use of this test in making choice of a fuel is obvious, and that fuel is most economical as regards heating power which gives the highest number when the calorific power in B.T.U. is divided by the cost of the fuel in pence per ton; thus a fuel with a calorific power of 12,000 at 10s. per ton is more economical than another with 10,000 at 8s. 6d. In comparing the values of fuels of low calorific power, however, some consideration must be given to the ash and other constituents, as a coal giving a large proportion of easily fusible clinker is less desirable than one at a slightly higher price per B.T.U. with a more dusty residue on combustion.

The calorific intensity, or maximum temperature producible from a unit weight of the fuel, is obtained by dividing the number of sensible heat units produced by its combustion (= cal. power) by the product of the weight and specific heats of the combustion products. With a good coal this will give a temperature of about 2500° F.; but this temperature is seldom attained in practice because of incomplete combustion, excess of air, heat losses due to radiation, and by absorption through the chimney and brickwork. In addition to this, the temperature attained depends on the rate of combustion, and so can never approach the theoretical figure when large quantities of fuel are used. The calculation of the calorific intensity is therefore of academic, rather than of practical, interest.

Chalk is a necessary addition to clays used for certain purposes, and, like all other naturally occurring minerals, it varies greatly in quality. It is therefore very desirable that it should be tested on the receipt of each new batch. Some clays contain notable proportions of this substance, which, if in a sufficiently finely-divided state, is often a welcome constituent of the clay, since in burning it promotes vitrification; but, on the other hand, when it appears in larger pieces, as in the case of clays containing limestone, it is quite unsuitable for the purposes of brickmaking unless the clay be previously washed so as to remove the pieces and concretions of chalky matter. Apparently 25 per cent. is the limit that a clay can stand without spoiling in the firing, and for this proportion the material must be in the form of the finest possible powder, as, unless it combines with the silica of the clay on firing, the articles will disintegrate on exposure to the air.

Chalk, with its allied compounds limestone and Paris white or whiting, is a more or less pure form of calcium carbonate, and when absolutely pure consists of—lime, 56 per cent.; carbon dioxide, 44 per cent. The most frequent impurities are silica, iron oxide, alumina, gypsum (sulphate of lime), and other sulphates. Some varieties of limestone contain magnesium carbonate as well. The characteristic constituent of chalk and of its congeners is, however, the carbon dioxide, and its valuation is commonly confined to a determination of the proportion of this constituent in the material. The carbon dioxide is most conveniently estimated by measuring the volume of gas liberated when the sample is mixed with an excess of dilute sulphuric acid. One of the most satisfactory appliances for this purpose is a Lunge's 'nitrometer,' or 'gas-volumeter' as the instrument in its modified form is called. This consists of a graduated glass tube, at one end of which is a glass stop-cock and at the other end a strong rubber tube connected to another glass tube (the 'pressure tube'), as shown in fig. 9.

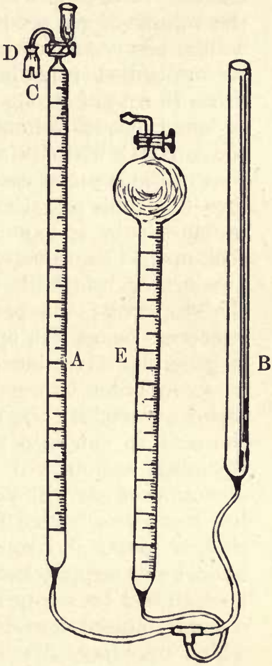


FIG. 9.

The apparatus is filled with mercury, or with strong brine made by shaking clean water repeatedly with table salt in larger proportion than the water can dissolve and allowing it to stand for some hours so that the water may become saturated with the salt; the clear liquid being then used for filling the instrument. Care must be taken that the graduated tube, A, is completely filled to the exclusion of all air; but the liquid should only reach a few inches above the lower end in the pressure tube, B, at the commencement of the test.

About 0·4 gramme of the sample to be tested is to be accurately weighed into a small tube, C, this being best accomplished by first weighing the empty tube, putting into it a small quantity of the powdered sample, and again weighing carefully. If the increase in weight is about 0·4 gramme, the exact increase is carefully noted; if much over or under this amount, some of the powder must be taken out or more must be added to the contents of the tube until the correct quantity is obtained. The reason for this is that if too much is used the apparatus will not hold the volume of gas produced, whilst if too little is taken the results will be less accurate owing to the larger number by which it must be multiplied in order to ascertain the percentage. About 50 drops (5 c.c.) of strong sulphuric acid previously mixed with three or four times its volume of water is placed in the little flask, D, the tube, C, with its contents carefully lowered into position as shown, the greatest care being taken that none of the acid gets into the tube, and the cork inserted tightly into the flask. The pressure tube is loosened somewhat in its clamp, the glass stop-cock opened cautiously, and the pressure tube raised so that the mercury or brine fills the graduated tube exactly to the top of the stop-cock; the pressure tube is then clamped securely, the stop-cock being left open. In making these final adjustments it is generally advisable to lower the pressure tube some six inches or so in order to see that the apparatus does not leak. If all seems satisfactory the flask, D, is cautiously tilted so as to allow the acid to run into the tube and thoroughly wet the sample. Chemical action will commence almost immediately, and the evolution of gas will continue until almost the whole of the sample has been dissolved. The flask and its contents should be gently shaken round and round so as to secure the thorough admixture of acid and sample, and, when all action appears to be over, the flask should be warmed gently to about blood heat by means of a small bunsen burner in order to dispel any carbonic acid gas which may have dissolved in the acid liquid. This having been done the stop-cock is again closed, the pressure tube raised or lowered until the liquid is at exactly the same level in both it and the graduated tube, and the volume of gas is then read off in c.c. As all gases change their volume very considerably with comparatively small changes of temperature, it is necessary to find the temperature of the carbonic acid gas. This may be done with sufficient accuracy by hanging a delicate thermometer near the apparatus and allowing some time to elapse between making the test and measuring the volume of the gas. As the pressure of the air has an effect on the volume of the gas, it is best to have a compensating tube E, (' volumeter '), attached to the instrument. This tube is arranged so as to hold exactly 100 c.c. at normal temperature and pressure; under other conditions the volume shown by it will be different, but the ratio of apparent volume to 100 c.c. will be the same as that of the gas which is being measured—thus if the compensating tube reading were 115 c.c. and the gas measured 23 c.c., the true volume of gas at normal temperature and pressure would be 20 c.c. for 115 : 100 = 23 : 20. In this way all the complicated reduction and correction for temperature and pressure is reduced to a simple proportion sum, and the reading of the thermometer and barometer eliminated.

As 1 gramme of pure calcium carbonate will liberate 222 c.c. of carbon dioxide at normal temperature and pressure, the percentage of pure calcium carbonate in the sample is found by multiplying the volume of gas measured by 100 and dividing this result by the product of 222 and the weight of sample used. Thus, in an actual experiment, 0·375 gramme of whiting gave 79·5 c.c. carbonic acid gas at normal temperature and pressure; hence 79·5 × 100 = 7950, and this divided by 222 × 0·375 (= 83·25) gives 95·5 per cent. pure calcium carbonate in the sample.

If magnesian limestones are being tested in this way the calculation does not apply, as magnesia has a different combining weight to lime, but the percentage of carbon dioxide present can be calculated by remembering that 1 c.c. at normal temperature and pressure weighs 0·00198 gramme. A typical dolomite contains about 48 per cent. of carbon dioxide.

An alternative method for the assay of calcium carbonate samples consists in determining the amount of acid which a given weight of the sample will neutralise. For this purpose about half a gramme of the sample (or more, if a low grade material is being tested) is accurately weighed in a watch glass, transferred with water to a small flask of about 4 oz. capacity, a couple of drops of methyl orange solution added, and then a standard solution of decinormal sulphuric or hydrochloric acid (obtainable from most large chemists) run in, drop by drop, from a burette until the colour of the liquid is changed from yellow to a yellowish pink, when the volume of decinormal acid used is read off. As 1 c.c. of this standard acid represents 0·005 gramme of pure calcium carbonate, the number of c.c. of acid used divided by twice the weight of sample taken for the test will give the percentage of calcium carbonate present. This is, however, only true when calcium is the only carbonate present. For all ordinary purposes the test is, however, sufficiently reliable, if care be taken to stir the liquid efficiently whilst adding the acid, and if, after the test is considered finished and the volume of acid used has been read off, a further quantity of acid is added in order to produce a decided pink and to ensure that the end point of the reaction has really been reached.

Iron in chalk, whiting, limestone, etc., must be determined by the usual methods of analysis given in the standard text-books. A rough idea of the proportion present may be gained by dissolving about 1 gramme of the sample in dilute hydrochloric acid and adding to it a few c.c. of a solution of potassium ferrocyanide. This will produce a dark blue colour, the intensity of which will depend upon the proportion of iron present. If a sample containing a known quantity of iron be similarly treated the comparative colour will give some idea of the quality of the sample under test.

Checking is an important operation which is often neglected in small factories, but which is nevertheless of great importance. This is not only the case with regard to the weight of goods delivered, but also with regard to their quality and price. It has more than once happened that a firm, unable to supply goods at the price offered and unwilling to stock an inferior quality, have systematically watered the materials sent out so that they might weigh correctly when received by the customer, who unsuspectingly paid for water in the belief that he was buying felspar or some other glaze material. A determination of the percentage of moisture in such materials should, therefore, always be made as soon as possible after receipt of the goods (see 'Moisture,' p. 284).

Tests for checking the quality of goods in other ways will be found under the headings of the goods or materials themselves.

Clay testing is a subject of considerable complexity, as so little, comparatively speaking, is known of the true internal constitution of clay. As already explained (p. 233) an analysis of a clay carried out by ordinary methods is of trifling value to the clayworker, as it does not give him the information he requires. On this account analyses have fallen into a somewhat undeserved disrepute, owing largely to the clayworker not knowing precisely the nature of the information of which he was in search.

To be of value, the examination of a clay must deal exhaustively with the following particulars at least :—

1. General composition, with especial attention to the presence and effects of certain small quantities of organic and mineral impurities, particularly iron compounds, with suggestions for their removal. This information is largely to be obtained from the results of various analyses of the clay (see p. 233), but it must

also be derived from a physical examination made in order to determine the proportion of stones, sand, and other foreign materials in the clay. These are separated from the clay by a process of careful sieving and washing, the different materials being then identified by chemical and other tests. Some of the methods by which this is accomplished will be found described fully in an admirable little book, by H. M. Ashby, on *How to Analyse Clay*.

2. Ease of working is an important characteristic in a clay, and though the final tests for this property must be made on a comparatively large scale, much information as to the ease or otherwise with which a clay may be ground, mixed with water, pugged, and made into goods, may be ascertained by careful working on fair-sized samples.

3. The behaviour of the clay at high temperatures is of great importance, and though this can often be predicted from the results of a rational analysis, the true test consists in an actual determination of the fusing-point of the clay (see p. 269).

4. The amount of contraction on drying and on burning must also be determined (p. 249), and attention paid to the ease and rapidity with which the drying may be allowed to take place. Some clays can be dried almost 'anyhow,' others require the greatest care and attention to prevent their cracking.

5. The appearance of the finished goods as regards colour, surface, soundness, and capability of taking a good glaze or engobe, must be ascertained.

6. The porosity and power of absorbing water, and the tendency to produce scum on standing exposed to the air (due to the presence of soluble salts), must also be tested when these are of importance, as in the brick trade.

When it is simply desired to establish the presence or absence of some particular constituent of the clay, so complete an investigation as that described above is not necessary; thus the percentage of lime in a calcareous (or 'limey') clay may be readily determined by either of the two methods described for the assay of chalk on page 242, except that not less than 1 gramme of the clay should be used in making the assay. The first method is more accurate than the second for clay, as the insoluble matter present makes it difficult to observe the change in colour.

Iron may usually be estimated in unburnt clays by boiling about 5 grammes (accurately weighed) for some hours with about 4 oz. of concentrated sulphuric acid to which a few drops of nitric acid have been added, allowing the solution to cool, diluting with water to about ten times its volume, and carefully adding a slight excess of ammonia so that the liquid is slightly alkaline after vigorous stirring. If iron is present, the precipitate which is formed will be brown. In order to estimate the iron present in the clay the precipitate must be filtered off, washed well with water, and the residue on the filter treated by some standard method (see p. 272, also Ashby's *How to Analyse Clay*).

Water in clay may be determined by the method described under 'Moisture' (p. 284). Alkalies are important fluxes and must, therefore, be practically absent from fireclay and other refractory clays; their peculiar characteristics render their estimation difficult, and it is better to entrust this work to a skilled analyst.

When in the form of slip, it is desirable to make frequent tests of the fineness of the clay; and in order to ensure that it is well mixed it is wise to dry small samples of the clay as rapidly as possible and to pass them through the kilns, so as to ensure the proper picking and cleaning of the clay before the bulk is used. This of course applies chiefly to the higher classes of goods, though a frequent inspection of the mill and clay in the various stages of manufacture is essential to success.

Coal testing is an operation requiring considerable skill if the true value of the fuel is to be ascertained. It is too often assumed that the calorific power (p. 239) or heating value of the coal is the sole criterion by which it should be judged, but in practice it is found that the nature of the ash is also of considerable importance. A further difficulty often arises from the circumstance that when a change in the source of supply is made, the kilns almost invariably go wrong if the firemen are aware of the change! The explanation of this curious result is not always easy, but in practice it is always best to bring about such changes gradually so that they shall not be discovered.

It is advisable to make frequent tests of the amount of *ash* in the coal. This is easily accomplished by heating about 2 grammes of the sample in a tared platinum crucible at a red heat until all the combustible matter has been burned off and the residue is white, or, at most, reddish or grey. Care must be taken that the heat is not applied too rapidly at first or some of the material may be projected out of the crucible. A good bunsen burner is the most suitable heater, the crucible being supported on a pipe-clay triangle on an iron stand. The percentage of ash in coal varies greatly with different qualities; for firing kilns it should not exceed 8 per cent.

When considering the question of obtaining coal from a fresh source it is advisable to calcine several pounds of the coal in a crucible, to form the resulting ash into a 'cone' (p. 249) by mixing it with a little gum-water, and to determine the fusing-point in a similar manner to that of clay (p. 269). Coals which give an easily fusible ash should be avoided for kiln purposes as they render the cleaning of the fireboxes difficult. Occasionally the admixture of a small proportion of 'grog' or sand will prevent coal ash from clinkering, but with some kinds of ash this will only increase the fusibility.

In collecting samples of coal for testing considerable care and skill are required if a fair, average sample is to be obtained. It is not sufficient to pick up any odd lump. The sampling must be done thoroughly and properly or it had far better not be done at all.

Compression tests are especially important to those branches of the clay trade where goods are used for architectural purposes. It is seldom, however, that a sufficient number of tests will be required to make it worth while to purchase a special hydraulic press for this purpose, and it is therefore usual to send the samples to a public testing works.

Cones form a special mode of ascertaining the temperature of kilns, etc., devised by the late Dr. Seger. They are particularly adapted for this purpose, and, in spite of much opposition, are rapidly gaining favour in this country. As the preparation of these cones is a matter requiring much skill and care, the clayworker should not attempt to make his own but should obtain them from the inventor's agents. For further details see page 308 *et seq.*

Contraction.—All clays diminish in volume on drying and, still more, on heating to a red heat. The causes of this having already been referred to (p. 12), the method of measuring the change may be briefly described here. Although various modifications and methods are used by different clayworkers the following will be found to be one of the most satisfactory, as it is sufficiently accurate without being tedious or complicated. A block of convenient size (say 9 × 4 × 4 inches) is made of the clay to be tested; the precise size is of little importance provided the sides of the block are as square and the arrises as sharp as possible. This block is laid carefully on a smooth, level slab and a distinctive letter or number marked on the top. This is done so that the block may always be laid in the same relative position to the operator. A sliding calipers graduated in millimetres, or in thirty-seconds of an inch, is applied to the block, and its length at the bottom carefully measured. A slip of wood, about a quarter of an inch thick, is then laid at each end of the block, the calipers again applied by resting them on the wooden slips, and the length again measured. This operation is repeated by the use of additional slips until the top of the block is reached, sixteen or seventeen measurements being taken in all. Very great care must be used not to alter the shape of the block during the measurements, as will occur if the calipers are moved carelessly. The block is allowed to dry white hard and the measurements are repeated, the difference being the contraction on drying. The block is then fired in the kiln, and, when quite cool, it is again measured as before, the difference between these and the first measurements showing the total contraction. The results may be expressed in various ways, but it is most convenient to express them in inches per foot—*i.e.* if a block of the wet clay exactly one foot in length is found to measure only 10·75 inches after firing, the total contraction would be $12 - 10{\cdot}75 = 1{\cdot}25$ inches per foot. As it can be proved that the contraction in volume is a simple multiple of the linear contraction, there is no need to determine the loss of volume.

Where sliding calipers are not at hand, a sufficiently accurate result may often be obtained by carefully ruling two lines about 8 inches apart on the clay with a needle and measuring their distance carefully before and after drying and firing. It is essential that the clay to commence with should be of the right consistency, and, if comparative tests of the clay are to be made at intervals, the actual amount of water in the clay should be determined, as small differences in the amount of water present have a considerable effect on the contraction during drying; the contraction between the white hard material and the same after firing is not so much affected.

Cornish Stone (china stone, pegmatite), which is important as a constituent of many bodies and glazes, cannot be distinguished from felspar by any simple chemical tests. To an experienced man the difference in texture and in melting-point would be sufficient to decide whether one had been substituted for the other. On chemical analysis, Cornish stone is readily distinguished by its containing only 3 or 4 per cent. of potash as against the 12 to 16 per cent. contained in felspar. It must, however, be borne in mind that both felspar and Cornish stone are not chemical compounds but rather types of minerals, and that therefore their composition varies considerably, especially in regard to the alkaline contents.

Apart from the appearance and 'feel,' Cornish stone is best tested by placing a good sample and the new one side by side in the kiln and removing them when the genuine sample has fused somewhat; the appearance of the two may then be compared. If they differ greatly, the new sample must be analysed before it can be used with safety to replace the original (good) stone.

As unscrupulous dealers are prone to water their stone it is wise to dry a weighed sample very carefully and to determine the moisture in it (see p. 284). Cornish stone is usually sold on the understanding that it does not contain more than 10 per cent. of moisture when in lumps, or 5 per cent. if water-ground and dried. The dealer will, if asked, state the limit of moisture at which he is willing to sell.

Counters which automatically register the number of waggons of clay, coal, etc., loaded are an invaluable check both on the material used and on the work done by the carters. There are various forms on the market for this purpose, most of them excellent, but several of the simplest have the disadvantage that the carter may easily rotate them by hand and so fictitiously increase the number of loads. This may to a large extent be prevented if each time the waggon, when travelling in one direction (*i.e.* full), is made to depress a lever and so mark a rotating dial in such a way that the *time* at which the waggon passed is noted. If the waggons succeed one another too quickly a further watch can then be taken.

Mill-counters and engine-counters, for determining the number of revolutions per day, are useful in keeping up the output and in ensuring the engine being run at a regular speed; they can be obtained of most manufacturing engineers, and should be well protected from the dust. On this account a plain counter with dials showing tens, hundreds, and thousands of revolutions is preferable to an automatic paper-registering apparatus. The counter should be so attached that it is out of gear when the machinery is running on the loose pulley.

Although no automatic counter exists which is specially sold for the purpose, it is very desirable that the amount of clay ground, tempered, pugged, pressed, and delivered should be registered daily, as in this way the regular working of the machinery is ensured and a product of higher average quality is obtained than when irregular work is the rule. In addition to this, loss of time is more readily noted and, if possible, stopped without its becoming serious.

With the advent of wire-cut bricks has come the necessity for a counter to indicate how many bricks are turned out by each machine. In the usual form of apparatus the ribbon of clay passes over rolls which, in rotating, indicate on a modified form of 'speed indicator' the number of inches of ribbon of clay produced, and this number divided by the average length of a brick gives (roughly) the number of bricks made. The number is often not quite correct owing to the tendency of the roller to 'stick' at times.

This sticking is reduced to a minimum by covering the roller with felt and attending very carefully to its lubrication.

Counters of time and work done by the makers may be more appropriately considered under the head of 'Costs' and 'Office Work.' Such appliances are obtainable from the very numerous promoters of card indexes, etc., both in this country and America.

Dampness of air in drying rooms (see p. 256); of materials (see p. 284).

Density is a term used to denote the relationship between the volume of a given mass of substance and its weight, or the relation between the weights of equal volumes of different substances. The term is also used somewhat loosely in the sense of being the opposite of porosity (p. 18).

The density of a clay may be expressed in three forms—referring to the clay (1) in its green or (2) in its fired state, or (3) to the density of a clay-slip.

In ordinary practice it is usual to consider the weight of a volume of water equal to the volume of the substance, whose density, or specific gravity, is being determined, as unity; hence the specific gravity of water is 1·000.

In the case of porous solids like fired clay the specific gravity may refer to the whole piece—including pores—or it may refer only to the solid material. If the former is understood, the specific gravity will vary with the fineness of the particles—*i.e.* with the grinding; but if the latter, it will be constant for the same material.

To find the specific gravity, including pores, of a lump of fired clay, or other material, not affected by water, the piece is weighed on a delicate balance in the ordinary way and is then hung from the arm of the balance by means of a hair, or fine piece of silk of negligible weight, in such a way that it is completely immersed in water contained in a small vessel when the balance swings evenly. It is then weighed in this position, when

$$\text{sp. gr.} = \frac{\text{ordinary weight in air}}{\text{ordinary weight} - \text{weight in water}}.$$

It is, however, necessary with porous materials to dip them first in melted lard or similar material to cover up the pores; the coating of fat should, of course, be as thin as possible so as not to affect the results.

To find the specific gravity of the substance itself (excluding pores) one of two methods may be used:—

(*a*) Find the ordinary weight of the piece, then soak it in water for some hours and find the weight of water absorbed (see

Absorption, p. 232) in grammes. This will give the volume of the pores in c.c. Now weigh the piece suspended in water as above described and find the loss of weight. Then

$$\text{sp. gr. of solid} = \frac{\text{weight dry}}{\text{weight dry—weight suspended in water}},$$

$$\text{sp. gr. of whole piece} = \frac{\text{weight dry}}{\text{weight soaked—weight suspended in water}}.$$

In the case of unfired clay water cannot be used for soaking the material; paraffin oil should be substituted, and the numbers obtained for the paraffin absorbed and for the loss of weight in paraffin divided by the specific gravity of the paraffin itself. Or the following method (*b*) for powders may be employed.

(*b*) To find the specific gravity of a powder, a bottle is weighed empty and dry, then it is exactly filled with water to a mark on the neck and weighed again; the increase in weight gives the weight of water held by the bottle. The bottle is again emptied and dried and nearly filled up with the powder and again weighed; the increase shows the weight of powder used. The bottle is now filled up to the mark with water and weighed once more; the increase between this and the previous weight shows the amount of water-filling space not occupied by the solid. Hence

$$\text{sp. gr.} = \frac{\text{weight of solid}}{\text{weight of water to fill empty bottle—weight of water occupying space not filled by solid}}.$$

To find the specific gravity of a liquid, whether a clear liquid or a slip matters not, weigh a dry empty bottle or flask, fill it to a certain mark on the neck (or, if a proper pycnometer is used, fill it completely) with water at a temperature of 60° F. and weigh again—increase in weight = water held by bottle. Empty out the water and dry it, and refill the bottle with the liquid, or slip, and again weigh so as to find weight of liquid. Then

$$\text{sp. gr.} = \frac{\text{weight of liquid}}{\text{weight of water}}.$$

It is important that the liquids should be as near 60° F. as possible, as the specific gravity diminishes with increased temperature.

To find the *density of a slip in ounces per pint*, multiply the specific gravity by 20; thus specific gravity 1·30 = 26 oz. per pint, and, conversely, the density in ounces per pint divided by 20 =

specific gravity, *i.e.* a slip weighing 27 oz. per pint has a specific gravity of 1·35 (see also p. 274).

It is becoming increasingly common on the Continent to express the density of clay in another form by quoting the weight of 1 litre of the dry powder. This figure is obtained by filling a tared litre flask to the mark with the powdered clay or other material, and then weighing. This gives results differing from those obtained by other methods, but they are consistent and easily obtained. Perhaps the best term for this figure is a direct translation of the German 'Volum-gewicht' = 'volume-weight'; in this way it may be distinguished from the ordinary terms, density and specific gravity.

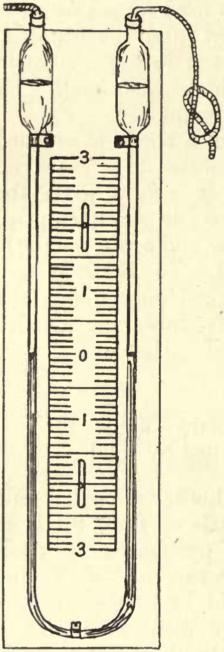


FIG. 10.

Draught measurers are instruments designed to measure the pressure of the air supplied to boilers and kilns, whilst anemometers (p. 232) measure its speed. As, however, the speed is dependent on the pressure, the two instruments replace each other to a certain extent. As the temperature of the fuel in burning depends upon the air supply, it is important to have some means of ensuring steadiness in this latter.

One of the simplest draught measurers is that devised by Seger (fig. 10), which consists of a long glass tube bent in the form of a U and enlarged at its open ends, so that it there has a section ten times that of the tube itself. Each half of the tube is filled with a different coloured liquid (a plain solution of carbolic acid and a similar solution stained almost black is commonly used). The instrument is provided with a sliding scale, so that the zero may be set at the junction of the two liquids when the instrument is at rest. One end of the apparatus is then connected with the flue, and the change in level of the liquid-junction is noted. This is ten times the actual depression of the liquid on the surface, so that the rise or fall in inches must be divided by ten. If, instead of keeping the instrument vertical, it is simplified into a plain tube with an inclination of one in ten, its sensitiveness will be correspondingly increased; or one arm may remain vertical, and the other may be so arranged as to have an inclination of one in ten with the horizontal (fig. 11).

Provided that the quantity of liquid (water stained dark with a little soluble aniline dye) is kept constant, it is only necessary

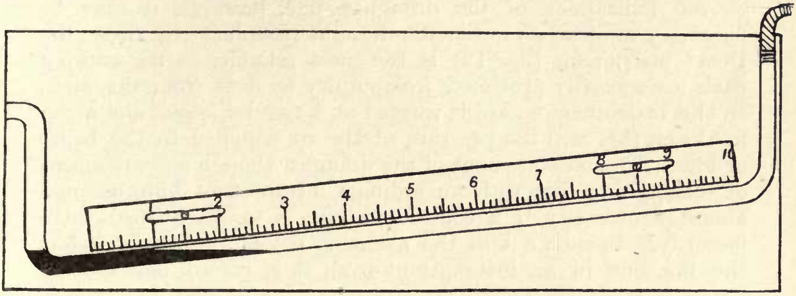


FIG. 11.

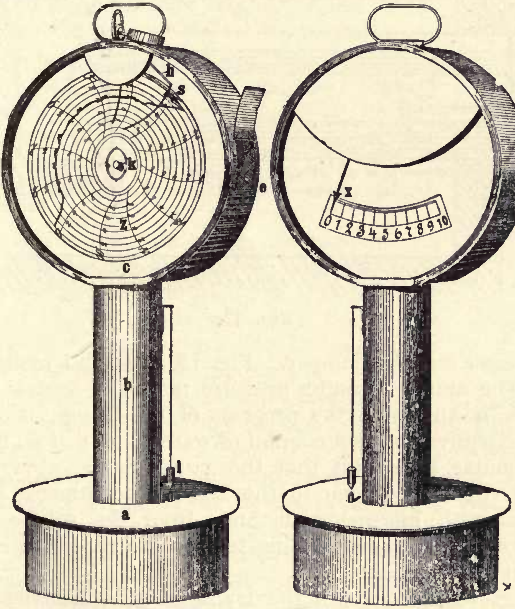


FIG. 12.

to read the sloping arm scale on the instrument. This greatly simplifies the matter for the fireman, and the simplicity of the apparatus itself gives it a great advantage over the more complicated dial instruments with self-registering apparatus attached. Where a difficulty is found in getting the kiln-burners to attend to the indications of the draught-gauge, however, it may be necessary to instal an automatic draught recorder. Of these, the Obel[1] instrument (fig. 12) is the most reliable, as its working parts are specially protected from injury by dust from the flues. In this instrument a card is rotated at a regular speed, and a pen marks on this card the pressure of the air supplied to the boiler or kiln. The measurement of the draught, though a great means of economising fuel with an ordinary intermittent kiln, becomes almost a necessity if a continuous kiln is to be burned satisfactorily. In such a kiln the gauge is placed nine holes before the fire, but in an intermittent oven it is placed between the burning space and the damper. Fig. 13 shows its position for a boiler. The actual draught pressure naturally varies with the kind of kiln and with the progress of the firing; it is seldom more than equivalent to a column of water $\frac{3}{5}$ or $\frac{4}{5}$ of an inch high. It is, of course, important that the gauge should always occupy the same relative position to the fire, as the draught gradually diminishes with increasing distance from the source of heat. Advantage may be taken of this to test the air-tightness of the flues from time to time.

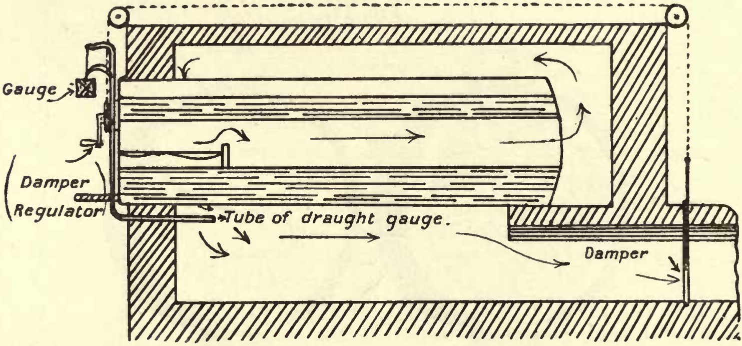


FIG. 13.

Drying.—The control of the drying of solid materials depends on the nature of the goods themselves. It is usually determined by noticing the loss of weight of a carefully weighed portion of the substance, which is re-weighed at intervals until it ceases to lose weight at the temperature at which the drying is allowed

[1] Obtainable from Seger & Cramer, G.m.b.H., Berlin.

to take place. If this temperature is rather above that of boiling water (212° F. or 100° C.), all the true moisture will be removed by this treatment, but any 'combined water' will still remain and is only to be completely removed at a red heat (see 'Drying,' p. 179). In drying clay goods on the large scale, however, so high a temperature cannot be used from the start, and the drying must be conducted under more gentle conditions. As the amount of drying the goods undergo depends on the amount of moisture the air in contact with them can take up, it is important to keep the air in such a state as to work as efficiently as possible. Air at any particular temperature can only hold a definite weight of water per cubic foot, but the amount of water so retained increases very rapidly with comparatively small increases in the temperature; thus, air at 30° C. can retain nearly twice as much moisture as the same volume of air at 20°, and more than three times that at 10°. The drying rooms should therefore be well supplied with thermometers hung in various parts, and the heating must be arranged in accordance with the indications of these instruments.

At the same time it must be remembered that merely heating in an atmosphere saturated with moisture will not dry the goods, so that frequent estimations of the moisture in the air of the dryers should be made, and the air supply so regulated that a definite quantity of water is abstracted from the goods in a definite time, the precise amount depending on the 'delicacy' of the clay.

A rough estimation of the evaporative power of the air may be made by means of a Piche evaporimeter, which consists of a graduated glass tube (fig. 14) with a small clamp on the lower (open) end supporting a small piece of filter-paper. The tube being filled with water and hung up in the dryer, the water is gradually evaporated from the filter-paper, a fresh supply from the tube keeping the paper always wet. The changing level of the water in the tube is read off at regular intervals and the rate of drying is thus ascertained. The results have no absolute value, but when obtained from instruments of identical dimensions

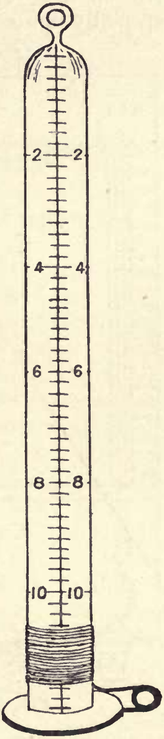


FIG. 14.

using clean filter-paper and pure water, they agree well amongst themselves.

For accurate determinations of the amount of drying which the air can do under given conditions, it is necessary to employ some form of hygrometer. These are instruments which record the amount of moisture in the air in which they are placed. Although several forms are in use there are two which are specially suited to the clayworker — the 'wet-bulb' and the 'hair' hygrometer. The former, though requiring rather more skill in use, gives the more accurate results and is the more durable instrument.

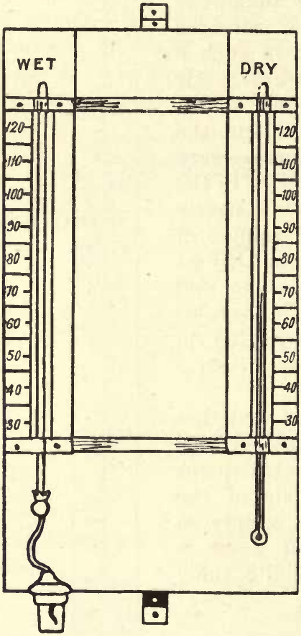


Fig. 15.

The wet-bulb hygrometer (fig. 15) consists of two precisely similar thermometers mounted side by side, one of which has the bulb covered with a small piece of cotton so arranged that it is kept constantly damp. Water is supplied to the cotton by capillary attraction from a small vessel placed underneath the thermometer. As the water surrounding the wet bulb evaporates it keeps the air in its immediate neighbourhood saturated with moisture, so that this wet-bulb thermometer reads lower than the dry one. This is because evaporation is always accompanied by a lowering of the temperature of the liquid evaporated, and in this case the depression is such as to cause the wet-bulb thermometer to register the dew-point of the air.

The absolute weight of water which the air can still take up may be calculated from the Table (at end) by deducting the maximum weight of water-vapour containable by air at the dew-point from that at the temperature of the dry bulb; thus, taking a numerical example, 1 cubic metre of air at 15° C. can take up 12·8 grammes, while at 10° C. it abstracts heat from the air in the immediate neighbourhood of the wet bulb, so that this thermometer reads lower than the dry one. From the difference in the reading of the two thermometers the dew-point, that is, the temperature at which (under these conditions) the air would be saturated with aqueous vapour can be calculated. This is done by multiplying the difference by a factor given in the Tables, and deducting this from the dry-bulb thermometer reading. If this showed a temperature of 15° C. and the wet bulb one a temperature of 10° C. with the barometer at 760 mm., the dew-point would be 5·6° C. The vapour tension at this temperature is about 6·8 mm., and at 15° C. about 12·673. The ratio of these is as 100 to 44; so that the air is only 44 per cent. saturated, and can take up an additional amount of vapour equal to more than half of that it already contains.

As the wet-bulb hygrometer is somewhat troublesome to keep accurate owing to the necessity of changing the cotton wrapping frequently, and considerable errors are introduced if the water supplied to it is dirty, a different form of instrument, due to Saussure and Kopp, is often preferred.

In this hair hygrometer a carefully prepared human hair is kept under tension by having one end fixed and the other attached to a small weight; to facilitate registration the hair passes over a tiny pulley, the axle of which carries a fine pointer. In a moist atmosphere the hair increases in length and so causes the pointer to turn towards the right, whilst in a drier atmosphere it turns towards the left, the extent of its motion in either direction being measured by means of a scale. In order that the instrument may be easily adjusted, the point to which the pointer turns when a small vessel of water is shut up for some hours in the apparatus, so as to completely saturate the air within it, is marked 100 on the scale. If for any reason this number is not indicated, the length of the hair must be increased or diminished until the correct position of the pointer is reached. The vessel of water is then removed and the apparatus is ready for use. The scale used is an arbitrary one, having usually been made by comparing the readings of the instrument with those of a wet-bulb hygrometer. The absolute weight of moisture in the air may then be calculated as usual, or advantage may be taken of an admirable chart (fig. 16) published in the *Tonindustrie Zeitung* for 1904, page 1665.

The numbers in the column A represent the numbers on the hair hygrometer scale, those in column B the relative humidity or dampness. Hence if the hair hygrometer shows a reading of 85, the relative humidity is 70 per cent. and the air contains 70 per cent. of the total moisture it can carry at that temperature. To calculate the total weight of water in the air in grammes per cubic metre, a knowledge of the tempera-

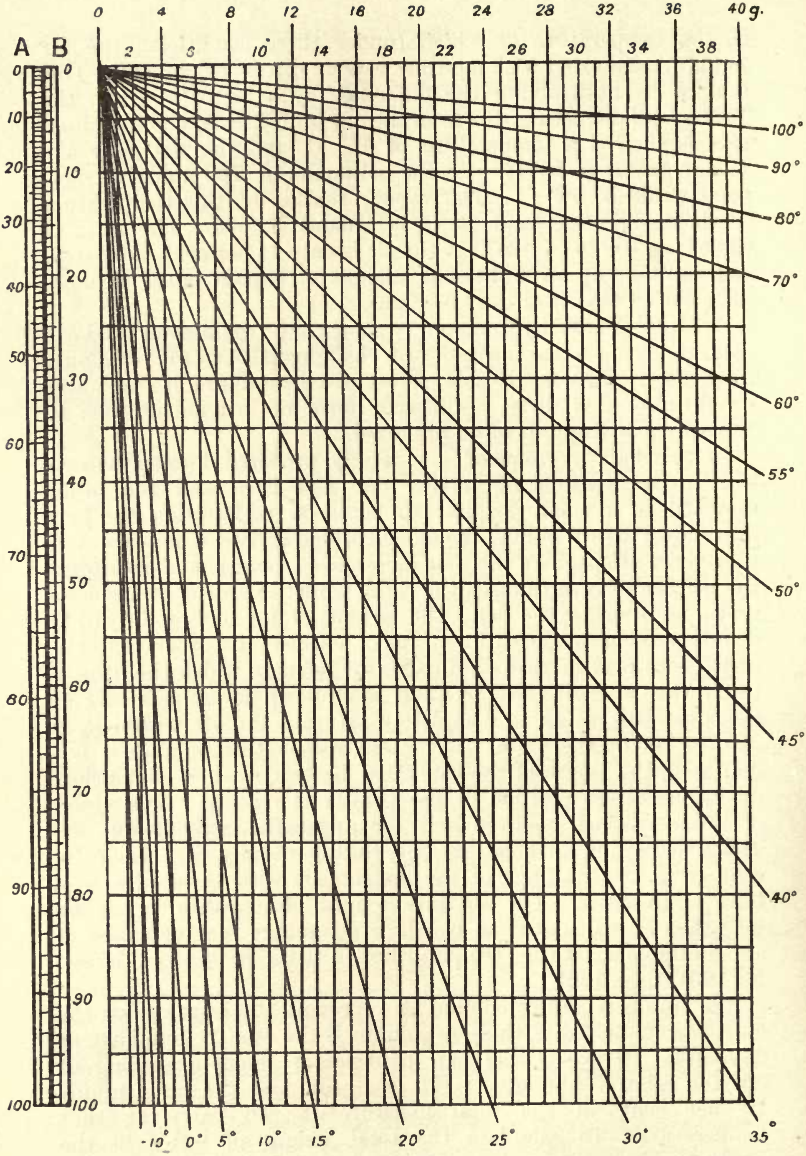

A
B
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
100
0
4
8
12
16
20
24
28
32
36
40 g.
2
6
10
14
18
22
26
30
34
38
100°
90°
80°
70°
60°
55°
50°
45°
40°
-10°
0°
5°
10°
15°
20°
25°
30°
35°

FIG. 16.

ture is required; supposing it to be 35° C., the hygrometer remaining at 85 as before, then, as 85 on the hair hygrometer scale represents 70 per cent. of humidity, the horizontal line 70 must be followed until it cuts the sloping line of temperature 35, and a vertical line must be taken upwards from this point to the top of the scale; in the present case this will end at 28, showing that the air contains 28 grammes of water per cubic metre. If the vertical line be taken downwards instead of upwards, the dew-point, or temperature at which the air will deposit dew, will be shown; in the present instance at 28° C.

The rapidity with which the sloping temperature-lines in the chart lose their perpendicularity shows, in a graphic way, the great advantage of a small increase in temperature in increasing the water-carrying power of the air.

Durability is an important factor of certain materials, particularly bricks and artificial stones.

Durability is usually tested in regard to three influences—rubbing, crushing, and weather. Resistance to rubbing may be tested (though only with partial satisfaction) by a rough practical test, as described on p. 295. Resistance to crushing may be tested by means of a special crushing or compression machine (p. 249).

Resistance to weather may be tested by soaking the bricks in water for some time, wiping them dry, and then keeping them at 15° C. (=5° F.) in a refrigerator for several hours and again warming them up to the ordinary temperature of the air. This process of soaking, freezing, and warming is repeated a considerable number of times (some authorities say twenty-five times), and the resistance of the bricks so treated to crushing is then determined; the difference between it and the results obtained with an unfrozen brick will give some idea of the effect of exposure of the brick to the weather. This test would seem, however, to be unnecessarily severe for general use. (See p. 294.)

For testing the durability of glazed bricks, etc., Weber exposes the sample under a glass 'shade' (such as is used for covering cakes by confectioners) to the vapours of strong hydrochloric acid for several hours. If, after this exposure, the sample on warming gently shows no signs of scumming, Weber considers it to be capable of resisting ordinary atmospheric influences.

Efflorescence is the term given to certain varieties of scum forming on bricks during use. It is commonly due to soluble salts soaked up by the goods through their standing on wet ashes, or to the presence of free calcium sulphate in the clay (see Chapter XI.). Soluble salts in bricks and similar goods may be estimated as described on page 295.

Engine testing. See 'Power,' page 289.

Expansion (see also 'Contraction,' p. 249). When fired, all clays have a less volume than in the unfired state, so that on the whole it is true to say that clays contract in firing. At the same time, however, it must be remembered that this contraction is really the difference between the expansion and contraction of the clay. Thus during the drying the clay contracts in proportion to the amount of drying it undergoes, but when placed in the kiln the heat causes the particles of clay to expand in proportion to the temperature, whilst at the same time the loss of water from the mass causes it to contract. As soon as this contraction ceases, the clay follows the normal characteristic of heated bodies and expands with increasing temperature.

This matter of expansion is chiefly of importance to the clayworker in reference to the application of engobes and glazes to his goods. If the expansibility of the clay (biscuit) goods differs much from that of the covering material the latter will roll off, blister, or craze. (See these various headings in Chapter XI.)

It is a matter of extreme difficulty to measure the expansion taking place at such high temperatures as occur in kilns, and, fortunately, it is not necessary to know the *actual* expansion. The defects arising with glazes and other 'covering materials' are dealt with in Chapter XI.

Felspar is a term used to denote a group of mineral silicates of which orthoclase or 'true felspar' is the best known member. When decomposed by atmospheric conditions it loses a variable proportion of its basic constituents and produces china clay, Cornish stone being an intermediate product. A theoretically pure potash felspar contains

Silica, ...	64·72
Alumina, ...	18·35
Potash, ...	16·93

but almost all analyses of orthoclase show varying small amounts of soda, lime, magnesia, or iron oxide.

When heated to a moderate temperature it smears, but at a temperature corresponding to Seger Cone 8 it melts to a white porcelain-like mass, which often breaks up into small white drops. At a considerably higher temperature it melts to a more or less clear glass. It is chiefly employed in the clay industry as a convenient means of introducing potash as a flux, as felspar is practically insoluble, although the finely-ground powder has a slight alkaline reaction.

The value of the felspar depends chiefly on the potash it contains, and this can only be ascertained by analysis. A determination of the fusing-point (p. 269) and a test to show its freedom from more than slight traces of iron oxide will, however, often be found to be sufficient tests of its purity. The iron oxide may be tested for as described under glaze (p. 272).

Firing Control.—The control of the firing of the kilns should be made in connection with:

(*a*) The Draught.
(*b*) The Temperature.
(*c*) The Composition of the Flue Gases.
(*d*) The Fuel.
(*e*) Warners.

These methods and instruments will be found described under their separate heads, and general information on the subject will be found on page 171. It is, however, essential to remember that firing kilns does not so much mean reaching a certain temperature as obtaining a certain result on the goods; hence skilled supervision can never be entirely replaced by any automatic appliances, though these latter are invaluable aids to the former.

Flint is a moderately pure form of silica, found in nodules in the upper strata of the chalk beds of this country. Its chief impurity is iron oxide, which may be tested like a 'frit' (see page 272), but when bought in the ground state it should be analysed in order to ensure its not having been contaminated with lime from the grinding stones. When heated to the highest heat of the kiln it should burn perfectly white and be quite unfused. When specially pure silica is required, ground quartz is sometimes substituted for flint. Ground flint is, like other ground glaze materials, liable to contain an excess of water; it should never lose more than one-twentieth of its weight on drying at 100° to 110° C., and should be bought only on condition that it will not do so.

Flue Gases.—As the proper combustion of the fuel in the boiler fires and kilns depends on the proper regulation of the air supply, it is necessary to make repeated tests of the products of combustion as they pass through the flues. The great heat of these gases makes their collection somewhat difficult, but, nevertheless, it should be attempted as often as possible.

As nine-tenths of the combustible matter in ordinary coal consists of carbon, the chief product of combustion is the compound of this with the oxygen of the air, viz., carbon dioxide, or (as it is often conventionally termed) carbonic acid gas. For its complete combustion carbon requires $2\frac{1}{2}$ times its weight of oxygen and about $13\frac{1}{2}$ times its weight of air. If too little air is present, a lower oxide of carbon (called carbon monoxide) will be formed in proportion to the lack of air; whilst if too much air is supplied, the unnecessary air must be heated, and so will absorb heat which would otherwise have been usefully employed in warming the kiln. It has never been found possible in practice to burn coal effectively with exactly the correct proportion of air, and so far, the best results have been obtained when 13 volumes of air were used in place of each 10 volumes theoretically needed; this corresponds to 15 per cent. of carbon dioxide in the flue gases. Should the flue gases contain less than 15 per cent. of this gas, an unnecessary waste of fuel is going on, probably caused by an improper regulation of the draught of the kiln, as must almost always be the case when no draught gauge (p. 254) is employed.

Two totally distinct methods are used in the testing of flue gases for their carbon dioxide content—the one physical and the other chemical. The physical method of testing depends on the fact that carbon dioxide is specifically denser than air, and that, consequently, the relative density of a gas composed of air and carbon dioxide will vary with the proportion of the latter gas present. Of the various forms of apparatus for determining this difference in density that of Krell & Schultze, of Berlin, deserves special mention. It consists of two vertical tubes, each nearly 6 feet long, the lower ends of which are connected with a differential pressure gauge consisting of a fine calibrated glass tube containing a thread of coloured alcohol. The position of this thread relative to the scale indicates the percentage of carbon dioxide present, as the flue gas passes through one of the tubes and ordinary air is passed at the same rate through the other. If the position of the thread of alcohol be registered photographically, a continuous record of the composition of the flue gases is obtained. Although the results obtained in this way agree remarkably well with the more accurate chemical analyses of flue gases, they are open to the objection that the nearer one approaches the correct proportion of air to fuel burned, the greater is the tendency to an insufficient supply of air and consequent production of carbon monoxide, which is not shown by this apparatus, but which, on account of its strong reducing action, would be very objectionable at certain stages in the burning of clay goods.

A similar criticism applies equally to the chemical analysis of flue gases for carbon dioxide only, although its continuous estimation by the ingenious 'Ados' automatic apparatus is of great value when supplemented occasionally by more complete analyses. In this instrument the flue gases are pumped at regular intervals into a measuring vessel acted upon by caustic potash, and the diminution in volume due to the removal of the carbon dioxide recorded, the whole of these operations being carried out automatically. Although only constructed for the determination of this one constituent of the flue gases, it is quite possible for the apparatus to also estimate the proportion of carbon monoxide present; when this is the case, the instrument affords an almost perfect control of the firing.

Where it is desired to make *analysis* of the flue gases in the ordinary way, the apparatus devised by Orsat or by Stead, or one of the many forms of the Lunge 'nitrometer,' may be employed. In all the best forms the volume of the sample is first accurately measured; the gas is then subjected to the action of some chemical which will remove one of the constituents without affecting the others, and the change in volume is noted. A second constituent is then removed and the volume of the gas is again ascertained, these operations being repeated until only the nitrogen remains.

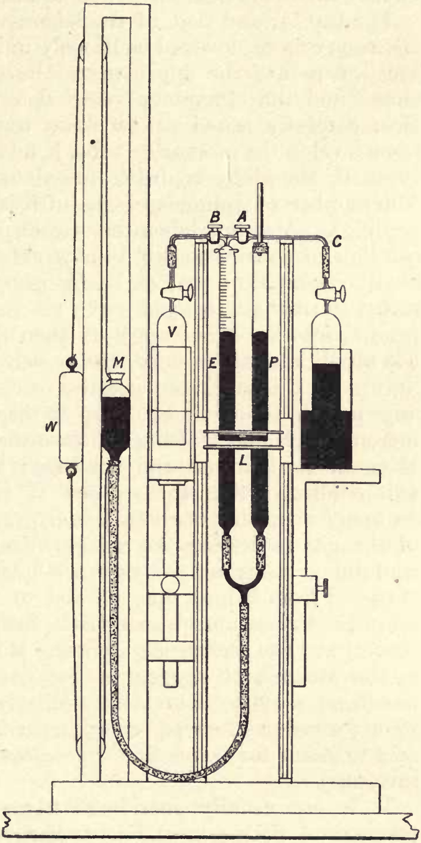


FIG. 17.

A fair, average sample of the gas to be tested having been obtained in the 'laboratory vessel' in the manner described on page 298, and the gas apparatus being filled with mercury and ready for use, the first operation consists in measuring off a definite quantity of gas. For this purpose a short piece of thick-walled rubber tubing is used to connect the fine capillary tube of the laboratory vessel with the corresponding capillary at A (fig. 17). (Before making the connection the gas apparatus must be filled with mercury to the end of the tube A, and the rubber tube just referred to should also be filled.)

The tap, A, and that of the laboratory vessel are then opened, the reservoir, M, lowered cautiously until about 80 volumes of gas are drawn into the apparatus. The taps of A and C are then closed and the laboratory vessel detached. The reservoir, M, is then carefully raised up or down until the mercury is at the same level in the measuring tube, E, and in the plain (or 'pressure') tube, P, the slide, L, being raised or lowered for this purpose. The number of volumes of gas in E is then carefully noted (first reading). A second laboratory vessel, V, containing a 30 per cent. solution of caustic potash, is now attached to the capillary tube at B; its tap and that of B are opened, and the reservoir, M, is raised so that all the gas and a few drops of mercury are passed from E into V. The tap, B, is then closed. After five minutes the tap B is again opened, the vessel M is lowered, and the gas drawn back into E, the greatest care being taken not to allow any potash to enter E. Tap B having been closed, and the mercury in E and P being at the same level, the volume of gas is again read off (second reading); the difference between the two readings being the volume of carbon dioxide in the gas. In many cases this is all that is required; but if a fuller analysis of the gas is desired, the vessel, V, is replaced by a similar one containing a strongly alkaline solution of pyrogallol, the gas is passed from E into this, allowed to remain in contact for some minutes and again drawn back into E and measured (third reading). The difference between this and the second reading is the amount of oxygen in the gas. The amount of carbon monoxide may be found by similarly treating the gas with a strong solution of copper chloride (made by allowing hydrochloric acid to stand for some time in contact with an excess of copper turnings).

It is not usually considered necessary to estimate the proportions of hydrogen and hydrocarbons present in flue gases as they can only be present in such small amounts; the volume of gas remaining in E after the removal of the carbon dioxide, oxygen, and carbon monoxide may, therefore, generally be regarded as nitrogen.

As it is the proportion of the various gases in the mixture and not their absolute volume that is required, it is not necessary to make any correction for temperature and pressure unless the duration of the analysis is unusually long; a 'compensating tube' (p. 245) may then be employed.

As a coal of average composition requires 10·34 times its own weight of air for its proper combustion, the percentage composition of the flue gases should, under perfect conditions, be about 19 per cent. of carbon dioxide, 81 per cent. of nitrogen, and should contain traces only of other gases, carbon monoxide being entirely absent. Consequently if 19 be divided by the percentage of carbon dioxide in the flue gases, the result will be the number of times excess of air over the theoretical amount which is passing through the flues. Thus, if only 3 per cent. of carbon dioxide is found, then $19 \div 3 = 6$, which shows that six times the proper quantity of air is being supplied. As already stated, however, it is never possible in practice to work with the theoretical volume of air and yet obtain perfect combustion, and 15 per cent. of carbon dioxide may be considered to be the highest obtainable in ordinary practice. Should notable quantities of carbon monoxide be found in the flue gases, this indicates, quite independently of the amount of carbon dioxide, that too little air is being supplied. As both these gases are derived from the carbon of the fuel, an increase in one may often be accompanied by a decrease of the other; but as the heat produced by burning fuel to the monoxide is far less than when complete combustion to dioxide takes place, the formation of the former should be regarded as a direct waste of fuel. The estimation of carbon monoxide should never be omitted in flue gas analysis, as the presence of a relatively small proportion of this gas may indicate a serious loss of fuel.

The presence of oxygen in the flue gases is another indication of an excess of air, although it is difficult to reduce the proportion of this to below 5 per cent. If both oxygen and carbon monoxide are present in the flue gases it is probable that the temperature of the fire is too low to bring about proper combustion; or imperfect combustion may be brought about by an insufficiency of air to the fuel, together with a leak, through which the kiln draws air which never comes in contact with the fuel.

The importance of avoiding these excessive amounts of air as well as leakages may be better realised by considering a by no means uncommon case, where the flue gases on analysis showed only 3 per cent. of carbon dioxide. This, as already explained, means that $\frac{19}{3} = 6{\cdot}33$ times the correct quantity of air was used.

As 1 lb. of coal requires 10·34 lbs. of air, in this case 55·14 lbs. of air were unnecessarily heated to the temperature of the flue, 450° F. above that of the surrounding atmosphere; and as 450 × ·237 B.T.U. (p. 128) are needed to raise 1 lb. of air by this amount, it follows that 450 × ·237 × 55·14 = 5880 B.T.U will be needed to heat the excess air supplied in this case, per pound of fuel. As good coal may be assumed to liberate 13,000 B.T.U. per pound, this means that 45 per cent. of the fuel used would be wasted in unnecessary heating of the air. A further short calculation will soon show in how short a time the expense of flue gas testing will repay itself.

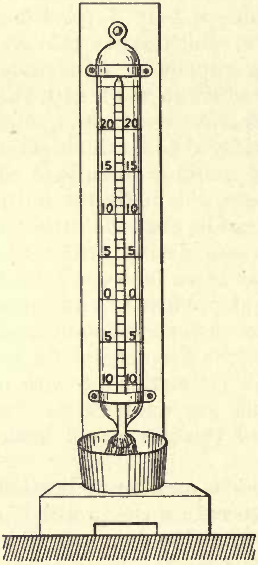


FIG. 18.

Frits.—Frits cannot well be tested by any simple rule, owing to the great variety of their composition. They may be tested for fineness, etc., in the same manner as glazes, and analysed in a manner similar to a fired glaze, although the presence of borax is apt to complicate matters. Further particulars regarding the composition, etc., of frits will be found on page 29 *et seq.*

Frost affects clay goods both in the green and in the biscuit state, although glazed goods are but little injured if the glazing has been properly carried out. If the glaze has a different coefficient of expansion to the body of the goods, exposure to frost will cause crazing in many cases.

The chief reason why frost damages goods is that the moisture in the pores increases in volume as it turns into ice, the expansion splitting the goods. It is, therefore, of the greatest importance that the temperature of the drying rooms or sheds should never fall below 32° F. (= 0° C.). Where artificial heat is employed for drying the goods this is easily arranged, but in outdoor drying any means of predicting frost is worth attention. On the Continent, it is invariably found that the reading of the 'wet bulb' of a thermometer (fig. 18) at 2 to 3 p.m. on any day is 4° C. (= 7° F.) higher than the lowest temperature likely to occur during the night. In England, the proximity of the sea makes the readings rather less constant than they are abroad; but this is, nevertheless, a valuable guide. It is not necessary to employ an expensive thermometer; an ordinary 'chemical' or 'dairy' one may be fitted in a suitable stand, its bulb wrapped round with cotton gauze or loose wick, which is kept moist by the lower end of the material dipping into a small vessel of clean water. The bulb of the thermometer should be at least an inch above the level of the water in the vessel; it is kept damp by the capillary action of the cotton. The instrument must be kept in the open air, in the shade, and protected from the wind and from radiations from buildings; the water and cotton used must be clean and free from grease. It will then be found, as a rule, that if the thermometer be a Fahrenheit instrument, whenever it indicates a temperature of less than 39°, or, if Centigrade, a temperature of less than 4° C., there will be frost during the night.

The capacity of bricks and of other materials to resist the action of frost may be tested as described under 'Durability' (p. 261).

It has also been suggested that a reliable way of testing the frost-resisting power of more or less porous goods is to soak the article in a cold, saturated solution of sulphate of soda. When quite saturated with the solution the article is hung up by a piece of fine string to dry. As the water evaporates the soda begins to crystallise, and, as the process of crystallisation goes on, goods which are not frost proof will be split. This test is admittedly only a rough one, but is useful in sorting out samples from a large number of different kinds of goods submitted for examination with a view to purchase.

Fuel.—Control must be maintained over the quantity used per gallon of water evaporated, per kiln fired, and per ton, or per thousand, of goods dried, etc. A careful analysis of the distribution of the coal and the amounts used for these purposes will often enable considerable economies to be effected. See also pages 65, 171, 182 and 224.

Fuel testing (see 'Coal,' p. 248). Producer gas, which is slowly replacing solid fuel, may be tested in a similar way to flue gases (p. 263); but the presence of hydrogen and of hydrocarbons complicates the analysis somewhat. The reader is recommended to get some analytical friend to show him how the estimation should be conducted, half an hour's observation of this nature being far more satisfactory than the reading of a whole volume on the subject. Good producer gas, as a rule, contains about 40 per cent. of combustible gases, the remainder being nitrogen with a few per cents. of carbon dioxide and a trace of oxygen.

Fusibility.—The fusibility of clays, glazes, etc., may be tested most conveniently by forming them into small tetrahedrons (fig. 19) of the same size and shape as Seger Cones. When the material has not sufficient plasticity to be formed into shape a little dextrine may be added to the water used for making it into a paste. These 'trials' are then placed side by side with suitable Seger Cones and heated in a muffle or Deville furnace until they begin to melt. The true fusing-point is to be taken as the temperature required to cause the trial to bend over until its point just touches the base line of the material on which it stands. The Seger Cone, which melts under the same conditions as the trials, indicates the temperature. If the cones used have all melted before the test piece, a fresh experiment must be made, using a higher series of cones; if the trials melt before the cones, a lower series of cones must be employed in the next attempt. In order to prevent the cones and trials from falling they are embedded to the depth of a quarter of an inch in a compressed mixture of fireclay (or china clay) and bauxite. Owing to the small size of experimental furnaces, great care and some skill is needed to obtain a correct result; the heating must not be too rapid, the trials and cones must be properly placed so as not to be unevenly heated and not to interfere with each other as they bend over. These conditions will be the more readily fulfilled if, instead of placing cones and trials at the bottom of the crucible, as in the ordinary way, a suggestion of Dr. Seger's successors is acted upon, and the cones, etc., attached to the base block, the crucible being merely used as a cover (fig. 20).

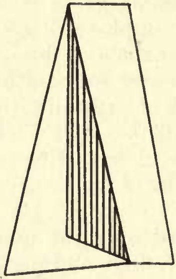


FIG. 19.

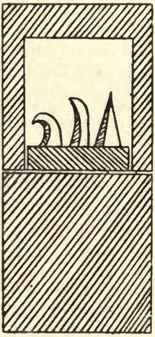


FIG. 20.

When testing clays which undergo great shrinkage on heating, the test pieces are almost certain to fall; in such cases it is best to use trials made of equal parts of the burnt and unburnt clay.

This does not in any wise alter the melting-point of the clay, but by diminishing the shrinkage enables the test to be made more speedily and accurately.

In determining the melting-point of a glaze the material, if in slip form, must first be dried, mixed into a paste with water containing a little dextrine, and moulded in the metal mould shown in fig. 19. (The mould must be slightly oiled between each filling.)

The tendency of coal to clinker may also be tested by (*a*) heating several pounds in a covered crucible, and (*b*) determining the melting-point of the ash as though it were a glaze material or clay.

Various forms of furnace may be used for making these fusibility tests; for clays, some form of blast will be required. On the Continent, a Deville furnace worked with charcoal is the usual form for the highest temperatures; but in England it is more convenient to use a Fletcher gas furnace with a current of compressed oxygen. This gas, being so largely used for magic lanterns, can now be very easily obtained in any part of the country. See also page 284.

Gases are tested according to the purposes for which they are required. Flue gases are apt to contain too much air, thus causing a waste of coal in the kilns. They may be tested as described on page 263.

Producer gas is sometimes used for heating kilns in place of solid fuel, over which it has several advantages. (See 'Fuel,' p. 43.)

Coal-gas is seldom or never made on a clayworks; its testing is therefore outside the limits of this book, especially as it is sold without any guarantee as to its quality, illuminating or heating power, or freedom from objectionable impurities.

Glazes require to be tested as regards (1) composition and purity; (2) fineness; (3) density (if in slip form); (4) fire test to ensure brilliancy, etc. These four points must be considered in turn:—

The composition of the glaze, and the purity of the materials used in its preparation, must be determined, when necessary, by analysis. The chemical analysis of glazes is, however, too complicated a matter to be treated here, as the number of different ingredients which may be present is almost limitless, and the accurate testing of a glaze in this respect offers such difficulties as to make the work almost impossible to anyone not possessing the necessary training and skill gained by years of practice in silicate analyses. The most that the ordinary clayworker can do, then, is to buy his materials under guarantee as to purity and condition, and to exercise the greatest care in the preparation of the glazes, etc., he uses. On this account, if for no other reason, it is generally advisable to buy the raw materials and to prepare the glaze one's self rather than to trust to ready-made glazes, the composition of which is unknown and unascertainable in the ordinary way. Of course, when large quantities of fritted glaze are used the case is somewhat altered, as it does not pay to prepare very small quantities of frit. It is of the greatest importance that no one should be allowed to speak to the glaze-mixer when he is weighing, or measuring out, his materials, as neglect of this precaution is one of the most frequent sources of error in the preparation of glaze.

Another source of error is faulty calculation, especially when larger or smaller quantities than those usually worked with are being prepared. If the calculations cannot be checked by some mechanical means, such as a slide-rule, it is always advisable to have them calculated by an independent worker so as to ensure the arithmetical part of the operation being correct. Glazers who have some knowledge of chemistry will often require to calculate the composition of a glaze, or engobe, from its chemical formula and *vice versâ*; and the chance of arithmetical error is then greatly increased, particularly with calculations involving the composition of substances, like felspar, which do not in practice correspond exactly to any definite chemical formula. In such cases it is generally best to calculate direct from the percentage composition of the material and not to first calculate the formula of each material. Where the materials are sufficiently pure the formulæ may, of course, be used, and the calculation correspondingly shortened. Examples of these calculations will be found in Jackson's *Ceramic Calculations* (see Bibliography).

Some rough tests of the purity of the materials will be found under the heading of the material itself.

Iron is, perhaps, the most frequent accidental impurity in the glaze not directly derived from the raw materials. Its detection in fritted glaze is somewhat difficult, as the frit must be fused with thrice its weight of pure sodium carbonate in a small platinum crucible, and the fused mass when cool tested like a raw glaze, as follows:—

One ounce or more of the glaze slip, or a proportionately smaller weight of the dry glaze material, is placed in a suitable glass flask, and hydrochloric acid, together with a few drops of nitric acid, added until the liquid is distinctly acid (the amount required will depend on the composition of the glaze). The acid liquid is boiled for a few minutes to secure complete solution of the iron, and is then filtered through a small paper filter contained in a glass funnel, the paper being folded in such a manner that it forms a cone which exactly fits the funnel. If dry glaze material is used, an equal weight of pure water should be added previously to the addition of the acid. The clear filtrate should be received in another glass flask, and the residue on the filter should be washed by pouring water on to it in small quantities at a time until the volume of water thus added is about equal to the original volume of the liquid filtered. The volume of the liquid is now made up to a convenient measure (say 100 c.c.) or to a convenient weight by the addition of more water, and a definite proportion of it is then transferred to a clear glass cylinder and 20 drops of a 10 per cent. solution of ammonium sulphocyanide in water is added and the liquid well stirred with a clean glass rod. If iron is present, a rich red colour will be produced, and the amount of it may be estimated by comparing this colour with that produced by treating various measured quantities of a standard solution of iron in a precisely similar manner (except that, as the iron solution is clear, there is no need for filtration). A suitable standard iron solution may be made by dissolving $2\frac{1}{2}$ grammes of iron wire (piano wire for preference) in a little hydrochloric acid to which a few drops of nitric acid have been added, warming until all the metal is dissolved and diluting the liquid with distilled water to exactly one litre. 1 c.c. of this solution will then contain ·0025 gramme of metallic iron, so that if 20 grammes of glaze material were found to produce the same colour with ammonium sulphocyanide as 2 c.c. of the standard solution, it is clear that 20 grammes of the sample contain $2 \times \cdot 0025 = \cdot 0050$ gramme of iron or 0·25 per cent. If the colour is too dark to compare properly, a smaller quantity of the sample or standard solutions must be employed for the test. On the other hand, if the colour is too light a larger quantity must be used. By testing glaze and body slips in this way before and after 'magneting,' the effect of the magnets can be estimated.

Where any of the materials have been fused the iron will not be extracted by acid, and the glaze must therefore be fused with carbonate of soda as if it were a frit.

It is always wise before actually using any glaze or similar material to send a small sample through the kilns as a trial; in this way with a minimum of trouble the spoiling of a whole batch of goods, owing to an error in mixing or in materials, may be avoided.

Fineness is an important factor in the successful application of glaze; if too finely ground it will not adhere properly to the clay, whilst if too coarsely ground complete combination of the different materials used will not take place and an irregularly fused product will result. The actual degree of fineness depends, of course, on the materials employed; the more easily fusible ones may, as a rule, be coarser than the more refractory, but in the case of colouring materials it is scarcely possible to obtain them in too fine a state. For sanitary ware, sieves with 60 or 80 meshes per linear inch are usually sufficiently fine, though 100-mesh sieves are sometimes employed; for art ware, finer sieves (lawns) with any number up to 250 meshes per inch may be used, according to the materials and the class of ware to be produced. In addition to the frequent sifting practised by the glazers it is always well to take a sample, at least once a day, from each tub in use and to sift this, carefully looking out for dirt, coarse particles, etc.; where the glaze is used in a pasty or solid condition (as when gelatin has been added to it) this testing of fineness takes a somewhat longer time, but it is nevertheless well worth while to make the test. This testing of fineness may conveniently precede the testing for iron and other impurities.

Density ('weight per pint') has already been referred to (p. 252). An ordinary specific gravity bottle is, however, not a practical piece of apparatus in the hands of a foreman or glazer; it is therefore replaced in the works by a specially constructed pint measure made of zinc, which is first weighed empty and then full of the slip, the increase in weight giving the density in 'ounces per pint.' From this the specific gravity may be found approximately by dividing by 20. Where more accurate results are required the pint measure may be replaced by a graduated litre flask, the specific gravity being found in this case by dividing the weight of slip held by the flask by 1000, or a specific gravity bottle may be used if a sufficiently delicate balance be employed.

To find the weight of dry material in a given weight or volume of slip it is necessary to know the specific gravity of the former as well as that of the latter. Hence, if W = dry contents of a pint of slip, P = weight to the pint in ounces, and G = specific gravity of the dry substance, then

$$W = (P - 20)\frac{G}{G - 1};$$

or if a litre flask be substituted for the pint measure, then

$$M = (L - 1000)\frac{S}{S - 1},$$

where M = dry contents of a litre of slip, L = weight of a litre of slip, and S = specific gravity of the dry substance.

Thus, if a material has a specific gravity (dry) of 2·5, and a pint of the slip weighs 28 oz. or 1 litre = 1400 grammes, then the dry contents will be

$$(28-20)\frac{2{\cdot}5}{2{\cdot}5-1}=\frac{8\times 2{\cdot}5}{1{\cdot}5}=13{\cdot}333 \text{ oz. per pint, or}$$

$$(1400-1000)\frac{2{\cdot}5}{2{\cdot}5-1}=\frac{400\times 2{\cdot}5}{1{\cdot}5}=666 \text{ grammes per litre}$$

respectively.

As volume = weight ÷ specific gravity, the volume of the dry solid matter is 13·333 ÷ 2·5 = 5·333 oz. per pint, or 666 ÷ 2·5 = 266 grammes per litre of slip, so that the slip is composed of

(By weight)	Solid	13·333	oz.	666 grammes
	Water	14·666	oz.	733 grammes
		28	oz.	1400 grammes
or (By volume)	Solid	5·333	fl. oz.	266 c.c.
	Water	14·666	fl. oz.	733 c.c.
		20	fl. oz.	1000 c.c.

From the formulæ just given it is clear that in slips of the same material, but of different strengths, the dry contents vary according to the difference between P and 20 or between L and 1000, so that where the different materials are made into slips and then mixed together it is not necessary to get the slips of exactly the right density, for a table can be drawn up from which the dry contents of the slips of varying densities can be ascertained. Thus, if, in a given recipe, it is usual to employ 12 volumes (whether 'wet inches,' gallons, or litres matters not) of a china clay slip at 26 oz. per pint, a table might be drawn up for 24 to 28 oz., rising ¼ oz. at a time, showing the volumes of slips at these densities equivalent to the standard (12 vols. at 26 oz.). For example, if the slip were at 25 oz.—as (25–20) : (26–20) : : 12 vols. : vols. required—viz., 14½ ; so that the whole table for china clay at these densities would be—

oz.	24	24¼	24½	24¾	25	25¼	25½	25¾	26	26¼	26½	26¾	27	27¼	27½	27¾	28
vols.	18	17	16	15¼	14½	13¾	13	12½	12	11½	11	10½	10¼	9¾	9½	9¼	9

If a similar table be drawn up for each kind of slip in common use, the control of the mixings will be greatly facilitated and a considerable amount of the glaze-mixer's time will be saved. As the specific gravity of the different solid materials is practically constant, a "Slip, Flint, and Stone Calculator," calculated by

W. J. Furnival of Stone, may be used for all but the most accurate work.

In those cases where the specific gravity of the dry substance is not known, the weight of dry material in a slip can only be ascertained by evaporating a weighed or measured portion of the slip to complete dryness in a weighed dish; the operation requires a considerable amount of care if accurate results are desired.

Attempts have been made to use hydrometers for estimating the density of slips, but though they may be used with some success in the case of glazes, with clay slips their readings are often far from accurate. Such hydrometers generally consist of two glass bulbs mounted on a glass stem, a little mercury or shot being introduced into one of them to secure the proper adjustment of the instrument. The stem is marked in such a way that the number on a level with the top of the liquid (slip) corresponds to the specific gravity. It is necessary to have the slip in a sufficiently deep vessel so that the instrument does not rest on the bottom, and care must be exercised in reading the instrument to get the eye of the observer as nearly as possible on a level with the top of the liquid.

The *fire test* is, after all, the most comprehensive test of the correctness of the composition of a glaze. It consists simply in firing a suitable piece of ware dipped or painted with the material as nearly as possible under the same conditions as the actual goods will be fired. In this way many mistakes in mixing, as well as impurities in the materials used, will be noticed before the glaze is fired, and the goods may thus be saved. It may be urged that this may require double the amount of storage room for glaze materials; but a little consideration will show that it is better to spend money on this, rather than run the risk of having a big batch of goods spoiled in the kilns. The test may be carried out in a small experimental kiln, or the articles used as test pieces may be placed in the ordinary kilns; for most purposes this latter is the more satisfactory course. In experimental work where various temperatures are required in making the tests, a small kiln is a necessity; but the difference in speed of heating between it and the larger kilns used in commerce renders its results somewhat uncertain, and it is therefore desirable to confirm them by another trial in a larger kiln. With care it is generally possible to get glossier results with a small kiln, particularly with leadless glazes, owing to the great rapidity with which it can be heated; on the other hand it is more difficult to avoid the action of undesirable fire-gases.

The melting-point of a glaze may be most conveniently tested by forming it into a small pyramid or 'cone' with the aid of a little dextrine and water (p. 269). It must, however, be remembered that not only the melting-point but also the covering and adhesive powers of a glaze are of the greatest importance; these can only be properly tested by working on articles of the size and kind it is desired to decorate or glaze; thus felspar cannot be used alone at temperatures near its fusing-point on account of its gathering together into drops instead of remaining evenly spread over the article it is supposed to cover. At higher temperatures this peculiarity is less marked.

Grinding.—The efficiency of the grinding machinery must be tested in regard to output and quality of product. The output depends so much on the character and condition of the plant, the way it is managed, and the nature and conditions of the materials to be ground, that no general figures can be given. The clay-worker should find by experiment the best speed at which to run the plant, the best way of feeding, and the most suitable quantity to feed in at once, and should endeavour by constant supervision to see that this standard is maintained. It is not enough to pay the men a price per ton and leave the rest to them, for it not infrequently happens that it pays the owner to pay a slightly higher rate of wages if he can in this way increase his output; this may be done by offering a bonus for each ton of material over a certain number ground each day, for the 'dead charges' of the works being the same whatever the output, it is clearly most profitable to make the output as large as possible within the given time.

The quality of the product requires even more attention; it must be frequently tested for fineness and freedom from impurity or admixture, and, when a number of different materials are mixed and ground in one operation, tests should be made to ensure that the proportions of the different ingredients are correctly arranged. This is difficult when they are of different degrees of hardness, and a preliminary crushing of the harder material is in such cases advisable. The fineness of the material may best be tested by mixing about 2 lbs. of it with four or five times its weight of hot water, rubbing it slightly with a wooden pestle so as to secure the breaking up of any cakes of material, and yet avoiding as much further grinding as possible. After being well mixed and stirred in this way the liquid is allowed to stand for four or five minutes, and the liquid is then decanted carefully through a sieve or lawn, the fineness of which depends on the material being tested. For clay, a sieve of 75 holes per linear inch is suitable at this stage. The material is aided in its passage through the sieve by gently rubbing with a soft brush about half an inch wide. The residue on the sieve is put back into the vessel from which it was originally decanted, again rubbed up with water and again sifted, this operation being repeated until the water running through the sieve is no longer rendered turbid by the material. The residue is then carefully dried and weighed; it may afterwards be examined with a lens so as to give some indications of its nature. This is especially desirable with clay. If the proportion of residue on the sieve is large it may be desirable to repeat the operation, using coarser sieves and weighing the different residues; much valuable information may often be gained in this way which will explain defects in the ware which would otherwise be puzzling to remove. In a similar way it may be desirable to use finer sieves, though it is then usual to substitute a 'washing apparatus,' such as that devised by Schoene. In this apparatus a given weight of the clay or other material is placed, and a stream of water of definite speed is allowed to pass through it and to wash out the finer particles. By working at various speeds (p. 54), particles of different sizes and characteristics are obtained separate from each other. Many precautions must be observed in using this apparatus in order to obtain accurate results; particulars of these will be found in Professor Ashby's *How to Analyse Clay*, or in Schoene's original paper. The principle underlying the process is that a stream of water moving at a definite and constant rate acts towards solid particles suspended in it like a liquid of greater density, with the result that the solid particles gradually rise to the top of the liquid and are carried away into another vessel, where, the water being allowed to remain motionless, they are again deposited; by changing these collecting vessels when the speed of the water is changed, a very complete separation of the different constituents of the material can be made. Seger, who studied this method in great detail, has proposed what are still regarded as the standard separations for clay, viz.:—

'Clay substance': all grains washed out by a stream of water of ·18 mm. velocity per second; less than ·01 mm. in diameter.

'Silt': all grains washed out by a stream of ·7 mm. velocity per second; from ·0 to ·025 mm. in diameter.

'Dust sand': all grains between ·025 and ·04 mm. in diameter, washed out with a stream of 1·5 mm. per second.

'Fine sand': all grains between ·04 and ·33 mm. in diameter.

'Coarse sand': all grains above ·33 mm. diameter (*i.e.* all that remain on a No. 75 sieve).

It is a matter of some difficulty to judge of the fineness of samples from the results of their treatment on sieves or on washing (elutriation), as just described. A tolerably good way is to calculate out the weight per cent. of material which would remain on sieves of different diameters; but when the samples are very nearly alike, exact comparison is almost impossible. In such cases the ingenious 'surface factor,' devised by W. Jackson, may be usefully employed. This factor is a single number based on the average surface of the particles, and depends on the fact that the finer the particles the greater the surface of the whole unit mass. As the average diameter of such small particles may be taken as being inversely proportional to their surfaces, the surface factor may be found for particles less than ·33 mm. diameter by multiplying the weight of the fraction whose extreme diameters are—

mm.		mm.		
0	to	·010	by	3367
·010	to	·025	by	962
·025	to	·040	by	518
·040	to	·330	by	91

adding all the products together and dividing by 100. Thus, if a clay contain the following sized particles:—

Diameter in mm.	0	to	·010	60·2	per cent.
	·010	to	·025	16·8	,,
	·025	to	·040	11·0	,,
	·040	to	·330	12·0	,,
				100·0	

the 'surface factor' is found by multiplying

60·2 by 3367 = 202693
16·8 by 962 = 16162
11·0 by 518 = 5698
12·0 by 91 = 1092
225645

which, divided by 100, gives 2256. A finer sample will give a larger surface factor and a coarser sample a smaller factor.

The principle may be extended, though with less accuracy, to the coarser fractions, the factors for which are as follows:—

Passing a No.	50 sieve	= ·5 mm.	diameter factor	33
,,	25 ,,	= 1 mm.	,,	17
,,	12 ,,	= 2 mm.	,,	8
,,	6 ,,	= 4 mm.	,,	4

Heat-measuring. See 'Temperature' and 'Calorimeters.'

Hygrometers. See 'Drying' (p. 256).

Indicators.—Indicators are of two kinds—mechanical and chemical; the former class includes temperature indicators, pressure measurers, water and gas meters, levels and floats, and various appliances for registering speed, counting, or weighing.

Chemical indicators on the other hand are less well known; they are used chiefly to indicate a change of state in the composition of a substance, and are mostly of organic origin and closely related to the dyes.

Acid and alkali indicator is usually a solution of litmus which turns red in presence of free acid or blue in presence of free alkali. It is used in the form of a solution or decoction in water, or in the form of paper which has been soaked in the solution and allowed to dry. As it is affected by carbon dioxide, it is often replaced nowadays by a solution of methyl-orange in the assay of whiting and similar substances (p. 245).

Boiler-water indicator is used to ascertain whether enough softening agent has been added to the water (p. 40); it usually consists of a very weak solution of phenolphthalëin in dilute alcohol, a drop of soda solution being also added so as to give the indicator a faint colour and ensure its neutrality. If a few drops of this indicator be added to a softened water where lime or soda has been employed as softening agent, the water will be coloured red if sufficient lime or soda has been used, otherwise it will remain colourless; if too much has been added, the colour will be an intense red. If the water is not colourless it is often easier to use strips of filter-paper soaked in the indicator and allowed to dry; to test the water, one of these strips is allowed to remain in the water for a few moments and it is then taken out and examined. The test is so simple that it ought to be made daily, so as to avoid undue production of scale on the one hand and waste of softening material on the other.

The term 'indicator' is used to cover so wide a range that reference must be made, for further particulars, to the object for which the indicator is required.

Iron should invariably be tested for in new batches of clay and glaze materials (p. 272). When used in machinery, it should have as much of its surface as practicable painted to prevent particles of rust and iron scale falling into the materials and so contaminating them.

Kilns are difficult to test satisfactorily, but especial attention should be paid to their 'tightness,' their draught, and general state of repair (see p. 230 *et seq.*).

Kilns and flues may be tested in regard to the tightness of their joints, etc. (1) by means of a candle placed on one side of the wall, the observer being on the other. This method is only of limited application; (2) by means of a draught gauge (p. 254). If the draught of the kiln or flue is measured in a number of different places it will generally be easy to determine, by means of the different readings of the gauge, where the leakage occurs. If a continuous kiln is being tested in this way it will, of course, be necessary to close the dampers of each chamber whilst it is being tested, so as to make the gauge readings as large as possible and also to prevent the inclusion of more than one leak for each reading. Wet clay containing a large proportion of burnt clay (sagger) is usually the most satisfactory material for repairing kiln cracks. This mixture does not contract so much as clay alone, and the crack or leak is therefore more durably mended.

Joints for steam and water pipes, unless well made, will require almost constant attention and will be an endless source of trouble and expense. Although this class of work belongs to the engineer, or plumber, yet a clayworks' proprietor or manager will often save himself much trouble and expense if he knows the best kind of joints for different kinds of work. This is especially the case with steam-joints in pipes, for the changes in temperature to which these pipes are subject renders them far more likely to leak than water or gas pipes, where the temperature and pressure are more uniform.

The usual form of steam-joint consists of screwed pipe-end fitting into a screwed socket. As the screw-cutting appliances become worn or broken with use, an imperfect thread is cut and some filling material must be used to prevent a leak. Red or white lead is frequently employed for this purpose; but, although it fills up the interstices well and hardens rapidly, the pipes in which it is used cannot be taken apart without fracture; it is therefore considered better practice now to use a paste made of graphite and a high-grade cylinder oil.

The flanged joint (fig. 21) is also in common use, especially for larger pipes. This flange may be cast in one piece with the pipe or it may be fastened to it with a screw-joint. In the latter case it is advisable to rivet over the end to secure additional tightness and to avoid possible stripping of the flange. As the faces of the flanges are seldom so well fitted as to make a good joint, some yielding material must be placed in between them to form a gasket and fill up any unevenness. Although sheet rubber is largely used, the heat causes the rubber to harden, and the expansion and contraction due to the changes in temperature of the pipes when the heat is on or off causes it to crack; asbestos should therefore be employed. Instead of using rubber or asbestos alone, a triple gasket consisting of two plates of copper or zinc with a sheet of asbestos between may be used; if the metal is corrugated parallel to its circumference (fig. 22) the joint will be still better. In cases of emergency several sheets of tough packing paper, each covered with a coating of cylinder oil, have often been found of service, and sometimes have lasted as long as a rubber gasket under similar conditions, especially when protected by thin copper or zinc gaskets. Plain gaskets of soft metal should be avoided in steam-pipes where the steam pressure is lower at nights and in pipes not in constant use, as the expansion of the softer metal differs from that of the flange and so is apt to cause leaks. Where trouble is experienced through the asbestos absorbing water from the steam, a deeply-grooved ring of thin sheet copper may be inserted in such a way that the steam and asbestos are kept out of contact with each other.

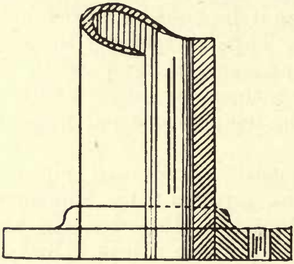


FIG. 21.

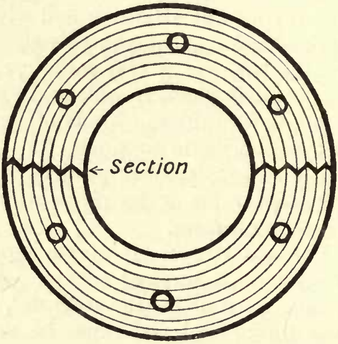


FIG. 22.

A continual supervision of gas and water meters is necessary in order to ensure that no serious leakage is taking place; steam leaks generally show themselves pretty readily.

Lead used in the form of the oxide (red lead), the basic carbonate (white lead), and in combination with tin oxide (tin ashes), is a source of continual trouble in those clayworks where it is used, owing to its poisonous nature and to the consequent requirements of the legislature. White lead is especially liable to adulteration with baryta and chalk. As the metal (lead) is the only constituent of importance to the clayworker, this may be conveniently determined by fire assay as follows:—

An accurately weighed portion of the sample (not exceeding 10 grammes) is mixed with about four times its weight of fusion mixture, consisting of (1) equal weights of sodium carbonate and potassium carbonate to which a little borax has been added, or, preferably, (2) argol with thrice its weight of sodium carbonate, and placed in a small porcelain crucible. The mixture is then covered with a further small quantity of fusion mixture, and the crucible and its contents heated for some time in a small muffle kiln until the mass is completely fused and the lead is formed into a distinct metallic bead. Excessive heating should be avoided. The melted mass is then poured on to a level cast-iron plate in such a way that the bead of metal is left at one end of the slag, which it should leave easily and cleanly when cold.

As tin produces a more infusible slag than when lead alone is present, a somewhat larger proportion of flux may be necessary when tin ashes are being tested, and the tin must afterwards be separated by analysis.

Lead in Glaze.—According to the Amended Special Rules for the Decoration of Earthenware and China, of 28th November 1903, it is ordered that "no glaze shall be used which yields to a dilute solution of hydrochloric acid more than 5 per cent. of its dry weight of a soluble lead compound calculated as lead monoxide when determined in the manner described below:

"A weighed quantity of dried material is to be continuously shaken for one hour, at the common temperature, with one thousand times its weight of an aqueous solution of hydrochloric acid containing 0·25 per cent. of HCl. This solution is thereafter to be allowed to stand for one hour and to be passed through a (paper) filter. The lead salt contained in an aliquot part of the filtrate is then to be precipitated as lead sulphide and weighed as lead sulphate."

The precipitation of the lead may be conveniently carried out as follows: 10 grammes of the glaze or frit are treated with acid, as described above, and the filtrate (contained in a small glass beaker) has an excess of a solution of ammonium sulphide added to it, or a current of sulphuretted hydrogen gas is passed through it until all the lead is precipitated as a black sulphide. After standing for some time to ensure the precipitation being complete and to allow the precipitate to settle, the liquid is filtered through a paper filter, the black residue washed with water to which a little ammonium sulphide or sulphuretted hydrogen has been added and then transferred to the filter and again washed; the filter with its contents is placed in a warm place to dry (care being taken to keep it free from all dust, etc.), and it is then placed in a weighed porcelain crucible, heated gently over a bunsen burner until all the paper has burned away and the sulphide is turning lighter by oxidation. It is then allowed to cool, is moistened with a few drops of nitric acid, and is again ignited over the burner, the treatment with nitric acid being repeated until the residue is white. The lead sulphate thus formed is then allowed to cool and is weighed. Its weight multiplied by 0·7364 gives the amount of lead (calculated as monoxide) dissolved out under the conditions of the test. It must not exceed one-twentieth of the weight of the sample used for the test.

Lubricants.—The testing of oils and lubricants is too complicated a matter for the non-professional analyst. They should therefore be bought with a guarantee as to their flash-point, and, if solid, as to their melting-point. In a matter of this kind the clayworker is, to a great extent, in the hands of his oil merchant, and should be careful to trade with reliable firms.

Melting-points of clays, glaze, etc., may be determined as described on page 269. ('Fusibility') by making a pyramid or 'cone' of the material and comparing its melting-point with that of a standard, such as the Seger Cones. A pyrometer may sometimes be used in those cases where the material to be melted has not any tendency to destroy the material of which the pyrometer is made, whilst for substances with a lower melting-point than 360° C. or 680° F. a mercury thermometer is most convenient. The bulb of the thermometer should be immersed in the material to be tested and the temperature raised slowly and regularly, the thermometer scale being carefully protected from draughts. A useful check on the accuracy of the result consists in allowing the molten mass to cool slowly whilst the thermometer bulb still remains in position, when it will be found that the temperature sinks gradually to a certain point, then remains constant for a certain time during which the mass becomes solid; a further decrease in temperature then continues until the mass is quite cold. The temperature at which the thermometer reading remained constant for some time is the 'solidifying point' of the substance: it should not differ materially from the melting-point. In the case of a mixture there may be two or more points at which a constant temperature is noticeable; in such cases these temperatures indicate the solidifying points of the different substances composing the mixture. Such mixtures can have no definite fusing-point.

Moisture.—No matter how dry a clay may feel, it often contains a considerable amount of water in the form of moisture, and the same is true of many glaze materials. Hence it is important in buying these materials to ensure that one is not paying for water at the rate of clay, felspar, etc. In addition to this, it is often desirable to ascertain the percentage of moisture left in goods which have been partially dried.

Although much may be accomplished without any special appliances for drying, yet, if accurate results are desired with the minimum of trouble, some form of drying oven with automatic temperature regulator will be required.

The temperature at which the drying should take place is of importance, as many materials contain combined water in addition to moisture, and this will be driven off if they are heated too strongly. As a general rule, then, moisture is understood to mean that water which is expelled from a sample exposed to a temperature not exceeding 120° C. or 248° F. until it is of constant weight, *i.e.* until no further loss of weight occurs on further heating. In practice, it is not usual to exceed 110° C.

The drying oven may conveniently take the form of a strong, double sheet-iron box about 18 inches each way, fitted with a door, inside which is another similar box, the space between the two allowing of a better distribution of the heat from the gas-burner or lamp placed underneath. This space between the two boxes should be about 3 inches at the bottom and 1 inch round the sides and top. The door is most convenient when at the front. Through the top of the oven two $\frac{3}{4}$-inch pipes are fixed, so as to allow of the insertion of a thermometer and of the tube of a temperature regulator. Where gas is not available, the oven may be heated by steam circulating between the boxes at a very low pressure, or the apparatus may be made of copper, and the space between the boxes arranged to contain water which can be kept constantly boiling by any convenient source of heat. In this case, the temperature can never exceed 99° C. (210° F.) in the inside of the oven, so that the drying will take somewhat longer. For a single test the ordinary domestic 'steamer' saucepan may be used, but this requires much attention to prevent the water boiling away, and is, in addition, scarcely hot enough.

There are many patterns of automatic temperature-regulators ('thermo-regulators') on the market. Although they vary greatly in efficiency, the same principle is used in all, viz., the expansion of a fluid moving a column of mercury in such a way as to shut off the gas supply. (If steam of sufficiently low pressure is used, or if the apparatus contains constantly boiling water, no regulator is required.) A sensitive pattern of regulator is shown in fig. 23.

The tube, A, is connected to the gas supply by means of rubber tubing; B is similarly connected to the gas-burner (a bunsen burner of the ordinary upright form, carefully made so as to allow of its being turned down considerably without 'lighting back'). A small hole in A (near C) permits of a sufficient passage of gas to keep the burner alight when the regulator has 'shut off' the supply, but the amount of gas passing through this by-pass must not be sufficient to keep the oven hot. The lower portion of the apparatus is occupied by mercury, which moves up and down the tube with the varying temperature, and, by allowing a freer or more restricted flow of gas to the burner, permits of increased or diminished heat supply. The regulator is so adjusted that, when the thermometer inside the oven shows the desired temperature (110° C.), the regulator just shuts off the gas supply, but partially opens it as soon as the temperature falls to 109° C.

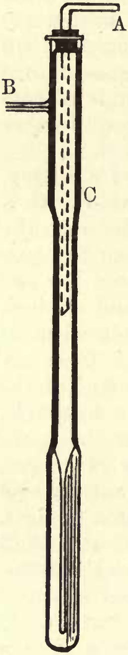


FIG. 23.

The size and weight of the pieces to be dried will vary with their nature; a greater weight of a porous article may be used, but, as a rule, 5 to 10 grammes is quite sufficient; if too large pieces are employed, the drying will be so prolonged as to be liable to introduce other errors. For many purposes half these quantities will be more satisfactory.

To determine the moisture in a sample, a definite portion is accurately weighed in a tared watch-glass or weighing-bottle (the weight must be exact to at least a milligramme); the glass, or bottle, with its contents is then placed in the oven and the drying commenced. After an hour (if the oven were at the proper temperature to begin with) the glass or bottle is taken out, and at once placed in a desiccator to cool.

The desiccator (fig. 24) is a vessel intended for keeping objects free from moisture whilst they are cooling, and consists of a glass basin, or vessel, with a well-fitting lid, the bottom of the vessel being covered with concentrated sulphuric acid. A small glass table or shelf inside forms a resting-place for the object to be cooled, and the acid keeps the air in the vessel dry by absorbing all its moisture. The acid must therefore be renewed from time to time.

When perfectly cold, the glass, or bottle, with its contents, is again weighed, the loss of weight being due to moisture which has been removed if the experiment has been properly performed. In order to ascertain whether all the moisture has been removed, the glass is again placed in the oven for another hour, cooled in the desiccator, and again weighed, these operations being repeated until two successive heatings, each lasting at least half an hour, show no difference in weight. Then the total loss of weight suffered by the sample represents the moisture originally present. Thus if the following figures were obtained :—

Weight of empty watch-glass	2·334 grammes
" glass + sample	4·462
" " " after drying one hour	4·322
" " " after drying two hours	4·316
" " " after drying three hours	4·315
" " " after $3\frac{1}{2}$ hours .	4·315 (const.)

Then $4·462 - 4·315 = 0·147$, which ÷ weight of original sample $(= 2·128)$ gives 6·91 per cent. of moisture.

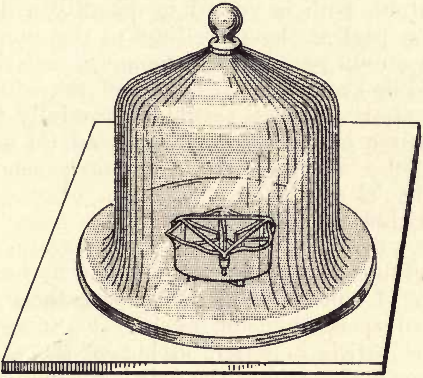


FIG. 24.

When, for purposes of getting out goods with the greatest speed, they are weighed during their drying on the flats, a large pair of scales must be used and the drying continued until a certain weight based on experience, or calculated on the previously estimated moisture in the clay, is reached. In such large blocks, as would occur in such a case, it is seldom possible to drive off all the moisture, but in practice all that is required is to eliminate so much of it that what is left will do no harm to the goods if they are placed in the kiln. It frequently happens that, with large pieces of ware, a little trouble taken in weighing them during the drying will not only ensure their dryness being known and not guessed at, but will often enable them to be placed in the kilns some days before it would otherwise have been considered safe. To prevent damage in handling, the goods should be kept on a board of some kind which should be weighed with them (tared). It is necessary that the weighing machine should be sensitive to a variation of at least 1 per cent. of the weight of the sample; thus, if a large slab weighing 1 cwt. were being dried, the scales should turn to at least 1 lb. Much greater sensitiveness is not absolutely necessary, as 1 per cent. of moisture in an article will cause no damage to it when placed in the kiln in the usual way.

In weighing small quantities of clay, it should be remembered that dried clay is very hygroscopic and rapidly absorbs moisture from the air; it must not, therefore, be allowed to cool in an exposed place, but a desiccator must be employed.

Mills.—The control of the mills chiefly consists in the keeping up of the output, both in regard to quantity and quality, due attention being paid at the same time to the amount of power absorbed. A careful record of the amount of material ground or pugged should be kept, with particulars of the cost of grinding. The quality of the product should be carefully tested for (*a*) freedom from iron and other impurities, and (*b*) fineness of the different particles of which the material is composed. (See 'Grinding,' pp. 56 and 277.)

Oils. See 'Lubricants.'

Plasticity. See 'Binding Power' (p. 237), also p. 11.

Porosity of fired clay goods may be tested by various methods, the commonest of which consists in replacing the air contained in the pores by an equal volume of water. This is accomplished by immersing the article in water, wiping off the excess of liquid after some time and weighing the article (p. 232). Its increase in weight is understood to be due to the water 'absorbed' by the pores, and the volume of the latter may be calculated from the weight of water thus retained on the assumption that 1 oz. of water measures $1\frac{3}{4}$ cubic inches, or 1 c.c. of water weighs 1 gramme. Although it is usual to express the porosity in a unit of *weight*, it is more correct to express it in terms of volume, and the figures representing the porosity of an article should indicate the volume of the pores it contains in relation to the total volume of the article itself. If the article under examination is regular in shape, its volume may be directly calculated (in the case of a brick, by multiplying its length by its breadth and the result by its depth); but if the shape does not permit of this being accurately carried out, the volume of the article may be determined by finding its loss of weight when suspended in water by means of a fine thread from one arm of a balance, as in 'specific gravity determinations.' Then

$$\text{Porosity} = \frac{\text{weight when soaked with water} - \text{weight when dry} \times 100}{\text{loss of weight when suspended in water by a thread.}}$$

If the porosity of unfired clays is to be estimated, some other liquid must be substituted for the water—paraffin is very suitable. The above formula holds in this case also if the word 'liquid' be substituted for water.

The volume of the original article may also be measured by means of a 'volumenometer'—a glass cylinder with a movable lid, the shape of an inverted funnel. The apparatus is filled, to a mark on the neck of this inverted funnel, with water, and some of the water is then run into a tared glass by means of a tap near the base of the cylinder. The lid of the apparatus is then removed, great care being taken that none of the water is spilt during this operation, and the article to be tested is placed in the cylinder. If sufficient water has been run into the tared glass none will overflow the cylinder when the test piece is inserted. The lid is now replaced and the apparatus again filled to the mark with water, this time from the tared glass. The tared glass and its contents are now weighed, the increase in weight being the weight of a volume of water equal to that of the test piece. The operation may be simplified somewhat by using a finely-graduated measuring glass instead of a plain tared one and so measuring the water displaced instead of weighing it. The Seger volumenometer is well adapted for this purpose, whilst in the Ludwig apparatus it is intended that the displaced water should be weighed. Considerable accuracy in weighing, or measuring, is necessary as different determinations made with the same piece of clay should not differ by more than $\frac{1}{400}$th of the weight of the test piece used.

Power.—The testing of the power given out by an engine is accomplished by means of an 'indicator' or by means of a special form of 'brake.' This latter may also be used to determine the power absorbed by the different mills, etc. Power is commonly measured in terms of 'horse-power,' one horse-power being the work done in raising 33,000 lbs. through a distance of 1 foot in one minute. This unit is a purely arbitrary one, as the power exerted by a horse varies with its condition and, to some extent, with the nature of the work.

The indicator not only enables one to calculate the indicated horse-power of an engine, but it also affords an excellent guide in setting the valves, and reveals the whole behaviour of the steam in the cylinder in a very satisfactory manner with a minimum of trouble and expense. Various forms of indicator, differing chiefly in the means used in amplifying the motion of the piston of the instrument, are employed. For general use in a clayworks, the McInnes-Dobbie continuous indicator is one of the best. The indicator is attached to a small pipe communicating with one of the steam cylinders, the connection being as short and direct as possible. When a test has been made, the other end of the cylinder should be connected to the indicator and the test repeated. The by no means uncommon practice of connecting both ends of the cylinder to a centrally placed three-way tap is not satisfactory, and if two indicators cannot be used the one employed should be moved to each end of the cylinder in turn.

The paper drum of the indicator is moved by connecting it through suitable reducing gear to the engine-crosshead, but considerable care is required in the arrangement of this mechanism or serious errors may result. On the whole, a long vertical lever with a long connecting link is the most suitable. Care is also required in the choice of a spring for the instrument, as too strong a spring produces too small a diagram, and with too weak a spring the lines are so wavy as to prevent accurate measurement. A 40-lb. spring is generally used for boiler pressures under 90 lbs. and a 60-lb. one for greater pressures.

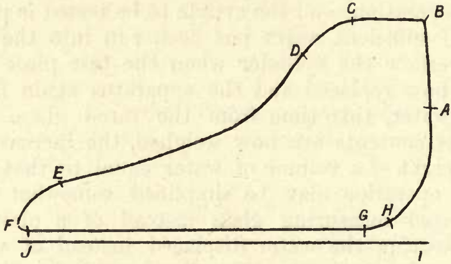


FIG. 25.

A piece of paper, or thin card, having been attached to the rotating drum of the indicator, and this set in motion by means of the reducing gear connecting it to the engine, the pencil on the instrument will draw a closed curve the shape of which will depend on the accuracy of the engine and its capability of using the steam supplied to it. (Fig. 25.)

This 'diagram,' if drawn by a correctly adjusted engine, will be made up as follows:—The admission of steam commences at

A and is continued to B, where the maximum pressure is reached (it will be seen that the point B is the highest above the base line JI); thence to C, the horizontal line BC showing that the steam pressure is fully maintained without leakage until the cut-off commences at C. At D the steam supply entirely ceases and the steam in the cylinder begins to expand, the amount of expansion being indicated by the line DE. The exhaust is similarly indicated by the line EH, and HA is the line representing the compression. The base line or atmospheric line is drawn by rotating the drum of the indicator before commencing the test, and therefore is the 'diagram' drawn when no work is being done by the steam. Variations from this standard diagram indicate various defects in the working of the engine; they are often of a complicated nature and are difficult to interpret without the aid of much experience; much information may, however, be obtained from *The Indicator Diagram: Its Analysis and Calculation.*

The indicated power of an engine may be calculated from the mean effective pressure recorded by the diagram, obtained by finding the average height of the line BF above the line FA and multiplying it by the scale of pressure for the particular strength of spring used. Then if

P = mean effective pressure of steam in lbs. per square inch,
L = Length of stroke in feet,
A = Area of piston in square inches,
N = Number of strokes per minute—revolutions per minute × 2;

$$\text{the indicated horse-power (I.H.P.)} = \frac{PLAN}{33{,}000}.$$

Brake Horse Power is the difference between the indicated H.P. and that absorbed by the friction of the engine itself. For most of the engines used in clayworks, the brake H.P. may be found by running the engine without any load and at the same time taking a diagram with the indicator, but for smaller and more delicate engines it must be measured by means of a special brake or dynamometer.

Boiler Power.—The power of a boiler depends on the engine used, and the amount of steam per hour this latter requires; thus if

G = Grate area of the boiler in square feet,
C = lbs. of coal consumed per square foot of grate area,
W = lbs. of water evaporated per lb. of fuel burned,
S = lbs. of steam per I.H.P. per hour consumed by the engine;

$$\text{I.H.P. of the boiler} = G \times C \times W \div S.$$

Hence the smaller the value of S the greater the I.H.P. of the boiler; this expression is therefore to be used with caution.

Pressure may be tested by suitable gauges the nature of which will depend on whether a gas, like air, at slight pressure, or at a higher pressure, as steam, is to be tested. For very slight pressures a 'draught measurer' (p. 254) is most suitable, or some form of barometer may be employed; but for greater pressures a Bourdon gauge, such as is used in connection with steam-engines, must be used.

A source of considerable loss of money may be found in connection with variations in the gas pressure of illuminating gas supplied to the works, with the result that sometimes too much gas is burned. This may, to a large extent, be avoided by the use of a governor on the main so arranged that the gas can never be supplied above a certain pressure (say that equal to two inches of water). Various forms of governor are on the market; the author has had most experience of one made by Stott Brothers, and has found it to be in every way satisfactory and economical.

Producer Gas may be conveniently tested in a similar manner to flue gases (p. 263). Its use, instead of coal, as a fuel for kilns is at present in a state of infancy, but it is more than probable that in the near future its employment will increase rapidly. It is essential for successful kiln-firing that the proportion of combustible gases should be maintained at as high a standard as possible, and that of these the proportion of hydrogen should be greater than is usually the case with producer gas in order that the carbonic oxide (CO) may be proportionately reduced, as its powerful reducing power is harmful in firing many of the more delicate colours. In this respect Mond gas has an advantage over the commoner Dowson gas.

Pugging Clay.—The mixing of clay and water may be tested most conveniently by 'washing' through a series of sieves of gradually increasing fineness, as described on page 317. This will ensure that no lumps of extraneous matter have entered the machine. When fine white clays, such as china bodies, are being made, the material should be tested with a magnet.

In the mixing of brick-clay, fireclay, and other relatively crude materials, the stiffness of the paste and its homogeneity are the most important characteristics needing attention. If the mixer is not working properly, an examination of the mass with a strong lens will show that some of the grains of clay are still dry, and the 'feel' of the clay together with its want of plasticity will indicate that it has not been thoroughly mixed. It is, however, a matter of some difficulty to say whether a sample containing much ground, fired material (sagger) has been well mixed or not, and if any doubt is felt in such cases it is better to put it through the machine a second time.

Plaster of Paris, which must not be confused with Paris White (see 'Whiting'), is used chiefly in the 'superfine' quality in clayworks. It varies greatly in quality even when from the same factory, and is at all times a difficult material to test, as its value for mould-making depends on its physical, rather than on its chemical, properties. The author has found that the following properties should be possessed by good plaster for clayworking purposes, and in this he agrees with the conclusions arrived at by the German Association of Plaster Makers as the result of experiments by their chemist, Dr. Moye:—

1. At least 95 per cent. of the plaster should pass through a sieve size No. 75, and about half of this through a No. 175.

2. For 100 parts of water, from 100 to 150 parts of plaster will be necessary to form a well-setting mass, and this mixture should stiffen so rapidly that after two or three minutes it can no longer be poured easily from one vessel to another. (Some mould-makers prefer a plaster which sets more slowly than this, as it allows them to work less rapidly; but, unfortunately, the slow-setting plasters seldom set so hard as the more rapid ones.)

3. The amount of water absorbed by a small cube of the set plaster which has been allowed to stand for several days will usually equal a quarter of its volume of water in ten minutes; but this test does not seem to be very reliable, as the presence of small quantities of sodium carbonate in the water used in mixing the plaster will make the cube absorb far more water after standing.

Pyrometers are instruments for measuring temperatures which are so high that a thermometer of the ordinary type cannot be employed. Pyrometers are of many and varied forms and types; the most important in regard to the clay industry are referred to under the heading of 'Temperature' (p. 302).

Quartz.—A very pure variety of silica (SiO_2) is used in glazes and bodies where unusual freedom from iron is required, especially on the Continent. In England, flint usually takes its place. It is highly refractory, and quite insoluble in all ordinary solvents with the exception of hydrofluoric acid, which reacts with it, as with all silicates, to form the volatile SiF_4. To test quartz for impurities it should therefore be warmed with this acid, and the residue left after several treatments examined as to its nature. Although generally very pure, the possible impurities in quartz are very numerous, and, being mostly of the nature of 'staining oxides,' their examination requires considerable analytical skill.

Refractoriness.—One of the most important properties of certain clays, notably the fireclays, may be tested by determining the fusing-point of the clay (page 269); but this is not always sufficient, particularly when the clay is intended for use in the interior of furnaces (furnace linings), where, in addition to the direct action of the heat, the variations in pressure, owing to the expansion and contraction of the material by the heat, produces strains which cause far more damage to the clay than the direct action of the heat itself. It is always difficult to ascertain, without actual trial, whether blocks or bricks made of a particular clay will efficiently resist the combined action of heat and pressure; probably the best way is to build a few of the bricks into a furnace lining, to watch them and to carefully note their behaviour in comparison with bricks of other clay in a similar part of the furnace. The resisting power of fireclay to the action of molten steel and other metals is also best ascertained in a similar manner; experiments on a very small scale are almost, if not entirely, unreliable.

Although the refractoriness of a clay is, to a certain extent, dependent on its composition, it does not at present seem possible to obtain any 'factor' which can adequately represent its power in this respect and be deduced from the analysis of the clay. Bischof and Seger both suggested factors of this kind, and although both are accurate within certain narrow limits, they are not, on the whole, satisfactory. Ludwig has plotted out a series of curves showing the relation of composition to refractoriness, on the assumption that the fluxing materials are in the form of a 'solid solution' with the clay as solvent. This is the most helpful work on this subject up to the present, but many more samples must be examined before this theory can be regarded as conclusive.

In making a direct determination of the fusing-point of a clay on a small scale (p. 269) by heating a small cone of the clay in an oxy-hydrogen furnace, great care must be taken to repeat the test several times, as, otherwise, the results may be far from accurate; on such a small scale the ordinary errors of experiment are necessarily very large, and in so important a matter as the resisting power of a clay to heat, too much care cannot be taken to obtain an accurate result.

Resisting Power to frost and weather may be roughly tested by soaking the finished goods in a hot, strong solution of Epsom salt and then allowing them to cool by exposure to air. The salt will crystallise out during the drying and cooling, and will tend to rupture the goods in a manner similar to frost and ice. If the crushing strength of goods treated in this way be compared with that of the untreated goods, a rough idea will be obtained as to the effect of weather. When a cold meat refrigerator is near it is usually possible to send the goods (previously well soaked in water) to such a place, and to examine them after they have been 'frozen' for several days. (See 'Durability,' p. 261.)

Resisting power to *rubbing* may be tested by placing a number of the pieces to be tested in a barrel, 20 inches in length and 28 inches in diameter, and rotating this vigorously for some time. The condition of the goods at the end of the operation is considered to give some idea of their resistance, but it is difficult to understand the precise value of the test. A somewhat more accurate result may be obtained with a 'rubbing machine,' consisting of a horizontal iron plate, which is rotated at a definite speed for a definite number of times. The clay, brick, or other test piece is fastened to a weighted horizontal arm in such a manner that its under surface is just in contact with the iron plate and presses on it with a force corresponding to the weight on the arm (say 10 lbs.). The piece is weighed both before and after testing in the machine, and the loss of weight is taken as the effect of the rubbing or 'wearing.' In order to facilitate the operation for very hard materials a weighed quantity of fine emery is applied to the rotating wheel. It is usual to express the result in terms of the percentage loss of volume; this is accomplished by dividing the loss of weight by the specific gravity (p. 252) of the material.

Resistance to *blows* is usually tested by dropping a heavy ball of iron from different heights above a flat piece of the material (such as a tile or brick) and recording the greatest height through which the weight can fall on the test piece without breaking it. The size of the weight will depend on the size of the test piece, and in making any report on the matter particulars of both these data should be mentioned.

Resistance to *weather* is referred to under 'Durability' (p. 261).

Salts in bricks and other terra-cotta goods are frequently the cause of a particular variety of scum known as 'efflorescence.' The sources of this defect remained for a long time undiscovered, but Dr. Mäckler, of Berlin, as the result of a lengthy research, has shown that the presence of crystallisable salts in goods with but little porosity is the chief cause.

In order to ascertain whether a particular material is likely to effloresce, the following test should be made. As the percentage of crystallisable salts is usually very small, chemical analysis is not of much use, and it is, consequently, far better to endeavour to produce the conditions under which efflorescence is most likely to occur, and from the results of such a test to pass or condemn the goods. The most satisfactory method of doing this consists in supporting the brick, or other article to be tested, on two horizontal glass rods over a shallow (photographic) dish, and on the top of the brick to place, upside down, a bottle full of distilled, or rain, water. If this is carefully done, the brick will slowly absorb all the water from the bottle and yet will not allow any of it to 'run away.' In this way the salts contained in the brick will be dissolved by the water, carried to the surfaces of the brick, and deposited there as a white scum when the brick dries. Although a pint bottle is the most convenient for ordinary use, a smaller one may be necessary with certain clays, as the water should not be supplied so freely as to drop off the brick. For the proper carrying out of the test it is necessary that the mouth of the bottle should be ground sufficiently flat to fit the brick. The easiest way to get the bottle inverted on the brick is to hold it the right way up in the right hand, place the brick on top with the left hand, and by a sharp turn invert both and place them on the glass rods.

As this test is a very delicate one, and will produce scums with such small quantities of salts as would never be detrimental in actual practice, it is safe to neglect very slight traces of scum and only to condemn those bricks which show a marked deposit. It is essential that the water used should be distilled or rain water, as if it contains any dissolved matter it will yield false results.

Sampling is an operation requiring the greatest care and no small amount of skill if reliable results are to be obtained. The principle involved in correct sampling is that if a sufficient quantity of the well-mixed material be itself well mixed, and a portion of this be removed, again mixed, and another portion abstracted, the process being repeated until a sufficiently small sample has been obtained, this resulting sample will, as far as possible, truly represent the composition of the whole bulk. It is usual to take one quarter of the mass in each abstraction, but in some cases $\frac{1}{8}$th or even $\frac{1}{12}$th will be found to yield accurate results. If the original bulk is in bags these should be emptied one at a time, their contents well mixed, and a reasonably large portion of the mixture set on one side, to be in its turn well mixed and quartered as often as may be considered desirable. If the material is in lumps it must, when the quartering has reduced it sufficiently, be ground roughly, again quartered, and the operations of grinding and quartering repeated until the requisite size of sample is obtained. Most materials used in the clay industry will be sufficiently ground when they will pass through a No. 10 sieve, but the chemist who undertakes their analysis will have to grind them still further before he can use them. He should in no case be supplied with less than half a stone of most raw materials, though where the material is expensive, as in the case of glaze stains, a much smaller quantity will have to suffice. With clay freshly dug, about a stone is the least that should be submitted for examination.

In taking samples of *clay* direct from the pit especial care is needed, and it is always wise to send a separate sample of each geological layer for examination, these samples being placed in separate wooden boxes carefully labelled so as to avoid error. It is not advisable to send borings for analysis as they are apt to mix the various layers and so yield a false result. It is preferable to draw a line on the surface of the ground equal in length to the depth of the clay seam, or to the depth to which it is proposed to dig, and to dig a trench whose length shall be that of the line, whose depth at one end will be that of the proposed workings and at the other but one yard, increasing by a yard with every yard in length. In this way a series of steps will be formed which form convenient shelves for the different samples.

Should this method of sampling not be feasible, it will be necessary to bore as many trials as possible in different parts of the estate and to examine these independently; but the results so obtained can never be relied on as really correct, as by the very action of boring an undue grinding of the material takes place.

In sampling slips and other liquids great care is necessary to have them well stirred up before the sample is taken, and even then it is advisable to take three or four times as large a sample as is really necessary and to stir this up thoroughly before withdrawing the final sample.

In sampling *gases*—particularly flue gases—care is required to avoid eddies in the gas. The sample is usually taken through an iron or glazed porcelain tube (4 feet in length) built into the flue, with one end projecting sufficiently to allow the attaching of a rubber tube or cork. This is connected to a glass sampling vessel of which there are various forms, the one described by Arnold (*Steel Works Analysis*) being both simple and strong. It consists, as will be seen from fig. 26, of a glass cylinder, A, 5 inches long and 2 inches diameter about one-third filled with mercury. In it is placed the 'laboratory vessel,' B, which has been filled by suction at the point C with mercury from A, the mercury being retained by closing the glass tap. It is important that the mercury shall rise well above this tap into the capillary tube.

The cork, or rubber stopper or tube, C, connects this apparatus to the gas to be sampled. In order to sweep out all the air from the tube between B and C, it is advisable to disconnect the rubber tube from the glass just above the tap and to allow a good current of the flue gases to sweep through the pipe; an aspirating pump may be used, if necessary. The laboratory vessel is then connected to the flue, the tap opened, and, by the fall of the mercury, the gas drawn into it. The tap is then closed, and the sample, after being allowed to cool, is ready for use. Although the operation of collecting a sample of gas is by no means difficult, it requires great attention to small details, such as air-tight taps, etc.; but if sufficient care is exercised, samples can be drawn with ease as often as may be desired. It is important that the portion of the tube inside the flue should project sufficiently far to be in the full flow of the gases; it is often bent at right angles to facilitate the entry of a fair sample. This tube should be blown through occasionally to ensure a clear passage through it as it is apt to become choked by dust, etc., from the fuel.

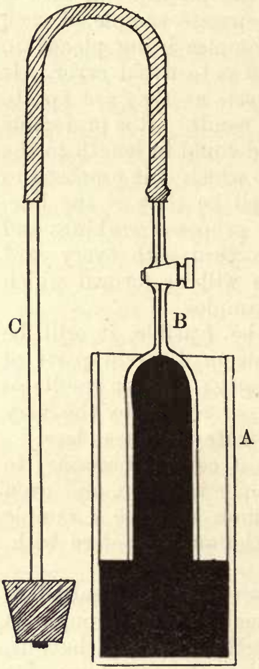


FIG. 26.

In many cases a Stead gas-sampler is preferable, or, for a 'makeshift,' a wash-bottle containing rape oil instead of water may be inverted and used to collect the gas.

Scum or deposit on the surface may be due to a great variety of causes (see 'Defects,' p. 210). Its composition is, therefore, complicated in the majority of cases, and it is better to examine it in conjunction with the conditions under which it was probably formed rather than to attempt to ascertain its composition by the ordinary processes of analysis.

Shrinkage. See 'Contraction' (p. 249).

Slip Testing consists chiefly of ascertaining that the slip has been sufficiently well ground and sifted ('lawned') and that it is of the correct density or 'volume-weight.' The fineness of the lawn or sieve used will depend on the nature of the material and the purposes for which it is intended. It is also wise to test with a magnet a portion of the slip at frequent intervals where white bodies are used, so that all particles of metallic iron may be detected when present. The density of a slip may be determined by one of the methods described on page 252 *et seq.*

Specific Gravity or density. See page 252.

Speed of engines, mills, and other machinery should be kept as constant as possible if the best results are to be obtained. Various speed indicators have been placed on the market from time to time, and they are useful as occasional checks; the value of a mill, however, is more directly ascertained from its output than from its speed, and a careful checking of the number of tons of material prepared per day will usually give a result which will replace any record of the speed, as an engine which often 'races' will generally give results inferior to one of a steady though somewhat less average speed. The manager of the works should, however, know the best speed at which to run the various machines, and should he notice that any of them are running slowly he should at once investigate the cause.

Steam-pipes should be continually under inspection, as a comparatively small leak will in the course of a few weeks lead to a notable waste of fuel, especially where the steam is used for drying and is, therefore, on both day and night.

Steam-pipes should always be kept as free as possible from water, and drain-cocks fitted wherever necessary, as, should any accumulation of water occur in a long horizontal pipe, not only is there a considerable loss of heat, but there is also a great danger of fracture of the pipe. Long pipes which have become water-logged should never be emptied when under pressure; the connection with the boiler must first be cut off.

If satisfactorily arranged, each foot run of 4-inch pipe should heat 150 to 200 cubic feet of air 1° F. per minute.

As steam-pipes expand about 1 inch in 40 feet when in use, some arrangement for this movement should always be made, preferably by springy lengths of curved pipe, though expansion sockets may be used on occasion.

Where passing through the open air, or where not required for heating purposes, steam-pipes should always be covered so as to reduce the loss of heat as much as possible. Uncovered pipes lose from six to twenty times as much heat per foot length per hour as they do when covered properly.

Steam-joints are referred to on page 281.

Temperature.—The measurement of temperature is comparatively simple at temperatures below 300° C. (570° F.), but above this it is complicated by the fact that ordinary thermometers cannot be used. In connection with drying rooms it is often convenient to use a maximum and minimum thermometer, such as is employed in meteorology. In this apparatus a small index is moved along by the liquid in the thermometer in one direction but not in the other, so that, according to the form of the instrument, the highest or lowest temperature since the last 'setting' of the instrument is automatically recorded. In some thermometers the mercury column is constricted very considerably so that the mercury can only flow in one direction, with the result that the maximum temperature only is shown. The clinical thermometer of the medical man is a well-known example of this type.

Thermometers used in *drying rooms* and similar places should be placed some inches, at least, from the walls, so as to truly register the temperature of the air of the room and not that which has been in contact with the walls alone. A useful form of thermometer for this purpose is shown in fig. 27. It is known as a 'window thermometer,' but an ordinary 'chemical thermometer' hung from a convenient beam will serve the purpose equally well. In purchasing a thermometer it is well to remember that the wider the column of liquid the less accurate is the instrument; but as a very fine column is often difficult to read, a compromise must be effected. For ordinary purposes an error of 1° is not of much importance in a dryer.

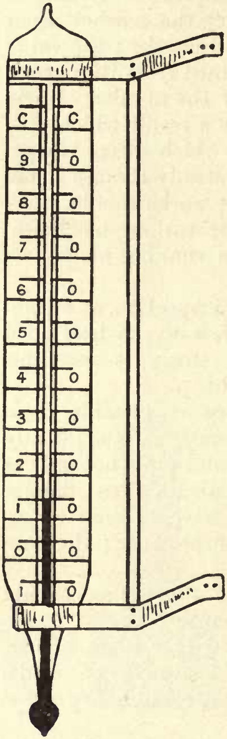


Fig. 27.

For indicating the temperature of the *boiler* feed-water a thermometer reading to 250° F. will be generally found satisfactory. It should be inserted into the direct current of water and at a fair distance from all check-valves, as these cause vibration and may easily break the thermometer.

Steam temperatures are best taken by the aid of a brass pocket let into the steam-pipe and containing quicksilver to the depth of $1\frac{1}{2}$ inches, the rest of the pocket being filled with cylinder oil to prevent undue cooling of the thermometer stem.

The best place to take the temperature of the *flue gases* is immediately beyond the boiler setting, and if a bolt be removed or a $\frac{1}{4}$-inch hole drilled in the side of the flue, the thermometer may be easily inserted. Of course, with brick flues it may not be possible to get a thermometer to work, in which case recourse must be had to a pyrometer. As regards the selection of the position of the thermometer—a most important point—care must be taken that the bulb is actually in the full current of the gases, or reliable readings cannot be obtained. It may happen that a bend in the flue, or the proximity of a damper, may so deflect the gases as to shield the thermometer effectively. This must be guarded against. For both flue and steam temperatures the same thermometer may be used—reading to about 600° F., depending chiefly on the steam pressure at which the boiler is working—though two thermometers will be found more convenient. The instrument should never be held horizontally when taking a reading or during cooling ; the bulb should always be lowest, or the readings will be valueless. It will be found best to keep the thermometers in the heat only just long enough to obtain a proper reading—itself a matter of minutes—as otherwise local heating of the mercury may cause the thread to split or even disintegrate into small bubbles, rendering subsequent reunion difficult. Indeed, it may be necessary to heat the instrument to the full temperature and allow it to cool slowly with the stem vertical. Further, deformation of the bulb may result from prolonged heating at 400° to 500° F. In ordinary use the thermometer may take days to return to its proper state after prolonged heating.

For determining the temperature of a *kiln* in the earlier stage of heating, and especially during the 'smoking,' a thermometer enclosed within a metallic case should be used, as it is then less liable to be broken. It should be capable of indicating up to 350° C. or 660° F., and the case should have a strong metal ring at the top by which to suspend the instrument in the kiln—a long, slender chain being attached for this purpose. As the thermometer is uncomfortably hot when withdrawn from the kiln, for the purpose of ascertaining the temperature a pair of thick gloves, or even asbestos gloves, should be worn.

For determining the heat in the *chimney* a similar thermometer, but with a stem two or three yards long, may be employed in those cases where the flue gases passing up the chimney never exceed the limits of the thermometer in temperature ; this should be very carefully watched, as the passage of gases at a higher temperature than 300° C. up the chimney-stack indicates great waste of heat.

For determining the temperature of a kiln, from dull red heat upwards, thermometers cannot be used as the liquids in them are volatilised at this temperature, and the use of fusible alloys has not met with much success in this direction. The instruments in use are known by the general term of 'pyrometers' (a word with a similar meaning to 'thermometer' but conveying the idea of a more intense heat), and the terms 'pyroscopes' and 'thermoscopes' are used for particular forms of pyrometers.

The skilled fireman does not, of course, depend entirely upon the instruments to be described presently, but pays attention also to the appearance and colour of the kiln itself, the rate at which the temperature increases, etc. In the table on page 337, the temperature was measured by a Callendar electric pyrometer couple placed immediately in front of a white porcelain tile heated in a large muffle kiln. It will be observed by those familiar with similar tables that the figures thus obtained are somewhat different from those usually published for the 'colours' of the interiors of furnaces, but the results given are the mean of a large number of experiments and may be taken as fairly correct.

Pyrometers have been made depending on almost every change of property undergone by bodies on exposure to heat. Many of these instruments have merely an historical or antiquarian interest; others are of great value to the clayworker, and will be mentioned briefly here.

The earliest form of pottery pyrometer is that devised by Wedgwood. It consists of small cylindrical pieces of clay which have been previously heated to a low temperature, and their length accurately measured in a special scale. These small pieces of clay are then placed in the kiln and are drawn out one at a time, allowed to cool, and their length again measured, the contraction giving a rough idea of the temperature. By the use of the special scale just mentioned all calculations are avoided and the method is, therefore, very simple and easy of application; but, unfortunately, the contraction of clay appears to depend on the manner of heating as well as on the nature of the clay, so that, though a useful test in the hands of a skilled worker well experienced in the clay he is burning, this form of pyrometer cannot be regarded as really satisfactory. The same principle (that of the contraction of the clay proportionately with the heat) may also be made use of in brick kilns by the use of a 'pining rod,' a long metal bar with a handle and a slide which can be moved up and down the bar, but which when left alone retains its position. This rod is inserted in the top of the kiln until its lower end rests on the top row of bricks in the kiln; the slide is then moved down as far as possible and the rod withdrawn. The position of the slide will indicate the amount of contraction which the clay has undergone during the firing. If the goods 'slip' in the kiln, this method is rendered inaccurate.

Optical pyrometers ('pyroscopes') in various forms are occasionally used for determining the temperature of a kiln, but they are scarcely accurate enough for this purpose. They are based for the most part on the comparison of the colour of the kiln with that of a standard flame, or electric lamp filament, the comparison being facilitated by inserting coloured glasses, or prisms, between the brighter light and the eye. The accuracy of which these instruments are capable is not, apparently, much greater than that of the practised eye of a skilled fireman, though they are of great assistance to a beginner. A modification of this plan consists in measuring the photometric value of the light from the kiln by allowing it to fall on a small disc of paper supported vertically in a large horizontal iron tube (the paper having a grease-spot at its centre) and allowing the light of a standard candle or lamp to illuminate the other side of this paper. The standard light is then moved nearer to or further from the paper until the grease-spot disappears. When this is the case, both sides of the paper are equally illuminated and the distance of the standard light from the paper then becomes an indirect measure of the temperature of the kiln. Except with very skilled observers this method is not sufficiently accurate for best work.

Various attempts have been made to dilute the hot air of the kiln with cold air, and to measure the temperature of the mixture with an ordinary thermometer, but without much success, though a similar instrument in which a current of water (instead of air) was allowed to flow through a coil of pipe inside the kiln has been used in the porcelain works at Sèvres and Limoges.

Siemens' pyrometer, in which a small piece of metal is placed in the kiln and withdrawn from thence into a measured quantity of cold water, and the rise in the temperature noted, may be used in connection with potters' kilns, but it does not possess any advantage over more easily manipulated pyrometers, such as the electrical ones or Seger cones. On the Continent a draught gauge is often used in order to control the temperature of the kilns. In this case the temperature itself is not measured, but, as it depends on the rate of combustion and this again on the air supply, an indirect reading is obtained. This method is exceedingly useful as an auxiliary, but, as the figures obtained in draught measurements are always so small, really accurate results cannot be obtained by this means.

The clayworker is, therefore, reduced in practice to three forms of pyrometer if he wishes to obtain constant results. These are:—(1) An accurate electric pyrometer; (2) Fusible masses; (3) Trials.

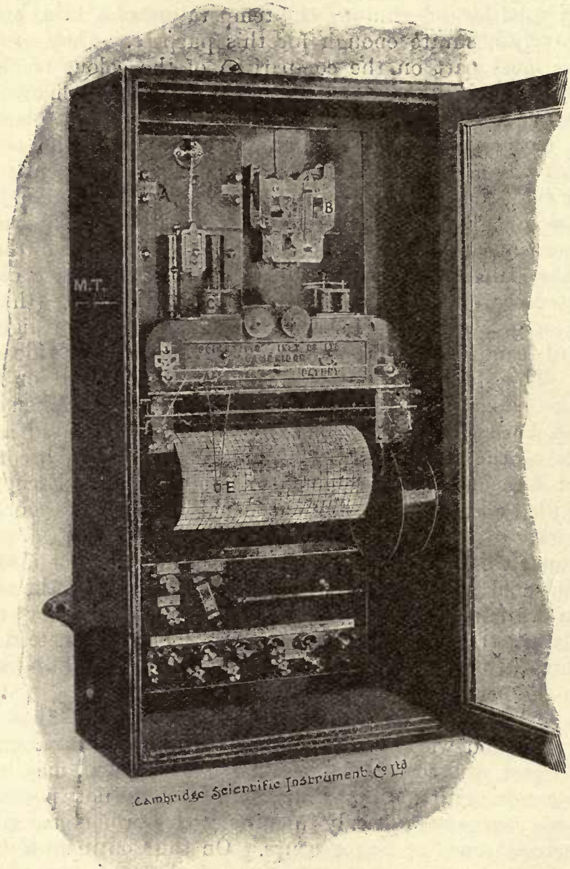


Fig. 28.

Of these the first is the most accurate in skilled hands, but is expensive in first cost and in upkeep, and requires considerable skill in use; the others may be used successfully by any intelligent workman who is used to firing.

Two main forms of electrical pyrometer are in use, viz., 'resistance pyrometers' and 'thermo-couples.' The former is in many ways the best and most accurate, except for the very highest temperatures, and, working chiefly under the patents of Professor Callendar and Dr. Griffiths, the Cambridge Scientific Instrument Co. have been able to supply these instruments at a moderate price and of remarkable accuracy and simplicity. The most suitable form of instrument is shown in fig. 28.

Briefly, it consists of a galvanometer, or electricity measurer, connected to an accumulator and to a Wheatstone bridge or current balancer, along which slides a self-acting arrangement, whereby the recording pen is moved backwards and forwards along the face of the paper cylinder according as the temperature rises or falls. To this recording apparatus is connected, by means of suitable wires, a resistance coil of platinum or a platinum alloy enclosed in a porcelain tube; this forms the 'thermometer' and is placed inside the kiln, and the connecting wires carried, in a manner similar to telegraph wires, to the recorder, this latter being advantageously placed in the office. As the paper roll revolves at the same time that the pen moves across its surface, a temperature-time diagram is obtained similar to that shown in fig. 29—in which vertical distances represent the temperature, and horizontal distances (from left to right) represent the time.

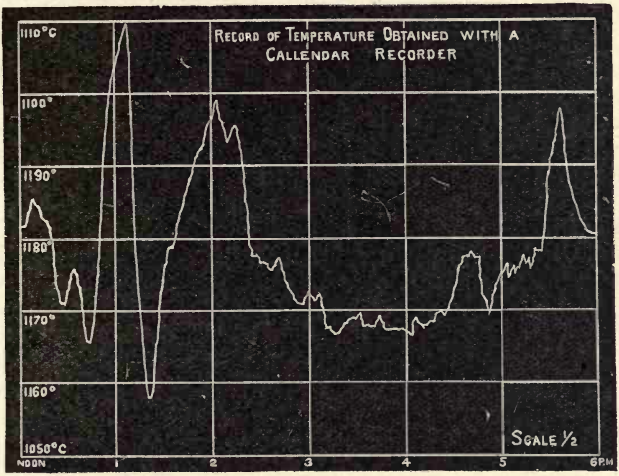


FIG. 29.

By means of a suitable switch any number of kilns can be connected, and their indications recorded, though if more than one kiln is at the same temperature the diagram becomes somewhat complicated.

In the 'thermo-couple' the resistance coils and Wheatstone bridge are unnecessary, and the current produced when two metals joined together are heated is measured directly by the galvanometer. The late Sir. W. C. Roberts-Austen, working on an instrument designed by Le Chatelier, has done an excellent work in introducing this instrument into this country. He also made it self-recording by causing the light from the galvanometer mirror to fall on a rotating drum of photographic paper which is afterwards developed.

Quite recently a combination of a pyroscope (p. 303) and of a thermo-couple pyrometer has been placed on the English market. This instrument, which is an improved form of the original Féry pyrometer, is capable of being used continuously at temperatures above 1000° C., at which the Callendar instrument becomes impracticable for commercial temperature-recording on account of the great wear and tear of the porcelain tubes and the wire forming the resistance.

In the Féry pyrometer the heat radiated through a 'sight-hole' in the kiln is received on to the junction of a copper constantan couple, and the radiation effect is measured by means of a sensitive galvanometer.

As the amount of heat radiated from the inside of a kiln, under the conditions under which such a pyrometer is used, is proportional to the fourth power of the temperature of the kiln, the readings of the galvanometer may, by suitable calibration, be made directly in ° C.

By using the radiated heat, instead of inserting a part of the pyrometer in the kiln, the wear and tear of the instrument is reduced almost to zero; an ingenious focussing arrangement enables the distance of the hot part of the kiln from the instrument to be varied within wide limits, and the original cost of the instrument is much less than that of the other forms of electric pyrometer, whilst its readings, so far as the author has been able to test them, seem to be equally accurate.

The construction of the instrument is shown in fig. 30, which is a sectional view of the pyroscope. This consists of a metal cylinder about 7 inches long and 4 inches wide, having a small eye-piece (O) at one end. Inside this cylinder, just behind the eye-piece, is a concave mirror which focusses the heat radiated from the kiln on to the thermo-couple junction, the two wires of which are marked R and D in the figure. In order that the accuracy of the focussing may be as great as possible, two small mirrors are placed immediately in front of the junction in such a manner that when the part of the kiln giving out the radiant heat it is desired to measure is in focus, a clear view of it (reflected from the large mirror on to the smaller ones) is obtained on looking through the eye-piece (O).

With this arrangement the distance of the heated object from the instrument is a matter of indifference so long as the image on the junction is more than sufficient to cover it. When this is the case the instrument gives identical readings at 3 feet and 30 feet from the object.

That the indications of the instrument, when used as directed, are independent of distance can be proved from theory as well as verified in actual work.

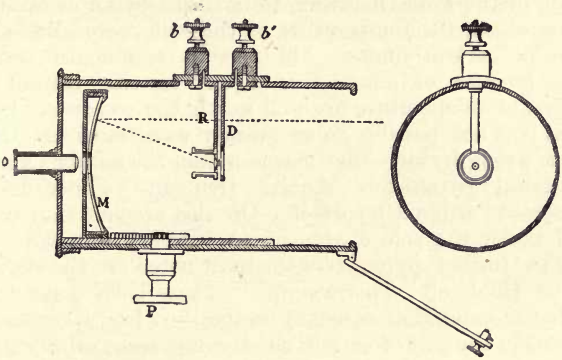


FIG. 30.

The radiated heat develops an electric current whose pressure is proportional to the temperature of the junction receiving the radiation. This current is led by wires from the terminals (b b') to a sensitive galvanometer, which, for convenience, may be graduated to show temperature-degrees instead of milli-volts. This enables the indications of the instrument to be read and understood without any calculation.

As one of the chief objects of measuring the temperature of a kiln is to have a continuous record of the manner in which it has been heated, it is advisable to substitute a recording galvanometer for the direct reading instrument just mentioned.

The Scientific Instrument Co., Ltd., Cambridge (who are the chief makers of electric temperature recorders in this country), have therefore patented a special form of recorder for the Féry pyrometer. In this recorder the pointer of the galvanometer moves backwards and forwards over a horizontal drum covered with a specially ruled paper, and at intervals of a minute it is pressed down by a light metal frame on to a thread soaked in a special ink in such a manner that the thread, on touching the paper, makes a small dot. As the drum revolves by clockwork once in twenty-four hours, the dots form a dotted line on the paper, the curves in this line representing the variations in the temperature of the kiln.

There is no reason why the 'warning attachment,' described previously, should not be added to this recorder as well as to the Callendar instrument, as it would then be possible for the head fireman, or the works manager, to be called by an electric bell if, for any reason, the temperature of the kiln were allowed to get outside of certain limits. Aid is thus summoned before any serious amount of mischief is done. In this respect electric recorders of temperature are well worth the somewhat high first cost, as it is not possible to so quickly warn outsiders that anything is wrong by any other means within the author's knowledge.

Electrical pyrometers require frequent 'standardising,' or their records will be incorrect. On this account they cannot be placed under the sole charge of an ordinary foreman.

Of the 'fusible' pyrometers the most noted are the Seger cones and the Holdcroft 'Thermoscope.' These both depend on the fact that a material of constant composition has a constant melting point in the case of certain silicates and some other substances. The most perfect substances for this purpose are the metals, but, unfortunately, these do not allow of any satisfactory series of indicators being made. Seger therefore proposed the use of mixtures of certain silicates with quartz and with certain fluxes compounded in molecular proportions in such a manner as to obtain masses of gradually increasing melting-point. The *average* difference between two consecutive Seger cones is 20° C. or 36° F., as is shown in the Table of Approximate Temperatures on page 337.

Seger cones are small pyramids (tetrahedrons) about 2½ inches high, this form being chosen as enabling the pieces to be placed vertically in the kiln, and at the same time to be very sensitive to heat, so that when the correct temperature is reached the 'cone' bends over until its point touches the tile or brick on which it is standing (see fig. 31).

If the cone is melted to a greater extent than this, a higher cone must be used; if not so much, it shows that the temperature corresponding to this particular cone has not been reached. Hence if the correct cone for finishing a kiln is known, the insertion of three cones will ensure a correct registration of the temperature, viz., one below the required temperature, one for the correct temperature, and one above it. Then the first cone will act as a warner that the finishing point is nearly reached, and the third cone will show, by its remaining unbent, that the temperature has not been excessive; underfiring and overfiring at the points where the cones are placed is therefore much less likely to occur than when other trials are used. In order that the cones may not fall over during the firing, it is convenient to insert them to the depth of $\frac{1}{4}$ inch or so in a piece of soft clay; this may then be placed directly in the kiln, or in small boxes of fireclay specially made for the purpose, in such positions that the cones can be easily seen during the progress of the firing through a sight-hole in the kiln wall. It is advisable to have a number of sets of cones in different parts of the kiln so as to secure an equal temperature throughout. For the determination of the highest temperature in a kiln (*i.e.* for the finishing heat) the Seger cones appear to be the most satisfactory form of pyrometer yet introduced. The Holdcroft 'Thermoscope' is practically a Seger Cone laid on its side and made of square instead of triangular section. A series of three or four thermoscopes are placed one above the other in a fireclay holder somewhat resembling a diminutive ladder, and, as the temperature affecting them is reached, they soften and bend downward in the centre; those which are not affected by the heat retain their straight, horizontal position. Although this form of test-piece finds many to recommend it, the author prefers the Seger cones as being more easily seen when in position in the kilns.

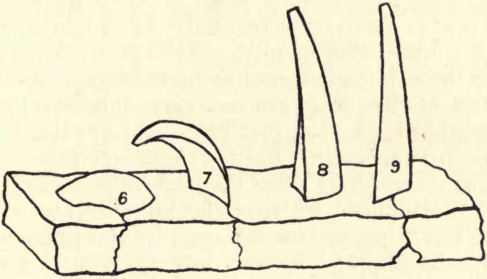


FIG. 31.

'Trials' are of various kinds, from the good old-fashioned rings of red-burning clay which are drawn out of the kiln at intervals and examined as to their colour and which are still of considerable value in careful and experienced hands, to pieces of clay glazed with special colours or glazes, and which are examined in a similar manner to the rings. In some cases a fusible 'body' is painted on to conveniently shaped test-pieces, and drawn out and examined from time to time, whilst for other classes of work it is sufficient to withdraw a piece of clay, such as the goods are made of, and to test that for hardness, porosity, etc. These methods, whilst sufficient for certain purposes, are not to be considered as pyrometers in the strict sense of the word, as they do not really measure the temperature of the kiln in terms of any particular scale; but they are still largely employed, and are most conveniently dealt with in this section.

In short, it is not safe to rely merely on the shrinkage of the clay to determine the finishing point of the kiln, as clay has a great tendency to contract irregularly, or a slip in the goods may cause them to shrink unduly. Electric pyrometers, though excellent for the automatic recording of the temperature throughout the whole of the firing, are not very durable when exposed for great lengths of time to great heats, and are therefore expensive in upkeep and repair. Lastly, the Seger cones are of the greatest value for finishing when the man responsible is at hand, but they do not indicate whether the kiln has lost any heat at any part of the firing, as, for instance, by the fireman going to sleep during the night; they are only 'maximum temperature recorders.' What is really wanted at the present time is a self-recording instrument of the Callendar type, but composed of a cheaper and more durable material than the platinum alloys at present employed. Some experiments in this direction have been made with certain earths, such as those used in the Nernst lamp, but, up to the present, no very successful results have been obtained. The direct-vision pyrometers, which depend on the colour of the inside of the kiln being directly proportionate to the temperature of the goods, are not sufficiently accurate for most clayworkers' use, and are in other ways more suited to the laboratory than the works.

A great number of other forms of pyrometer have been used at various times in connection with clayworking, but they have not met with sufficient success to be regarded as of practical value for this purpose, though often useful in other industries. The 'air-thermometer' and the 'water-current-pyrometer' are good instances of this class of instrument.

In order to study the firing of a kiln, it is advisable to construct a temperature diagram such as that shown in fig. 32, where vertical distances represent the temperature and horizontal ones the time; hence a point on the diagram which is on both

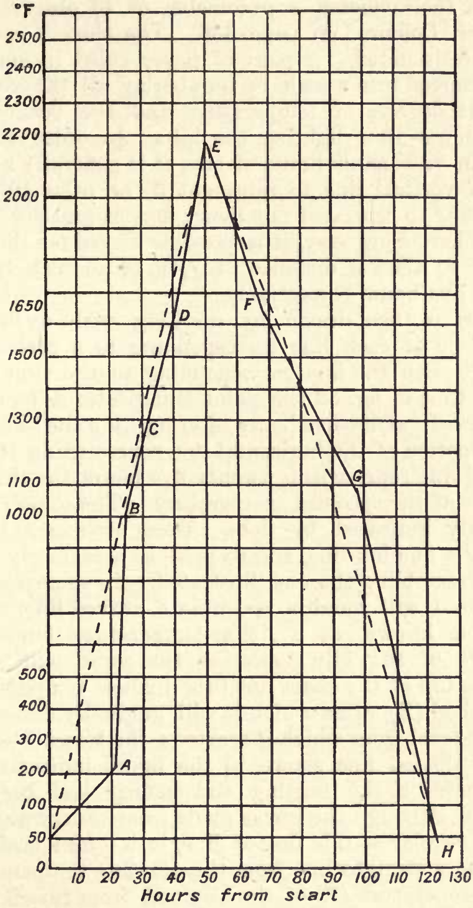


FIG. 32.

a temperature and a time line will indicate the temperature of the kiln at that particular time. Such a diagram will be automatically drawn by pyrometers of the Callendar (electric) type, but in other cases they must be made out by observation as follows:—

The time of lighting the kiln is noted, and at sufficiently frequent intervals the temperature of the kiln is ascertained by means of a thermometer, a pyrometer, or, by observation, using the Table of 'Colours' on page 338. The time of each observation is carefully noted. A piece of paper ruled in small squares is next converted into a scale by numbering all the vertical lines to represent degrees of temperature and the vertical lines to represent hours after lighting the kiln. In order to keep the chart within reasonable limits of size, it is generally advisable to allow each vertical line to represent 5° or even 10°, and each horizontal line to represent one hour; but as practice renders the use of the chart more easy, it is possible to reduce the scale still further and to allow a distance of $\frac{1}{25}$th of an inch to represent 10° C. and five hours respectively.

The chart is then drawn by marking with a fine dot the meeting place of each line corresponding to a certain observed temperature with the line corresponding to the time of the observation: thus in fig. 32 the point B indicates a temperature of 1000° observed twenty-five hours after lighting the kiln, because it is at the junction of the horizontal line representing 1000° and of the vertical line representing twenty-five hours, the time at which the kiln was at the specified temperature. The other observations are similarly indicated by dots. These dots are then joined together by a fine ink line, and so produce a curiously shaped line somewhat resembling the one illustrated. In some cases the line thus produced will roughly resemble a curved line, and it is on this account known as a 'time-temperature curve.' As the temperature of the kiln increases, the curve will tend to rise towards the top of the chart until the highest temperature of the kiln is reached (E), after which it will gradually descend until it reaches the level from which it started; the kiln is then perfectly cold. The dotted line shown in the figure indicates the shape of the 'curve' if the heating and cooling had been perfectly regular, and although the curve made from observations of kilns is never so regular as this dotted line, it is often useful to draw it (by ruling a straight line from the starting temperature to the finishing temperature (E) of the kiln and from this latter to the cooling point H, in order to see how far the actual result has followed this theoretical line. It will, of course, be understood that this chart will only show serious variations in the temperature of the kiln; smaller variations require the use of an automatic recorder, in which the record is continuous and not made at more or less regular intervals; but in spite of this disadvantage the chart illustrated is of great value in accounting for otherwise inexplicable variations in the quality of the ware. For the sake of clearness, only eight observations are shown, but in practice the observations would be made much more frequently than this, especially when the kiln was near its finishing point; at this stage the presence of three or four Seger cones is invaluable (in the absence of an electrical pyrometer) for recording the exact temperatures. It is then best to mark on the chart the time at which the different cones bend slightly, moderately, and completely.

A useful accessory to this chart consists in drawing a second vertical scale (preferably on the right-hand side of the paper) which shall represent the weight of fuel consumed by the kiln. If the kiln is properly fired this fuel-time line will then have a similar form to the heating line of the kiln, but will often be somewhat steeper near the top, as more fuel is required per hour when the kiln is at a bright heat than when it is but moderately heated. A study of this fuel line has on more than one occasion enabled the author to detect the stealing of fuel by the fireman or his friends. It also provides information as to the most economical temperature at which to finish the heating of the kiln.

In all kiln-firing it must not be forgotten that the pyrometer will indicate the temperature much more rapidly than the goods themselves, and that if the kiln is considered to be 'finished' as soon as the pyrometer (of whatever make) indicates a certain temperature, perfect goods will not be obtained; the temperature must be maintained for a certain time—particularly in glazed goods—to allow the glaze to mature. When Seger cones are used, the length of this maturing time is so short as to be practically negligible because the cones themselves take a certain time before they bend over completely. This slight disadvantage of the cones for certain purposes is an actual gain to the clay-worker, as it saves him from worrying about the time to continue his heating: he may consider the kiln as finished as soon as the desired cone has bent over until its point just touches the clay on which the cone stands.

For notes on suitable temperatures for drying, see page 122, and for firing various classes of goods, see page 178. For the automatic regulation of steam to drying-rooms in which steam is used as the heating agent, a self-acting regulator devised by Sodeau (*Jour. Soc. Chem. Ind.*, 1904, 1134) is useful. This consists of 1½-inch valve actuated by a zinc tube some 66 inches long, directly connected to it by means of a wooden insulator. Such a tube expands ·002 inch for each ° C. rise of temperature; hence all the connections must be free from play as far as possible. On this account Sodeau substitutes a slate slab for the wooden base usually provided with such instruments, and attaches the instrument by steel bolts of about the same expansion as the slate. Conduction of heat from the valve is greatly reduced by fitting a steel cap to the end of the valve spindle (V S), the point of the cap resting in a hole in the steel plate P^1. A similar plate, P^2, on the end of the zinc tube, T, is connected to P^1 by means of three steel distance-pieces D, slipped into slots in the plates, stiff paper being used to prevent metallic contact. All play is taken up by a strong spring, S, coiled around the external portion of the valve spindle, V S. The zinc tube is supported by a series of guides, G, and is prevented from rotating by means of a pin sliding in a slot (not shown in the fig.). The further end of the tube is adjusted by means of a differential screw (twelve and sixteen threads), one turn of which made an alteration of $\frac{1}{48}$-inch, or a difference in temperature of 16° C. The steam may be supplied at a low pressure (say 10 lbs. per square inch), and should, preferably, be passed through a separator to remove water and other impurities which might clog the valve. With careful use this arrangement works exceedingly well, and will run many months without any attention. A thermometer should, however, be placed in the dryer, and read at occasional intervals, in order to ensure that the adjustments have not been interfered with.

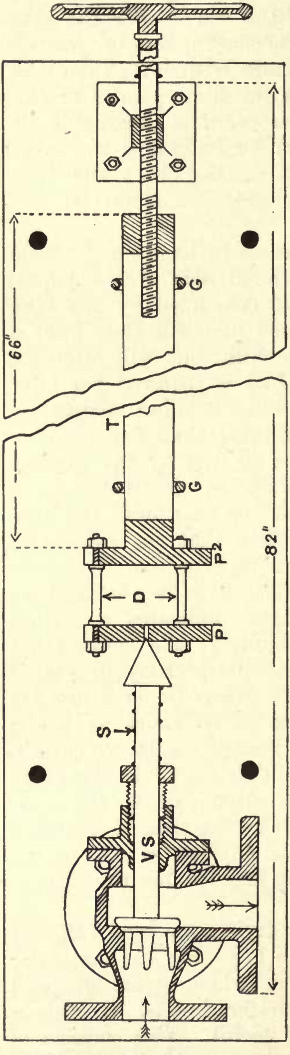


FIG. 33.

If such an apparatus is not installed in the dryers, it is at least desirable that a sensitive 'fire alarm' should be installed, so that a too sudden rise in temperature may be at once communicated to the person in charge, as otherwise, in the case of delicate clays, the goods may be easily spoiled. Such alarms may be obtained in various forms, and need no further description here than to say that when the temperature reaches a predetermined point, an electric circuit is completed and a bell rung, either until switched off and the alarm re-set or until the temperature falls again to its normal height.

Tension Tests of the tensile strength of clay are made in a special tensile strength machine which is beyond the reach of the ordinary clayworker, who must, therefore, send his bricks to an expert to be tested. The general principle on which such machines work is similar to that described as being used for determining the binding power of clay (p. 237), only that the enormously greater power required necessitates the use of a different method of applying the force. As these tensile machines are used for testing steel, an acquaintance in a neighbouring large steel-works may be able to make the test, but it is better, as a rule, to get it carried out by an expert in *clay*, who, by his constant practice, is more likely to obtain a correct result.

H. Ries (*Trans. Amer. Ceramic Soc.*, 1904, 79) has shown that an excessive proportion of fine clay particles weakens raw clay in the same manner as a large amount of sand, and that the strongest clays are those with grains of various sizes, so that they will interlock with each other; the fine particles of the clay substance must, however, preponderate. By the careful consideration of the sizes of the grains of two clays, Ries was able to prepare a mixture which had a higher tensile strength than either clay separately. It is interesting to note that this worker, contrary to many others, considers it incorrect to use the tensile strength as a measure of the plasticity of green clays (see 'Binding Power,' p. 237).

Texture varies greatly in various clays, and does not readily admit of numerical comparison, though the results of a careful washing of the clay through a series of sieves of gradually increasing fineness, and drying the residues on each sieve and weighing them (see p. 317), will prove of great assistance. The texture is really best ascertained by observation, with or without a powerful lens, and these two tests will usually prove sufficient for all ordinary purposes. The microscopical study of the texture of clay has not, up to the present, yielded results of great value to the clayworker. The relative 'fatness' or 'leanness' of two clays may be quite clear in the mind of a clayworker without his being able to express this relationship according to any definite scale.

Thermometers; **Thermoscopes.** See 'Temperature' (p. 299).

Volumenometers are used for determining the specific gravity and the porosity of fired clay goods (see p. 289).

Warners are used in connection with firing kilns, and are intended to secure a regular attention from the fireman, especially at night, when the temptation to neglect duty is apt to be greater and to be fraught with more serious consequences than during the daytime (see p. 239).

A perfect warner will indicate any serious alteration of temperature, first to the fireman, and then, if he does not attend, to the foreman or some other responsible person. Up to the present, however, no entirely successful warner has been placed on the market. An electrical one used by the author in connection with a Callendar pyrometer has proved entirely so under his care, but is too delicate for use by those not accustomed to instruments of precision. The warner most favoured abroad is so arranged that a bell rings at definite intervals (usually every fifteen minutes), indicating that it is time for the man to attend to his fires, after doing which he must move a small lever to indicate that he has done his duty. Should he neglect to move this lever (through being asleep or some similar cause) within ten minutes of the ringing of the bell, another alarm is sounded in the manager's or foreman's house, so that the cause of the fireman's neglect can be speedily ascertained. As will be seen, this instrument does not work directly in connection with the kiln, and is to this extent unsatisfactory, but, as already stated, no better means of warning the manager or his deputy of anything going wrong with the firing has yet been devised which can be placed in the hands of an ordinary foreman, and which at the same time cannot be tampered with by the fireman should he be so disposed. An electrical connection with a draught-gauge appeared at one time to promise success, but it was found on continued use that draught variations were sometimes beyond the control of the fireman, and that they were not always injurious to the contents of the kiln, so that those responsible were often unnecessarily 'warned' at much inconvenience to themselves.

Waggons, although nominally of a definite size, are notorious for containing different weights of material. Hence if each waggon cannot be weighed at each time of loading, the average weight should be taken from as large a number as possible. This is especially necessary where two different sets of waggons are used for the same material, as when coal is brought from the pit and delivered into bunkers from which it is taken in other waggons as required to the kilns, etc. If, as should be the case, each waggonman reports the weight of coal moved by him, the two weights will often fail to tally when 'stock' is taken of the fuel left in the bunkers, if the weight of it held by the waggons is estimated from an average load, with the result that the sole object of the reports of the men (viz., to prevent stealing of coal) is frustrated. Now that there are several forms of weighing machines made for this purpose on the market which do their work automatically, there is no excuse for a discrepancy of this sort.

Washing Clay is an operation which needs particular care and oversight. A good test of its efficiency consists in (1) washing a carefully weighed quantity of the clay through a special set of sieves of gradually increasing fineness, and (2) drying and weighing the residue left on each sieve. For this purpose about 2 lbs. of the dry clay, or an equivalent amount of the wet, is well mixed with about two quarts of hot water in a gallon basin, a wooden stick of about an inch in diameter and with slightly rounded ends being used to rub the clay into the consistency of a thin cream. After standing for a couple of hours about two quarts more of water are added, the mixture well stirred, allowed to settle for five minutes, and the liquid then poured carefully through a No. 75 sieve, as much as possible of the heaviest sediment being allowed to remain in the basin. The contents of the sieve are then brushed gently so as to cause as much of the clay as possible to pass through, the residue in the basin is rubbed up with a fresh quantity of water passed through the same sieve, and the operation repeated until no more clay will go through the sieve and the water used runs through quite clear. The residue on the sieve is then dried and weighed. The sifted clay and water ('slip') is next passed in a similar way through a finer sieve and then through another still finer, until a sieve with, say, 200 meshes per linear inch (No. 200) is reached. For most purposes this is sufficiently fine, but in the case of special work it may be necessary to make a supplementary test by means of Schoene's apparatus. (See p. 278, also Ashby's *How to Analyse Clay.*) It will generally be found in practice that three sieves will be sufficient in testing all but the finest varieties of clay, the precise sizes of mesh of these sieves being dependent, of course, on the particular class of work for which the clay is to be used. It is essential that the clay be not forced through the sieves; on this account a wooden tool is used to break up the 'cakes' of clay in the first instance, and a soft brush is used on the sieve. A sieve of moderate coarseness should always be used first, as this, by preventing hard pieces of material from getting on to the finer sieves, prevents their being so rapidly worn, or torn, as they would otherwise be.

Water for clayworks purposes does not need to be of the same degree of purity as that supplied to towns; at the same time certain impurities should be avoided. Amongst these are an excessive proportion of soluble salts, determined by evaporating a gallon of water (or less, according to the accuracy of the scales available) in a small weighed evaporating dish and weighing the residue after drying it to constant weight (p. 286) at 105° C. It is not possible to fix a limit for the proportion of soluble salts permissible, as so much depends on the temperature and method of firing of the kilns (*i.e.* on the class of goods made); but, as a general rule, waters containing more than 100 grains per gallon should be regarded with suspicion.

For use in boilers it is important to know how much matter will be deposited as scale in the boiler. This may be estimated by the following method, which will be found, in practice, to be superior to the usual 'soap test,' which is very unsatisfactory with magnesian waters.

To a convenient volume of the water (say, 500 c.c.) which has been carefully measured, a few drops of methyl-orange solution are added, and *decinormal* hydrochloric acid (to be obtained of exactly the correct strength from the best scientific instrument dealers and chemists) is then added drop by drop from a burette until the yellow colour of the water has been changed to a distinct pink, which remains after much stirring. Great care must be taken not to add too much acid, and to measure accurately the volume of acid necessary to bring about this change in colour. The number of c.c. of the acid required when multiplied by 350, and divided by the number of c.c. of water taken for the test, will indicate the number of grains of chalk per gallon in the water ('temporary hardness'), and this result divided by 2 will show approximately the number of grains of quicklime which must be added in the form of lime-water to remove this form of hardness from a gallon of the water.

To the pink liquid is added 100 c.c. or more (the exact volume added must be accurately known) of a solution of *decinormal* sodium carbonate solution by means of a pipette, and the liquid is boiled gently for a few minutes and is then filtered through a paper filter. The clear solution is allowed to cool, and *decinormal* hydrochloric acid is run in drop by drop until the colour is again just pink. If only two or three drops of the acid are required it shows that an insufficient quantity of the sodium carbonate solution has been added, and the test must be commenced afresh, using more of the solution. The number of c.c. of the acid used the second time is deducted from the number of c.c. of sodium carbonate solution used, and the result multiplied by 476 and divided by the number of c.c. of water used gives the number of grains per gallon of 'sulphate of lime' ('permanent hardness') in the water, and this result multiplied by 0·78 gives the number of grains of soda ash needed to remove it from each gallon of the water.

If magnesia is present in the water it will be reckoned as chalk or sulphate of lime, according to its state of combination. This will not, however, affect the proportions of lime or soda needed for softening the water.

It is advisable to occasionally draw samples of water from the boiler and to determine their 'hardness'; in this way the necessity for softening will be made clearer, or the accuracy with which the softening is being carried out will be shown.

It need scarcely be pointed out that when town's water is used to any considerable extent, a careful comparison of the readings of the meter week by week will often prevent any serious waste of water without much trouble; any serious variations in the amount of water used should always be accounted for if waste is to be prevented.

Weights per Pint. See 'Density' (p. 253).

Weights and Scales should be tested periodically by the recognised inspectors, even though they are not used for 'purposes of trade,' as in this way assurance is obtained that serious errors in the weights of glaze materials, etc., are not due to defective appliances.

Whiting may be assayed as chalk (p. 242).

Zinc Oxide is occasionally added to glazes in small proportions as an 'anti-craze.' For this purpose the white, light-weight variety is to be preferred to the denser, heavier one. By the method of its manufacture it is obtained so pure that it is scarcely worth assaying if obtained from reliable firms. If assayed by titration with decinormal hydrochloric acid after the manner of chalk (method (*b*), p. 245), it will be found that 1 c.c. of the acid is equivalent to 0·004 gramme of zinc oxide; hence if 0·4 gramme of the sample be used for the assay, each c.c. of acid required will represent 1 per cent. of pure zinc oxide in the sample. A more accurate assay of the material is beyond the powers of one not trained as a chemist and is, therefore, outside the scope of this book.

APPENDIX.

GENERAL INFORMATION.

Post Office Regulations.

Post Cards, with a halfpenny impressed stamp, may be sent to any part of the United Kingdom. Ten thin cards, 5½d., or 240 for 11s.; ten thick ones, 6d., or 100 for 5s. Reply cards, thin, five for 5½d.; thick, five for 6d. Private cards may be sent as post cards, with a halfpenny stamp affixed to the face thereof.

Inland Letters.—Not exceeding 4 oz., 1d.; 6 oz., 1½d.; 8 oz., 2d.; 10 oz., 2½d.; 12 oz., 3d.; 14 oz., 3½d.; 16 oz., 4d.; 18 oz., 4½d.; and so on at the rate of ½d. for every additional 2 oz.

An Inland letter must not exceed the dimensions of 24 ins. in length, 12 ins. in width, and 12 ins. in depth. The weight is not limited.

The Registration of any Inland letter, newspaper, or other packet, is 2d., and all letters containing coin, posted without registration, will be charged on delivery with a registration fee of 8d., in addition to the ordinary postage.

Registered Letter Envelopes are sold at all Post Offices, and by rural messengers, according to size, from 2¼d. to 3d. each. These registered letter envelopes are available for forwarding Foreign registered letters as well as Inland letters.

Book Post.—Postage, one halfpenny for the first 2 oz. or part of 2 oz. The postage must be prepaid in full; every packet must be sent either without or in a cover open at the ends or side. Above 2 oz., the rates for Inland letters apply.

Newspapers registered at the G.P.O. and published at intervals not exceeding seven days, postage one halfpenny each. No packet must exceed 14 lbs. in weight or 2 ft. by 1 ft. in size, and must be open at both ends.

Inland Parcel Post.[1]—3d. for first lb., and 1d. for every successive lb. up to 11 lbs. Length, 3 ft. 6 in.; length and girth combined, 6 ft.

Foreign Parcel Post.—A Parcel Post service has been established between the United Kingdom and the countries of the Continent of Europe and the British Colonies and Foreign Possessions generally. For rates and other conditions, see p. 322, also the *Post Office Guide*, published quarterly.

Inland Telegrams.—For twelve words or less, 6d., and one halfpenny per word afterwards. Addresses will be charged for.

Telegraph Money Orders.—Money may be transmitted by means of Telegraph Money Orders, the commission being: For sums not exceeding £1, 4d.; above £1 and not exceeding £2, 6d.; above £2 and not exceeding £4, 8d.; above £4 and not exceeding £7, 10d.; above £7 and not exceeding £10, 1s. In addition to the commission a charge will be made for the official telegram authorising payment at the office of payment, and for the repetition thereof, the minimum being 9d.

Money Orders (*Inland*).—For sums not exceeding £1, 2d.; not exceeding £3, 3d.; above £3 and not exceeding £10, 4d.

Money Orders Payable Abroad.—Foreign Orders are issued at the following rates: On sums not exceeding £2, 6d.; £5, 1s.; £7, 1s. 6d.; £10, 2s.

Postal Orders[1] issued for 6d., 1s., and 1s. 6d., at a cost of ½d. each; for 2s. up to 10s. 6d., at a cost of 1d. each; and from 15s. to 20s., at a cost of 1½d. each.

Post Office Savings Banks are established at every Money Order Office for the receipt and repayment of money. Deposits must not be less than 1s., or more than £50 in one year, or more than £200 in all, inclusive of interest, which is allowed at the rate of 2½ per cent. for every complete pound. At every Post Office in the United Kingdom forms can be obtained, free of charge, on which twelve penny postage stamps can be fixed, and when the form has been thus filled up with twelve penny stamps, it will be received at any Post Office Savings Bank as a savings bank deposit for 1s.

Stock can be bought at any Post Office Savings Bank. Any depositor who wishes can invest in Government Stock at the current price of the day. The least amount of stock which can be purchased or sold at one time is now reduced to the nominal sum of 1s. A small sum is charged by way of commission on investment and sale.

---

[1] There is a probability of these charges being revised in the near future.

PARCEL POST RATES BETWEEN HANLEY AND THE CONTINENT OF EUROPE.

		For parcels under		
		1 Kilo. 3 lbs.	3 Kilos. 7 lbs.	5 Kilos. 11 lbs.
Austria	*via* Ostend,	1/6	2/-	2/7
Belgium	,, ,,	1/3	1/8	2/2
France	,, Calais,	1/4	1/9	...
Germany	,, Ostend,	1/4	1/9	2/3
,,	,, Hamburg,	1/-	1/7	...
Holland	,, Ostend,	1/-	1/8	2/3
Italy	,, France,	2/1	2/1	...
Spain	,, ,,	2/1	2/1	...
Sweden	,, Hull,	1/3	2/3	...
Switzerland	,, Ostend,	1/9	2/2	...
,,	,, France,	1/6	2/-	...

Metrical Equivalents of British Weights and Measures.

ENGLISH.

1 Inch = 2·54 centimetres (cm.).
1 Foot = 30·48 centimetres (cm.).
1 Yard = ·91 metres (m.).
1 Mile = 1609 metres (m.).

METRIC.

1 Millimetre = 0·04 in.
1 Centimetre = 0·39 in.
1 Metre = { 39·37 in. / 3·28 ft. / 1·09 yds.
1 Kilometre = 1093·6 yds.

Area.

1 Sq. inch = 6·45 sq. cm.
1 Sq. foot = 0·093 sq. metre.
1 Sq. yard = 0·836 sq. metre.
1 Acre = 4040 sq. metres.

1 Sq. cm. = 0·155 sq. in.
1 Sq. m. = 1·194 sq. yds.

Volume.

1 Cubic inch = 16·4 c.c.
1 Cubic yard = ·76 cb. m.
1 Pint = 568¼ c.c.
1 Gallon = 4·55 litres.

1 C.c. = 0·061 cb. in.
1 Cb. metre = 1·33 cb. yds.
1 Litre = 1·76 pints = 1000 c.c.
= 0·35 cb. ft.

Weight.

1 Ounce = 31·1 grammes.
1 Pound avoir. = 453·7 grammes.
= 0·454 kilo.
1 Ton = 1016 kilos.

1 Kilogramme (kilo.) = 2·20 lbs.
1000 kilo. = 1 ton (nearly).

British Weights and Measures.

1 Pint = 20 oz. of water.
1 Gallon = 8 pints.
= 10 lbs. of water.
= 277·27 cb. inches.

1 cubic inch water = 0·036 lb.
1 cubic foot water = 1000 oz. (nearly).
= 6·23 gallons.
= 0·028 cubic metre.

When other substances than water are measured the weight will vary with the specific gravity of the material.

Volume × Sp. Gr. = Wt. (for Metric measure).

Volume (in pints) × Sp. Gr. = Wt. (in lbs.) × 0·8 (for British measures).

Metric Weights and Measures.

1 Metre = 100 centimetres (cm.).
1 Centimetre = 10 millimetres (mm.).
1 Gramme of water measures 1 c.c.
1 Kilogramme = 1000 grammes.
1 Litre = 1000 c.c.

Formulæ relating to the Circle, etc.

The circumference of a circle = diameter $\times \frac{22}{7}$ (or 3·1416).

Area of circle = square of diameter $\times \frac{22}{28}$ (or 0·7854).

The side of a square equal in area to a given circle = diam. × 0·8852.

Area of a triangle = half base × perpendicular height.

The capacity of a tank or cistern with straight sides is found in cubic inches by multiplying the length by the breadth and then by the depth (all measured in inches). To convert cubic inches into cubic feet, divide by 27; to convert cubic inches into gallons, divide by 277.

Chemical Calculations.

To find the Percentage Composition having the Formula given.—Find the molecular weight by adding the atomic weights of the different elements in the formula, taking care that when more than one atom is present that the proper multiple of the atomic weight is used; then

$$\frac{\text{Molecular weight}}{100} = \frac{\text{Weight of constituent in a molecule}}{\text{Percentage of constituent}};$$

or multiply the molecular weight of the constituent by 100 and divide by the molecular weight of the whole substance.

To find the Empirical Formula of a substance from its Percentage Composition.—Divide the percentage of each element by the atomic weight of that element, and divide all the numbers thus obtained by the lowest; if the numbers thus resulting are not whole numbers, the nearest whole numbers may usually be taken as correct.

In calculating the formulæ of glazes and bodies divide the percentage of each oxide (K_2O, Al_2O_3, SiO_2, etc.) by the molecular weight of that oxide, and divide the numbers so obtained by the number found for the total of the alkalies (K_2O, Na_2O, PbO, CaO, MgO).

Before this calculation can be made, it is obviously necessary to know the percentage composition of each constituent of the glaze or body.

Fire-resisting Materials Defined.

The first schedule of the London Building Acts (Amendment) Act, 1905, contains the list of materials which are considered fire-resisting by the London County Council, and the following extracts are of interest :—

The following materials shall, for the purposes of the Act of 1894, the Act of 1898, and this Act, be deemed to be fire-resisting materials:

I. For general purposes:

1. Brickwork constructed of good bricks well burnt, hard and sound, properly bonded and solidly put together—
   - (*a*) With good mortar compounded of good lime and sharp, clean sand, hard, clean broken brick, broken flint, grit, or slag; or
   - (*b*) With good cement; or
   - (*c*) With cement mixed with sharp, clean sand, hard clean broken brick, broken flint, grit, or slag.
2. Granite and other stone suitable for building purposes by reason of its solidity and durability.
3. Iron, steel and copper.
4. Slate, tiles, brick and terra-cotta, when used for coverings or corbels.
5. Flagstones when used for floors over arches, but such flagstones not to be exposed on the underside, and not supported at the ends only.
6. Concrete composed of broken brick, tile, stone chippings, ballast, pumice or coke breeze, and lime, cement or calcined gypsum.
7. Any combination of concrete and steel or iron.

II. For special purposes:

In the case of floors and roofs—brick, tiles, terra-cotta or concrete composed as described in paragraph I. 6 of this schedule, not less than 5 inches thick, in combination with iron or steel.

In the case of floors and of the roofs of projecting shops —pugging of concrete composed as described in the said paragraph I. 6, not less than 5 inches thick, between wood joists, provided a fillet 1 inch square is secured to the sides of the joists, and placed so as to be in a central position in the depth of the concrete or concrete blocks, not less than 5 inches thick, laid between wood joists on fire-resisting bearers secured to the sides of joists.

In the case of internal partitions enclosing staircases and passages, terra-cotta, brickwork, concrete or other incombustible material, not less than 3 inches thick.

TABLES RELATING TO MATERIALS.

Common Chemicals and their Scientific Names and Formulae.

Common Name.	Scientific Name.	Formula.
Alum,	Potassium or ammonium aluminum sulphate,	$K_2SO_4Al_2(SO_4)_3 24H_2O$ or $(NH_4)_2SO_4Al_2(SO_4)_3 24H_2O$
Aqua fortis,	Nitric acid,	HNO_3
Aqua regia,	A mixture of nitric and hydrochloric acids.	
Barytes (heavy spar),	Barium sulphate,	$BaSO_4$
Bauxite,	Impure alumina,	$Al_2O_3 2Al_2(OH)_6$
Biotite (mica),	A complex silicate of potassium, magnesium, and iron.	
Blue vitriol,	Cryst. copper sulphate,	$CuSO_4 5H_2O$
Brown coal (lignite),	Contains 55 to 75 per cent. carbon.	
Calcine,	A heated mixture of lead and tin.	
Chalk,	Calcium carbonate,	$CaCO_3$
Chili saltpetre,	Sodium nitrate,	$NaNO_3$
China clay,	(See Kaolin),	
Colcothar,	Ferric oxide,	Fe_2O_3
Common salt,	Sodium chloride,	$NaCl$
Copperas (green vitriol),	Ferrous sulphate,	$FeSO_4 9H_2O$
Corundum,	Impure alumina,	Al_2O_3
Crocus martis,	An oxide of iron containing some nitrate.	
Dolomite,	Calcic magnesiocarbonate,	$CaOMgO2CO_2$
Epsom salts,	Magnesium sulphate,	$MgSO_4 7H_2O$
Felspar,	Usually orthoclase ; but anorthite, albite, labradorite, oligoclase, and other similarly constituted minerals in which the potassium is in different proportion or is partially or completely replaced by other metals. See Sodalite.	$K_2OAl_2O_3 6SiO_2$
Fire-damp,	Light carburetted hydrogen.	
Flint,	Amorphous silica,	SiO_2
Fluorspar,	Calcium fluoride,	CaF_2
Galena,	Plumbic sulphide,	PbS_2
Glauber's salt,	Sodium sulphate,	$Na_2SO_4 7H_2O$

Common Name.	Scientific Name.	Formula.
Glucose,	Grape sugar,	$C_6H_{12}O_6$
Gypsum,	Calcium sulphate,	$CaSO_42H_2O$
Hæmatite,	Impure iron oxide,	Fe_2O_3
Hausmannite,	Impure manganese oxide,	Mn_3O_4
Heavy spar,	Barium sulphate,	$BaSO_4$
Ilmenite (titaniferous iron ore),		$FeOTiO_2$
Iron Pyrites,	Iron sulphide,	FeS_2
Kaolin,	China clay,	$Al_2O_32SiO_22H_2O$
Kieselguhr,	A form of silica,	SiO_2
Labradorite,	A felspar,	$(Na_2Ca)OAl_2O_3 3SiO_2$
Lignite,	(See Brown coal).	
Lime,	Calcium oxide,	CaO
Magnesite,	Magnesium carbonate,	$MgCO_3$
Malachite,	Cupric carbonate,	$2CuCO_3H_2O$
Marble,	Calcium carbonate,	$CaCO_3$
Mennige,	(See Red lead).	
Oligoclase,	A felspar,	$2(Na_2Ca)O2Al_2O_39SiO_2$
Pyrites (iron),	Iron sulphide,	FeS_2
Pyrolusite,	Manganese dioxide,	MnO_2
Quartz,	Cryst. silica,	SiO_2
Realgar,	Arsenic sulphide,	AsS
Red lead,	Triplumbic tetroxide,	Pb_3O_4
Rock crystal,	Quartz,	SiO_2
Rock salt,	Sodium chloride,	$NaCl$
Rutile,	Titanium oxide,	TiO_2
Rust of iron,	Iron oxide more or less hydrated,	$Fe_2(OH)_6Fe_2O_3$
Salammoniac,	Ammonium chloride,	NH_4Cl
Saltpetre,	Potassium nitrate,	KNO_3
Salt of tartar,	Potassium carbonate,	K_2CO_3
Smaltite,	A cobalt ore,	CoS_2CoAs_2
Sodalite,	A felspar,	$3Na_2O3Al_2O_3 12SiO_2$
Spinel,		$MgOAl_2O_3$
Spirits of hartshorn,	Ammonia solution.	
Spirits of salt,	Hydrochloric acid.	
Stucco or plaster of Paris,	Calcium sulphate.	$CaSO_42H_2O$
Sugar of lead,	Lead acetate,	$Pb(C_2H_3O_2)_2$
Talc (steatite),	A magnesium silicate,	$3MgO4SiO_2H_2O$
Tincal,	Impure borax,	$Na_2B_4O_710H_2O$
Tin ash,	A heated mixture of tin and lead more or less completely oxidized.	
Umber,	An earthy mixture rich in iron and manganese oxides.	
Verdigris,	A basic acetate of copper of somewhat varying composition.	
Vinegar,	Is chiefly used for the acetic acid it contains. Coml. acetic acid (pyroligneous acid) is cheaper, and for most purposes equally suitable.	
Vitriol, oil of,	Sulphuric acid,	H_2SO_4

Common Name.	Scientific Name.	Formula.
Vitriol, blue,	Copper sulphate,	$CuSO_45H_2O$
Vitriol, green,	Ferrous sulphate,	$FeSO_49H_2O$
Vitriol, white,	Zinc sulphate,	$ZnSO_47H_2O$
Wad,	Impure manganese oxide.	
Witherite,	Barium carbonate,	$BaCO_3$
Yellow ochre,	Ferruginous calcareous clay.	
Zinc spar (spathic zinc ore),		$ZnCO_3$

Formulæ of some Compounds used in Clayworking.

Name.	Formula.	Molecular weight.
Alum (ammonium),	$(NH_4)_2SO_4.Al_2(SO_4)_3.24HO$,	904
,, (potassium),	$K_2SO_4Al_2(SO_4)_324H_2O$,	948
Alumina,	Al_2O_3,	102
Aluminium sulphate,	$Al_2(SO_4)_318H_2O$,	665
Antimony oxide,	SbO,	287
Arsenic oxide,	As_2O_3,	198
Barium carbonate,	$BaCO_3$,	197
Barium chloride (cryst.),	$BaCl_22H_2O$,	244
Barium oxide,	BaO,	153
Barium sulphate,	$BaSO_4$,	233
Bismuth oxide,	Bi_2O_3,	468
Borax,	$Na_2B_4O_710H_2O$,	382
Boric acid,	H_3BO_3,	62
Boric oxide,	B_2O_3,	70
Calcium carbonate,	$CaCO_3$,	100
Calcium oxide (lime),	CaO,	56
Calcium phosphate (bone phosphate),	$Ca_3P_2O_8$,	310
Calcium sulphate,	$CaSO_4$,	136
,, ,, 'gypsum,' ,, ,, 'plaster,'	$CaSO_42H_2O$,	172
Carbon dioxide,	CO_2,	44
Carbon monoxide,	CO,	28
Chromium oxide,	Cr_2O_3,	153
Chromium sulphate,	$Cr_2(SO_4)_318H_2O$,	717·7
Chromium tri-oxide,	CrO_3,	100·2
Cobalt carbonate,	$CoCO_3$,	118·5
Cobaltic chloride,	Co_2Cl_6,	329·4
Cobalt nitrate,	$Co(NO_4)_36H_2O$,	290·1
Cobalt sulphate,	$CoSO_47H_2O$,	280·1
Copper oxide (black),	CuO,	79·5
Copper oxide (red),	Cu_2O,	143·0
Copper sulphate (blue vitriol),	$CuSO_45H_2O$,	249·5
Ferric oxide,	Fe_2O_3,	160
Ferrous oxide,	FeO,	72
Ferric sulphide (pyrites),	FeS_2,	120
Ferrous sulphate (cryst.),	$FeSO_47H_2O$,	278
Ferrous sulphide,	FeS,	88
Ferroso-ferric oxide,	Fe_3O_4,	232
Hydrochloric acid (gas),	HCl,	36·4

(The liquid hydrochloric acid only contains about 40 per cent. of the gas.)

Iron compounds—see Ferrous and Ferric.		
Lead carbonate,	$PbCO_3$,	266
Lead, basic carbonate (white lead),	$Pb(OH)_22PbCO_3$,	773
Lead chromate,	$PbCrO_4$,	323
Lead oxide (litharge),	PbO,	222·4
Lead, red,	Pb_3O_4,	685
Lead sulphate,	$PbSO_4$,	302
Lead sulphide,	PbS,	238·4
Magnesium carbonate,	$MgCO_3$,	84
Magnesium oxide (magnesia),	MgO,	40
Manganese carbonate,	$MnCO_3$,	115
Manganese oxide (braunite),	Mn_2O_3,	158
Manganous oxide,	MnO,	71
Tri-manganic tetroxide,	Mn_3O_4,	229
Manganese dioxide (pyrolusite),	MnO_2,	87
Mennige (see Red lead).		
Nickel oxide,	NiO,	75
Nickel sulphate,	$NiSO_47H_2O$,	280·8
Nitric acid,	HNO_3,	63
Potassium alum,	$K_2SO_4Al_2(SO_4)_324H_2O$,	948
Potassium antimonate,	$KSbO_3$,	206·5
Potassium bichromate,	$K_2Cr_2O_7$,	295
Potassium carbonate,	K_2CO_3,	138
Potassium carbonate (cryst.),	$K_2CO_32H_2O$,	174
Potassium chrome alum,	$K_2SO_4Cr_2(SO_4)_324H_2O$,	999
Potassium iron alum,	$K_2SO_4Fe_2(SO_4)_324H_2O$,	1006·5
Potassium hydrate,	KHO,	56
Potassium nitrate (nitre),	KNO_3,	101
Potassium oxide ('potash'),	K_2O,	94
Potassium sulphate,	K_2SO_4,	174
Silica,	SiO_2,	60
Sodium bicarbonate,	$NaHCO_3$,	84
Sodium carbonate ('soda ash'),	Na_2CO_3	106
Sodium carbonate (washing soda cryst.),	$Na_2CO_310H_2O$,	286
Sodium chloride (salt),	$NaCl$,	58·5
Sodium hydrate,	$NaHO$,	40
Sodium nitrate,	$NaNO_3$,	85
Sodium oxide ('soda'),	Na_2O,	62
Sodium silicate (water glass),	$Na_2Si_4O_9$ (approx.),	302
Sulphuric acid,	H_2SO_4,	98
Tin oxide,	SnO_2,	150
Titanium oxide,	TiO_2,	80
Uranium oxide,	UO_2,	272
Zinc oxide,	ZnO,	81

Molecular Weights arranged in Alphabetical Order of the Symbols of the most Important Elements.

Al_2O_3	102	KNO_3	101
$Al_2O_3.2SiO_2.2H_2O$	258	K_2SO_4	174
$Al_2O_3.2SiO_2$	222	$K_2Cr_2O_7$	295
$Al_2(SO_4)_3.18H_2O$	665	$K_2O.Al_2O_3.6SiO_2$	556
As_2O_3	198	MgO	40
BH_3O_3	62	$MgCO_3$	84
B_2O_3	70	$MgSO_4.7H_2O$	246
$BaCO_3$	197	MnO_2	87
$BaCl_2.2H_2O$	244	Na_2O	62
$Ba(OH)_2.8H_2O$	315	Na_2CO_3	106
BaO	153	$Na_2CO_3.10H_2O$	286
$BaSO_4$	233	$NaCl$	58·5
CO	28	$NaNO_3$	85
CO_2	44	$Na_2B_4O_7$	202
$CaCO_3$	100	$Na_2B_4O_7.10H_2O$	382
$CaFl_2$	78	$Na_2SO_410H_2O$	322
CaH_2O_2	74	$Na_2O.Al_2O_3.6SiO_2$	524
CaO	56	NiO	75
$CaSO_4$	136	$NiSO_47H_2O$	280·8
$CaSO_4.2H_2O$	172	PbO	222
CoO	74·5	Pb_3O_4	685
Cr_2O_3	153	PbS	238
CuO	79·5	$PbCO_3$	266
$CuSO_4.5H_2O$	249·5	$2PbCO_3.PbH_2O_2$	775
Fe_2O_3	160	Sb_2O_3	287
FeO	72	SiO_2	60
$FeSO_4.7H_2O$	278	SnO_2	150
K_2O	94	$SrCO_3$	147·5
K_2CO_3	138	UO_2	272
$K_2CO_3.2H_2O$	174	ZnO	81

Table of Atomic Weights of the Chief Elements.

Name.	Atomic weight	Name.	Atomic weight.
Aluminium,	27·3	Molybdenum,	95·6
Antimony,	122·0	Nickel,	58·6
Arsenic,	74·9	Niobium,	94·0
Barium,	136·8	Nitrogen,	14·01
Beryllium,	9·0	Osmium,	198·6
Bismuth,	210·0	Oxygen,	15·96
Boron,	11·0	Palladium,	106·2
Bromine,	79·75	Phosphorus,	30·96
Cadmium,	111·6	Platinum,	194·7
Cæsium,	133·0	Potassium,	39·04
Calcium,	39·9	Rhodium,	104·1
Carbon,	11·97	Rubidium,	85·2
Chlorine,	35·37	Ruthenium,	103·5
Cerium,	141·2	Selenium,	78·0
Chromium,	52·4	Silicon,	28·0
Cobalt,	58·6	Silver,	107·66
Copper,	63·0	Sodium,	22·96
Didymium,	147·0	Strontium,	87·2
Erbium,	169·0	Sulphur,	31·98
Fluorine,	19·1	Tantalium,	182·0
Gold,	196·2	Tellurium,	128·0
Hydrogen,	1	Thallium,	203·6
Indium,	113·4	Thorium,	231·5
Iodine,	126·53	Tin,	117·8
Iridium,	196·7	Titanium,	48
Iron,	55·9	Tungsten,	184·0
Lanthanum,	139·0	Uranium,	240·0
Lead,	206·4	Vanadium,	51·2
Lithium,	7·01	Yttrium,	93·0
Magnesium,	23·94	Zinc,	64·9
Manganese,	54·8	Zirconium,	90·0
Mercury,	199·8		

Table giving the Weight of 1 Cubic Foot of Various Materials.

	Lbs.
Water,	62
Clay (before digging), rough average,	125
Clay (after digging), ,,	72
Sand (before digging), ,,	119
Sand (after digging), ,,	110
Burnt bricks (closely piled),	112
Broken bricks (roughly crushed),	150
Coal (unscreened),	45
,, (slack),	50
Chalk,	85
Portland cement,	85
Concrete (varies with the stone used),	110–137
Plaster or stucco (in use),	61
Slate,	168
Glass,	165
Marble or granite,	168
Fir or pine wood,	37–40
Beech or oak wood,	47–50
Cast iron,	380–470
Cast steel,	440–492
Lead,	695
Copper,	550
Zinc,	450
Aluminium,	160

Specific Gravity of Various Substances.

Material.	Sp. Gr.	Material.	Sp. Gr.
Cement,	2·7–3·5	Mica,	2·7–3·2
Chalk,	1·8–2·7	Pitch,	1·1
Coal,	1·37	Quartz,	2·5
Coke,	1·5	Salt,	2·1
Clay,	1·8–2·7	Sandstone,	2·3
Glass,	2·5–3·3	Sand,	1·9
Granite,	2·7	Tiles and bricks,	1·5–2·0
Hematite ore,	5·0	Wax,	0·97
Marble,	2·7	Wood,	0·47–0·85

Water = 1.

Standard Sizes of Bricks in different Countries.

In many countries there is no official standard; when such is the case the average size is given.

Country.	Length, inches.	Breadth, inches.	Thickness, inches
Great Britain,	9	$4\frac{3}{8}$	$2\frac{5}{8}$
Germany,	10	$4\frac{3}{4}$	$2\frac{5}{8}$
Austria,	$11\frac{5}{8}$	$5\frac{5}{8}$	$2\frac{5}{8}$
France,	$8\frac{3}{4}$	$4\frac{3}{8}$	$2\frac{3}{8}$
Italy,	9	$5\frac{1}{2}$	$2\frac{3}{8}$
Holland and Belgium,	$9\frac{5}{8}$	$4\frac{3}{4}$	$2\frac{3}{8}$
Switzerland,	10	$4\frac{3}{4}$	$2\frac{3}{8}$
Russia (varies greatly),	$11\frac{1}{2}$	$5\frac{1}{8}$	$2\frac{3}{4}$
United States,	8	4	$2\frac{3}{8}$

The Royal Institute of British Architects standard size lies between—Length, $8\frac{7}{8}$ in. and 9 in.; Breadth, $4\frac{5}{16}$ in. and $4\frac{3}{8}$ in.; Thickness, $2\frac{5}{8}$ in. and $2\frac{11}{16}$ in.

The method of measuring the bricks as set out in the standard is as follows:—

(1) The length of the brick should be double the width *plus* the thickness of one vertical joint.

(2) Brickwork should measure four courses of bricks and four joints to a foot.

Joints should be $\frac{1}{4}$ in. thick, and an extra $\frac{1}{16}$th, making $\frac{5}{16}$th, for the bed joints to cover irregularities in the bricks. This gives a standard length of $9\frac{1}{4}$ in. centre to centre of joints.

The bricks, laid dry, to be measured in the following manner:—

A. Eight stretchers laid square end and splay end in contact in a straight line to measure 72 in.

B. Eight headers laid side to side, frog upwards, in a straight line to measure 35 in.

C. Eight bricks, the first brick frog downwards and then alternately frog to frog and back to back, to measure $21\frac{1}{2}$ in.

A margin of 1 in. less will be allowed as to A and $\frac{1}{2}$ in. less as to B and C.

The standard has been agreed upon between the Royal Institute and the Institute of Clayworkers, and has been drafted in consultation with these bodies and with representatives of the Institution of Civil Engineers.

It was ordered to come into force on 1st May 1904.

The council recommend that members should insert this standard in their specifications under the title of "The R.I.B.A. Standard Size of Bricks."

Composition of Various Fuels.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Coal—						
Lancs.,	79½	5	9	1½	1	4
Newcastle,	83	5	5	2	1	4
Yorkshire, Derbyshire,	80	5	10	1	1	3
Welsh,	85	5	3	1	2	4
Scotch,	78	7	9	1	1	4
Anthracite,	90	2	4	¼	¾	3
Coke,	94	...	...	...	1	5
Dry wood,	50	6	41	1	...	2
Dried peat,	59	6	30	1	...	4
Petroleum,	85	13	2	...	...	...

The above figures are the average of a large number of analyses, but individual samples of any of the fuels may vary greatly from the typical ones quoted; thus peat may have as much as 30 per cent. of ash, and coal, if small ('slack'), may often be obtained with 10 to 15 per cent. of ash.

Coal Ash varies somewhat in composition according to the seam from which it is obtained, but the following is a fair average:—

Silica,	43 per cent.	Magnesia,	2 per cent.
Alumina,	26 ,,	Alkalies,	1 ,,
Iron oxide,	15 ,,	Sulphuric acid,	5 ,,
Lime,	7 ,,	Phosphoric acid,	1 ,,

Approximate Composition of Various Gases.

	Carbon dioxide.	Oxygen.	Carbon monoxide.	Hydrogen.	Methane.	Nitrogen.
Coal gas,	2	...	15	43	31	2
Producer gas,	5	...	25	12	2	56
Air,	...	21	...	...	...	79

Composition of Boiler Water.

The proportion of solid matter left on evaporation should be as small as possible, but the composition of this matter is usually of more importance than its amount when the latter is large. If producing temporary hardness it may easily be removed by lime

(p. 40), or permanent hardness less easily by sodium carbonate; but if the water contains a large proportion (say over 30 grains per gallon) of sodium or potassium sulphates or chlorides it is seldom fit to use. Water containing more than 10 grains per gallon of magnesia (MgO) is apt to cause corrosion at the water line if the water also contains chlorides.

Temperature and Pressure of Saturated Steam.

Absolute Pressure in lb. per sq. in.[1]	Temperature or Boiling Point in ° F.	Total Heat in Thermal Units per lb. of Steam from 0° F.	Absolute Pressure in lb. per sq. in.	Temperature or Boiling Point in ° F.	Total Heat in Thermal Units per lb. of Steam from 0° F.
1	102·1	1145	68	300·9	1205
3	141·6	1156	70	302·9	1205
5	162·3	1163	72	304·8	1206
6	170·2	1165	74	306·6	1206
8	182·9	1169	76	308·4	1207
10	193·3	1172	78	310·2	1208
12	202·0	1175	80	312·0	1208
14	209·6	1177	82	313·6	1209
14·7	212·0	1177·8	84	315·3	1209
16	216·3	1179	86	316·9	1210
18	222·4	1181	88	318·6	1210
20	228·0	1182	90	320·2	1211
22	233·1	1184	92	321·7	1211
24	237·8	1185	94	323·3	1212
26	242·3	1187	96	324·8	1212
28	246·4	1188	98	326·3	1213
30	250·4	1189	100	327·9	1213
32	254·1	1190	105	331·3	1214
34	257·6	1192	110	334·6	1215
36	260·9	1193	115	338·0	1216
38	264·2	1194	120	341·1	1217
40	267·3	1194	125	344·2	1218
42	270·2	1195	130	347·2	1219
44	273·0	1196	135	350·1	1220
46	275·8	1197	140	352·9	1221
48	278·4	1198	145	355·6	1221
50	281·0	1199	150	358·3	1222
52	283·5	1199	155	361·0	1223
54	285·9	1200	160	363·4	1224
56	288·2	1201	165	366·0	1224
58	290·4	1202	170	368·2	1225
60	292·7	1202	175	370·8	1226
62	294·8	1203	180	372·9	1227
64	296·9	1204	190	377·5	1228
66	299·0	1204	200	381·7	1229

---

[1] To find corresponding "Gauge Pressure" deduct 14·7 lb. per sq. in. from Absolute Pressure.

TABLES RELATING TO HEAT.

Conversion of Degrees Fahrenheit into Degrees Centigrade.

In order to calculate the temperature on one of these scales into the corresponding temperature on the other, it is well to remember that

Temperature of melting ice = 0° C. and 32° F.
Temperature of boiling water = 100° C. and 212° F.

Hence

Deg. Cent. = deg. Fah. − 32, divided by 9 and multiplied by 5.
Deg. Fah. = deg. Cent. multiplied by 9 and divided by 5, and 32 added to the result.

Thus $15\frac{1}{2}$° C. = 60° F., because

Deg. Cent. = 60 − 32 = 28, which divided by 9 = $3\frac{1}{9}$, and this multiplied by 5 = $15\frac{5}{9}$, or $15\frac{1}{2}$° C.
Deg. Fah. = $15\frac{1}{2} \times 9 = 139\frac{1}{2}$, which divided by 5 = 28 (nearly), to which add 32, giving 60° F.

For most purposes the Centigrade scale is much more convenient than that of Fahrenheit, and it is, in consequence, more generally used for accurate measurements of temperature.

A third scale, devised by Reaumur, is sometimes used for domestic purposes in Germany, but it is of no value to British clayworkers. Its degrees are exactly $1\frac{1}{4}$ the value of those on the Centigrade scale.

Heat Units.

Care must be taken to distinguish between the temperature of a body and the number of heat units it contains (see p. 45).

The British Thermal Unit is the standard unit of heat in this country, and is defined as the amount of heat required to raise the temperature of 1 lb. of water from 60° to 61° F., or 1° F. Hence the amount of heat which will raise 1 lb. of water 50° F. is 50 B.T.U., or if 2 lb. of water have their temperature raised 50° F, 2 × 50 = 100 B.T.U. will be needed.

The more scientific unit of heat is the Calorie, which is the amount of heat required to raise the temperature of 1 kilo of water through 1° C.

Table of Maximum Flame-temperatures.

The following Table of maximum flame temperatures shows the difficulty which exists in the measurement of the highest extent to which clay can be heated. The first part of the Table is due to Professor Smithels (whose work on flames is so well known), and the second part was published recently by Professor Féry, as the result of an ingenious, though not entirely unexceptionable, method of measurement, based upon the reversal of the D line of sodium vapour in a flame when viewed against an electric filament of known and alterable temperature. These figures will give an idea of the intensity of heat obtainable with gaseous fuel.

Maximum Temperature in Flame of Bunsen Burner using Coal Gas.

Date.		° C.
1860.	Bunsen and Kirchhoff,	2350
1877.	Rosetti,	1360
1892.	Rogers,	1230
1892.	Lewes,	1630
1895.	M'Crae,	1725
1896.	Waggener,	1770
1899.	Berkenbusch,	1830
1902.	White and Traver,	1780
1905.	Féry,	1871

Maximum Flame Temperatures (Féry, 1904).

	° C.	° F.
Bunsen burner, gas fully aërated,	1871	3400
Bunsen burner, insufficient air,	1112	3114
Acetylene flame,	2548	4618
Alcohol flame,	1705	3101
Denayrouze bunsen, alcohol and air,	1862	3384
Denayrouze bunsen, half each alcohol and petroleum spirit,	2053	3727
Hydrogen, free flame and air,	1900	3452
Oxy-coal gas blowpipe flame,	2200	3992
Oxy-hydrogen blowpipe flame,	2420	4388

Calorific Power of Various Fuels.

	Approximate Total Heat of Combustion of 1 lb. of Fuel.	Equivalent Evaporation of Water from and at 212° F. per lb. of Fuel.	Air Chemically Consumed per lb. of Fuel.	
	B. Th. Units.	lbs.	lbs.	Cubic Feet. @ 62° F.
Coal (average),	14,000	15¼	11	140
Coke,	13,500	14	11	142
Wood (dried),	11,000	11	4½	60
Peat (dried),	12,000	12	7½	100
Petroleum oils,	27,000	28	15	200

The figures given in the last two columns for the amount of air required are the minimum, and in practice twice or more times these amounts must be employed. Thus ordinary coal usually needs 18 to 25 lb. of air per lb. of coal in actual practice.

Seger Cones and Thermometer Scales.

Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.	Seger Cone.	Deg. Cent.	Deg. Fah.
022	590	1094	07	1010	1850	9	1310	2390	24	1610	2930
021	620	1148	06	1030	1886	10	1330	2426	25	1630	2966
020	650	1202	05	1050	1922	11	1350	2462	26	1650	3002
019	680	1256	04	1070	1958	12	1370	2498	27	1670	3038
018	710	1310	03	1090	1994	13	1390	2534	28	1690	3074
017	740	1364	02	1110	2030	14	1410	2570	29	1710	3110
016	770	1418	01	1130	2066	15	1430	2606	30	1730	3146
015	800	1472	1	1150	2102	16	1450	2642	31	1750	3182
014	830	1526	2	1170	2138	17	1470	2678	32	1770	3218
013	860	1580	3	1190	2174	18	1490	2714	33	1790	3250
012	890	1634	4	1210	2210	19	1510	2750	34	1810	3290
011	920	1688	5	1230	2246	20	1530	2786	35	1830	3326
010	950	1742	6	1250	2282	21	1550	2822	36	1850	3362
09	970	1778	7	1270	2318	22	1570	2858	37	1870	3398
08	990	1814	8	1290	2354	23	1590	2894	38	1890	3434
...	...	...	...	...	...	...	...	...	39	1910	3470

As Seger cones are 'heat-measurers' rather than 'thermometers,' it is not strictly correct to translate the numbers of the cones into 'degrees,' and it is far better to record simply the number of the cone which indicates the particular temperature to be recorded.

Seger Cones suitable for Various Classes of Goods.

The following particulars are taken from a list published some years ago by Messrs Seger & Cramer, and are useful for those who wish to fire a class of goods to which they are unaccustomed or who have not previously used Seger cones. It will be understood that the figures are only approximate.

For porcelain colours and lustres, use cones 022 to 010 inclusive.
For bricks and tiles of limey clay containing iron, use cones 015 to 01.

For bricks and tiles of clay free from lime and iron, ⎫ use cones
For clinker, footplates, and similar goods, ⎭ 1 to 10.
For stoneware and salt glaze, use cones 5 to 10.
For white stoneware (soft glaze), use cones 09 to 3.
For white stoneware (hard glaze), use cones 1 to 10.
For fireclay, cement, and porcelain, use cones 10 to 20.
For silica bricks, specially hard glazes, use cones 20 to 25.
For testing the refractoriness of clays, etc., use cones 26 to 39.

The approximate temperatures corresponding to these cones will be found above.

Wedgwood's Pyrometer, Seger's Cones, Colour Scale, and Degrees Cent.

Wedgwood Pyrometer.	Seger Cones.	Deg. Cent. (approx.).	Colours corresponding to Temperature (Pouillet, etc.).
0	022	580	
1	020	650	Earliest visible red.
2	018	710	
3	015	800	Dull red.
4	013	865	
5	010	940	Red.
6	07	1000	Cherry red.
7	04	1080	Orange.
8	1	1155	
9	5	1230	Bright orange or yellow.
10	9	1300	White.
11	12	1370	Steel melts about 1350° C.
12	16	1445	Dazzling white.
13	19	1515	
14	23	1590	Welding heat about 1540° C.
15	27	1670	
16	30	1735	
17	34	1810	
18	37	1880	
19	...	1950	Highest Seger cone (No. 39) = 1910° C.
20	...	2020	
21 to 30	...	...	These temperatures have never been accurately ascertained, though the original pyrometer of Wedgwood was arranged to indicate to this temperature.

It must be remembered in using the above Table that the figures given are at the best but rough approximations, as temperature is of less influence in causing the contraction of clay than the duration of exposure to heat. This latter property of clay is of more importance to the potter and clayworker, so that Wedgwood's pyrometer is of considerable use, although its indications may not be translatable into actual degrees on Fahrenheit's or the Centigrade scale.

Holdcroft's Thermoscopes.

Suitable for Various Classes of Goods, etc.

	Nos.
Enamel kilns,	1 to 13
Tiles and red bricks,	8 to 22
Majolica,	10 to 20
Fireclay goods,	23 to 32
Glost ovens,	14 to 30
Earthenware biscuit,	20 to 35
China biscuit,	25 to 40

The makers in giving the above figures state that, without placing too much reliance on the relation between the thermoscope number and the temperature it indicates, it may be assumed that thermoscope No. 13 = 1094° F.

„ 19 = 1763° F.
„ 23 = 2073° F.

At the same time, according to Messrs Holdcroft, "no accurate figures can be given for the melting points of the various strips."

In spite of this apparent difficulty these thermoscopes find a considerable sale in the Potteries. But see pages 302, 308.

Melting Points of Various Substances.

The following list of melting points is often useful for lower temperatures than are indicated by Cones, and in situations where a thermometer cannot be conveniently employed.

		° C.
Beeswax (yellow),	melts at	65
An alloy containing 3 parts of tin, 5 parts of lead, 8 parts of bismuth,	,,	100
Sulphur (though difficult to see),	,,	115
An alloy containing 8 parts of tin, 1 part of bismuth,	,,	200
An alloy containing 1 part of tin, 3 parts of lead,	,,	250
Zinc,	,,	425
Silver,	,,	1000

Various other alloys of tin, lead, and bismuth melt at temperatures varying from 93° to 295° C., but owing to the ease with which they become oxidized their indications are not really reliable.

TABLES RELATING TO MACHINERY.

Strength of Chains for Slings, Cranes, and Haulage.

Diam. of Chain.	Working Strain.		Weight per Yard.	Diam. of Chain.	Working Strain.		Weight per Yard.
Inches.	Tons.	Cwt.	lbs.	Inches.	Tons.	Cwt.	lbs.
$\frac{3}{16}$	0	5	$1\frac{1}{4}$	$1\frac{1}{8}$	7	18	40
$\frac{1}{4}$	0	8	2	$1\frac{1}{4}$	9	0	50
$\frac{5}{16}$	0	13	$3\frac{1}{4}$	$1\frac{1}{2}$	11	0	60
$\frac{3}{8}$	1	0	5	$1\frac{5}{8}$	15	6	70
$\frac{1}{2}$	1	8	7	$1\frac{3}{4}$	18	10	82
$\frac{5}{8}$	2	5	$10\frac{1}{4}$	$1\frac{7}{8}$	21	4	95
$\frac{3}{4}$	3	5	16	2	24	2	112
$\frac{7}{8}$	5	0	29	$2\frac{1}{16}$	27	2	120
1	6	8	30				

The above Table is obtained from actual tests, allowing an ample factor for safety. For intermediate sizes it is usually sufficient to consider the safe working strain as one-tenth of the square of the diameter of the chain, when the diameter is measured in eighths of an inch. Thus for a chain of 1 in. diam. $(=\frac{8}{8})$ one-tenth of the square of $8 = 6{\cdot}4$ tons $=$ 6 tons 8 cwts.

Strength of Common Ropes.—Multiply the square of the diameter by 8 and divide the product by 10; this will give the maximum safe working load in tons; thus with a rope $\frac{3}{4}$ in. diameter the safe working load is $\frac{3}{4} \times \frac{3}{4} \times \frac{8}{10} = 9$ cwt.

Horse Power Transmitted by Driving Ropes.—The power transmitted by ropes is highest (taking into effect centrifugal tension) at a speed of 4800 ft. per minute. At this speed Mr. C. N. Pickworth found the following data to be accurate :—

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

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

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

$$\text{H.P.} = \frac{W \times V}{746} \qquad W = \frac{746\ \text{H.P.}}{V}.$$

Thus a belt travelling 1000 ft. per minute and 7½ ins. wide will transmit $\frac{1000 \times 7\frac{1}{2}}{746} = 10$ H.P., or conversely a belt travelling 1000 ft. per minute to transmit 10 H.P. must be

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

Shafting.—The following tables from the *Mechanical World Diary* show somewhat lower transmission powers than many others which have been published, but they are not far from the truth, and err, if at all, on the side of under-estimation.

HORSE-POWER OF SHAFTING.

As Main Shafting, Carrying Driving Pulleys or Gears.

Diameter of Shaft in Inches.	Number of Revolutions per Minute.										
	60	80	100	125	150	175	200	225	250	275	300
1¾	2·6	3·4	4·3	5·4	6·4	7·5	8·6	9·7	10·7	11·8	12·9
2	3·8	5·1	6·4	8	9·6	11·2	12·8	14·4	16	17·6	19·2
2¼	5·4	7·3	8·1	10	12	14	16	18	20	22	24
2½	7·5	10	12·5	15	18	22	25	28	31	34	37
2¾	10	13	16	20	24	28	32	36	40	44	48
3	13	17	20	25	30	35	40	45	50	55	60
3¼	16	22	27	34	40	47	54	61	67	74	81
3½	20	27	34	42	51	59	68	76	85	93	102
3¾	25	33	42	52	63	73	84	94	105	115	126
4	30	41	51	64	76	89	102	115	127	140	153
4½	43	58	72	90	108	126	144	162	180	198	216
5	60	80	100	125	150	175	200	225	250	275	300
5½	80	106	133	166	199	233	266	299	333	366	400

As Second Motion or Line Shafting.

Bearings 8 feet apart.

Diameter of Shaft in Inches.	Number of Revolutions per Minute.										
	100	125	150	175	200	225	250	275	300	325	350
1¾	6	7·4	8·9	10·4	11·9	13·4	14·9	16·4	17·9	19·4	20·9
1⅞	7·3	9·1	10·9	12·7	14·5	16·3	18·2	20	21·8	23·6	25·4
2	8·9	11·1	13·3	15·5	17·7	20	22·2	24·4	26·6	28·8	31
2⅛	10·6	13·2	15·9	18·5	21·2	23·8	26·5	29·1	31·8	34·4	37
2¼	12·6	15·8	19	22	25	28	31	35	38	41	44
2⅜	15	18	22	26	29	33	37	41	44	48	52
2½	17	21	26	30	34	39	43	47	52	56	60
2¾	23	29	34	40	46	52	58	64	69	75	81
3	30	37	45	52	60	67	75	82	90	97	105
3¼	38	47	57	66	76	85	95	104	114	123	133
3½	47	59	71	83	95	107	119	131	143	155	167
3¾	58	73	88	102	117	132	146	162	176	190	205
4	71	89	107	125	142	160	178	196	213	231	249

For Simply Transmitting Power.

Diameter of Shaft in Inches.	Number of Revolutions per Minute.										
	100	125	150	175	200	233	267	300	333	367	400
1½	6·7	8·4	10·1	11·8	13·5	15·7	17·9	20·3	22·5	24·8	27
1⅝	8·6	10·7	12·8	15	17·1	20	22·8	25·8	28·6	31·5	34·3
1¾	10·7	13·4	16	18·7	21·5	25	28	32	36	39	43
1⅞	13·2	16·5	19·7	23	26·4	31	35	39	44	48	52
2	16	20	24	28	32	37	42	48	53	58	64
2⅛	19	24	29	33	38	44	51	57	63	70	76
2¼	22	28	34	39	45	52	60	68	75	83	90
2⅜	27	33	40	47	53	62	70	79	88	96	105
2½	31	39	47	54	62	73	83	93	104	114	125
2¾	41	52	62	73	83	97	111	125	139	153	167
3	54	67	81	94	108	126	144	162	180	198	216
3¼	68	86	103	120	137	160	182	205	228	250	273
3½	85	107	128	150	171	200	228	257	285	313	342

SPACING OF SHAFT BEARINGS.

Table I.—When carrying Own Weight only.

Diameter of Shaft.	in. 1	in. 1½	in. 2	in. 2½	in. 3	in. 3½	in. 4	in. 4½	in. 5	in. 5½	in. 6	in. 6½	in. 7	in. 8
Distance between Centres.	ft. in. 5 0	ft. in. 6 6	ft. in. 8 0	ft. in. 9 3	ft. in. 10 6	ft. in. 11 6	ft. in. 12 6	ft. in. 13 6	ft. in. 14 6	ft. in. 15 6	ft. in. 16 6	ft. in. 17 4	ft. in. 18 4	ft. in. 20 0

Table II.—When carrying Pulleys, etc.

Diameter of Shaft.	in. 1	in. 1½	in. 2	in. 2½	in. 3	in. 3½	in. 4	in. 4½	in. 5	in. 5½	in. 6	in. 6½	in. 7	in. 8
Distance between Centres.	ft. in. 4 8	ft. in. 6 3	ft. in. 7 6	ft. in. 8 9	ft. in. 10 0	ft. in. 11 0	ft. in. 12 0	ft. in. 13 0	ft. in. 14 0	ft. in. 15 0	ft. in. 15 9	ft. in. 16 9	ft. in. 17 6	ft. in. 19 0

RULES FOR THE SPEED OF SHAFTS, AND SIZE OF PULLEYS TO GIVE A DEFINITE SPEED.

1.—*To ascertain the Speed of a Machine.*

Multiply the revolutions per minute of shaft, whose speed is known, by the sum of the mulplication together of diameter in inches of all the *driving* pulleys, and divide by the sum of the multiplication of the diameter in inches of *driven* pulleys. Result is speed of machine.

EXAMPLE.—Engine 120 revolutions per minute, 30-in. driving pulley.

No. 1 Shaft, . .	12-in. driven pulley,	20-in. driving.
,, 2 ,, . .	15 ,, ,,	30 ,,
Machine, . .	6 ,, ,,	

$\frac{120\times30\times20\times30}{12\times15\times6}=\frac{2,160,000}{1080}=2000$ revolutions of the machine per minute.

2.—*To calculate Size of Pulleys required for a given Speed.*

Divide speed required by speed of nearest available shaft. Result is the diameter of pulley required to drive one of 1 ft.

If the pulley on machine is less or more than 1 ft., the driving pulley will be proportionately altered, *e.g.* if 6 ins. it will be half the number given.

If this gives too large a driving pulley, a countershaft or shafts may be interposed to reduce the size half or quarter, as convenient.

EXAMPLE.—Shaft, 90. Speed required 1600 with 3-in. pulley, $\frac{1600}{90}=17\frac{7}{9}$ (say 18), pulley on machine being 3 in. ($\frac{1}{4}$ of 1 ft.), driving pulley required $=\frac{18}{4}$ or 4½ ft.; if 4½ ft. be too large, reduce it by interposing a countershaft thus:—

36 ins. on 90 shaft to 18 ins. on counter = 180;
27 ins. on counter to 3 ins. on machine = 1620;
Or 36 ins. on 90 shaft to 12 ins. on counter = 270;
18 ins. on counter to 3 ins. on machine = 1620.

NOTE.—Take *accurately* the speed of the shaft from which the calculation is commenced, as a slight error there is enormously multiplied.

Fuel Consumption per H.P. Hour.

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

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

Force Required to Move a Weight.

Along a rough chiselled floor, .	Two-thirds of its weight.
Along a rough chiselled floor, using rollers, . . .	One-thirtieth ,,
Along a wooden floor, . .	Three-fifths ,,
,, using rollers,	One-fortieth ,,

Table for ascertaining Elevator Capacity.

The capacity of the buckets in cubic inches and the speed of the elevator (=number of buckets passing a given point per minute) being given, the following Table shows the number of cubic feet of material the elevator will deliver per hour :—

Capacity of Buckets. Cube Ins.	Number of Buckets per Minute.									
	60	70	80	90	100	125	150	175	225	275
10	20·8	24·3	27·8	31·2	34·7	43·4	52·1	60·8	78·1	95·5
15	31·2	36·4	41·7	46·9	52·1	65·1	78·1	91·1	117	143
25	52·1	60·8	69·4	78·1	86·8	108	130	152	195	239
35	72·9	85·1	97·2	109	121	152	182	213	273	334
45	93·7	109	125	141	156	195	234	273	351	430
60	125	146	167	187	208	260	312	365	469	573
75	156	182	208	234	260	325	391	456	586	716
100	208	243	278	312	347	434	521	608	781	955
125	260	304	347	390	434	542	651	759	976	1193
175	364	425	486	547	608	760	911	1063	1367	1671
225	469	547	625	703	781	976	1172	1367	1758	2147
275	573	668	764	859	955	1193	1432	1670	2142	2625
325	677	790	903	1015	1128	1410	1692	1975	2538	3102
375	781	911	1042	1172	1302	1627	1953	2279	2929	3580

Data for Pumps and Movement of Liquids.

1. Divide the gallons to be raised per minute by the speed of the piston in feet per minute, divide the answer by 34 and multiply the result by 1000, then take the square root in order to find the diameter of piston of pump required. It is usual to take a pump $1\frac{1}{4}$ times the diameter thus found in order to overcome the friction; thus, if a pump is required to deliver 100 gallons per minute with a piston speed of 90 ft. per minute. $\frac{100}{90} = 1{\cdot}111$. $\frac{1{\cdot}111}{34} \times 1000 = 32\frac{2}{3}$, and the sq. root of $32\frac{2}{3} = 5\frac{3}{4}$ ins.

2. Multiply the piston speed of the pump (in feet per minute) by 34 and divide by 1000, and multiply the result by the square of the diameter of the piston. This will give the delivery in gallons per minute. It is, however, advisable to multiply this figure by $\frac{3}{4}$ in order to allow for friction in working. For example, a pump with $5\frac{3}{4}$ ins. diameter and a piston speed of 90 ft. per minute may be expected to deliver $\frac{34VD^2}{1000} = \frac{34 \times 90}{1000} \times 5\frac{3}{4} \times 5\frac{3}{4} = 100$ gallons per minute, but in practice only $\frac{3}{4}$ of this volume, viz., 75 gallons, would be looked for.

Water and similar liquids flowing through pipes discharge $16{\cdot}3\sqrt{H} \times D^2$ gallons per minute when $H =$ head in feet and $D =$ orifice of the pipe in inches; but if the aperture is of considerable thickness or the pipe very short, the factor 13 must be substituted for 16·3 in the above formula.

For each right-angled bend in the pipe an additional Head of $\frac{002d^3V^2}{R^3}$ is necessary.

In this case $R =$ radius of bend in feet, and $d =$ bore of pipe in inches.

The following equivalents are often useful:—

1 Imperial gallon $= 277\frac{1}{4}$ cb. in.
$= \frac{1}{6}$ cb. ft. (roughly).
$= 10$ lbs.
Piping 1 in. inside diam. holds $\frac{1}{3}$ lb. of water for each foot length.
1 cb. ft. water $= 6\frac{1}{4}$ galls.
$= 62\frac{1}{3}$ lbs.
1 litre of water $= 0{\cdot}22$ gall.
$= 61$ cb. in.
$= 2\frac{1}{4}$ lbs. (nearly).
1 ton of water $= 224$ galls. $= 35\frac{3}{4}$ cb. ft.

TABLES RELATING TO DRYING.

Condensation of Steam in Pipes.

The following Table shows the number of B.T.U. lost per hour from each square foot of surface for each degree Fah. difference in temperature between the steam and the outside air :—

Thickness of Cover.	Covering.	Steam Pressure.			
		25 lbs.	50 lbs.	70 lbs.	100 lbs.
0	Uncovered, .	2·20	2·95	3·20	3·20
1·25 in.	Slag-wool, .	·52	·58	·62	·66
1·20	Hair and felt, .	·49	·59	·58	·58
·90	Felt, . .	·70	·76	·79	·79
1·5	Magnesia, .	·50	·56	·59	·60

The above results were obtained as the result of a large number of very careful experiments by W. N. Bolam and T. Grieve in the Fulton Engineering Laboratory, Edinburgh.

Vapour Pressure of Water (Proctor).

Temperature °C., .	–10	–5	0	5	10	15	20	25	30	35	40
,, °F., .	14	23	32	41	50	59	68	77	86	95	104
Pressure mm. .	2·2	3·2	4·6	6·5	9·1	12·7	17·4	23·5	31·5	41·9	54·9
Grammes per cb. m.,	2·4	3·4	4·9	6·8	9·3	12·8	17·2	22·8	30·1	39·2	57·0
Lbs. per cb. yd., .	·004	·006	·008	·012	·016	·022	·029	·039	·052	·067	·097

NOTE.—Grammes per cb. m. is practically equivalent to ounces per 1000 cb. ft.

The following particulars, calculated by A. E. Brown, show the weight of air required to drive off 1 lb. of water from goods when the air enters and leaves the dryer at the temperatures named, providing the air leaves the dryer saturated with moisture, a condition never attained in practice. This Table is chiefly of value in showing the much smaller quantities of air required when it enters the dryer at a higher temperature.

Temperature of Air entering Dryer.	Temperature leaving Dryer.	Weight of Air required.	Heat required to dry 1 lb. of Water in B.T.U.
72 °F.	52 °F.	227 lbs.	2156
98 ,,	62 ,,	125 ,,	1954
130 ,,	72 ,,	77 ,,	1788
170 ,,	82 ,,	50 ,,	1652
220 ,,	92 ,,	34 ,,	1537

In practice the actual heat required, as shown in the preceding Table, must be augmented by 50 to 100 per cent. to allow for the heating of the dryer walls, loss by radiation, and warming of the clay in the goods.

Grammes per cb. m. of moisture in air $= \frac{288P}{T}$, where P = pressure of water vapour and T = alsolute temperature of air (= temperature in ° Cent. + 273).

The pressure of the water vapour in the air is found from the following Table, used in conjunction with a 'wet and dry bulb thermometer' (hygrometer) (see p. 258).

WET AND DRY BULB HYGROMETER TABLE.

Pressure of Aqueous Vapour in Millimetres.

Dry Bulb Reading.	Excess in Temperature of Dry over Wet Bulb.						
	0° C.	1°	2°	4°	6°	8°	10°
0° C., ...	4·6	3·7	2·9	1·3	...	...	...
2, ...	5·3	4·4	3·4	1·9	...	...	...
4, ...	6·1	5·1	4·1	2·4	·8	...	...
6, ...	7·0	5·9	4·9	2·9	1·1	...	...
8, ...	8·0	6·9	5·8	3·7	1·7	...	...
10, ...	9·2	8·0	6·8	4·6	2·5	·5	...
12, ...	10·5	9·2	8·0	5·6	3·4	1·3	...
14, ...	11·9	10·6	9·2	6·7	4·4	2·2	...
16, ...	13·5	12·1	10·7	8·0	5·5	3·2	1·0
18, ...	15·4	13·8	12·3	9·5	6·8	4·3	2·0
20, ...	17·4	15·7	14·1	11·1	8·3	5·6	3·1

Thus to find the mass of moisture in 1 cb. m. of air when the dry bulb thermometer is at 16° C. and the wet bulb at 10° C., it is necessary, first of all, to find the vapour pressure from the above Table. As the difference between the wet and dry bulbs is 6° C., line 9 in the Table and Column 6 shows this to be 5·5 mm. Hence $\frac{288P}{T} = \frac{288 \times 5{\cdot}5}{16 + 273} = \frac{1584}{289} = 5{\cdot}5$ grammes per cb. m., or 5·5 oz. per 1000 cb. ft.

The following Table, by A. E. Brown, gives the weights and volumes of air at certain temperatures which will contain, when saturated, 1 lb. of water in the form of vapour :—

Temperature.	Weight of Air.	Volume of Mixture.
42	178·18 lbs.	2272 cubic feet.
52	122·17 ,,	1595 ,,
62	84·79 ,,	1135 ,,
72	59·54 ,,	819 ,,
82	42·35 ,,	600 ,,
102	21·98 ,,	333 ,,
132	8·49 ,,	151 ,,
182	1·402 ,,	48·7 ,,

The striking feature of the Table is the rapid decrease in the quantity of air necessary as the temperature of it increases.

Loss of Heat by Radiation.

This is a quantity which it is almost impossible to determine accurately in practice; several authorities have published figures showing the results of their experiments, but they do not agree well with one another. The following figures, calculated from Box's experiments and compared with others, appear a fair average :—

A 4½-in. brick wall loses ·45 B.T.U. per hour for each sq. ft. of surface, and for each deg. Fah. difference in temperature between the two sides of the wall. Similarly,

a 9-in. wall loses	·36 B.T.U.
13½-in. ,,	·28 ,,
18-in. ,,	·25 ,,
Window glass,	·75 ,,
Door of 1-in. board,	·47 ,,

Stone walls need only be half the thickness of brick ones to retain the same amount of heat within the walls.

The absolute loss by radiation from a wooden surface being reckoned as unity (=1), the following are the relative losses from other substances :—

Iron, . . .	291	Concrete, . . .	4
Lead, . . .	145	Sand or earth, . .	2½
Glass, . . .	8	Sawdust, . . .	1¼

Table Showing Relative Cost of Progressive Tunnel Dryers (A. E. Brown).

Name.	Bricks easily dried.			Moderately easy to dry.			Difficult to dry.		
	Cost in £.	Area in sq. yds.	Time taken in days.	Cost in £.	Area in sq. yds.	Time taken in days.	Cost in £.	Area in sq. yds.	Time taken in days.
Blackman, with slab heater, . . .	100	30	1	...	...	...	...	...	...
Blackman or Sutcliffe, with tubular steam heater, . . .	117	30	1	...	...	...	...	...	...
A.B.C. dryer, . .	150	30	1	...	...	...	...	...	...
Blackman 'improved,'	133	30	1	400	90	3	...	...	...
Wolff (without tempering chamber), . .	200	45	2	...	...	...	...	...	...
Wolff (with tempering chambers), . .	...	...	...	330	80	3	...	...	...
Bucyrus, . . .	117	25	1	290	63	2½	468	100	4
Möller and Pfeifer, .	278	53	⅔	417	80	1	625	120	1½
Brown, . . .	140	30	1	280	60	2	420	90	3

USEFUL RECIPES.

Cements.

A. For steam joints use a mixture of 100 parts of fine iron filings, 2 parts of salammoniac, and 10 parts of water. This mixture soon rusts, becomes very strong, and is proof against water and steam.

B. Fireproof cement may be made by mixing into a paste with vinegar 140 parts of iron filings, 20 parts hydraulic lime, 25 parts ground flint, and 3 parts of salammoniac. When the cement is perfectly solid the joint may be heated; this will cause it to set stone hard.

C. A handy solder for brass or bronze sieves or lawns is made by melting 2 parts of tin and 1 part of lead together, and casting into fine sticks. This alloy melts at about 300° F.

D. Cement for covering defects in the surface of glazed goods may be made by mixing a saturated solution of zinc chloride into a paste with dense zinc oxide. (The ordinary light oxide is useless.) This cement has an ivory colour; if pure white is required, Keene's or Parian cement should be employed. If properly worked, the above give a fairly glossy surface.

E. For cementing glass, boil together 1 part of caustic soda, 3 parts of rosin, 3 parts of gypsum, and 5 parts of water. This cement sets in thirty minutes, and must therefore be used quickly. During the boiling it must be stirred constantly, and all the solid materials must be in fine powder.

Typical Clays.

District.	Clay.	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Alkalies.	Water, etc.
Stourbridge,	Fire clay,	65	22	2	0·3	0·5	Traces	10
Leeds,	Fire clay,	60	29	2	...	...	...	9
Glasgow,	Fire clay,	50	30	1·5	0·4	0·5	1·5	16
Northumberland,	Fire clay,	60	28	2	1	0·2	1·8	7
Peterborough,	Red-burning,	62	14	11	2	...	2·0	8
Cambridgeshire,	Marl,	17	7	...	41	...	0·5	34
Medway,	Blue gault,	44	15	6	15	2	0·6	17
Warwickshire,	Blue lias,	38	15	4	18	3	0·5	22
Ruabon (Wales),	Red-burning,	63	20	6	...	...	5·4	5
Wareham (Devon),	Ball clay,	46	38	0·5	1·5	...	...	14
St. Austell,	China clay,	46	40	...	1	...	...	13

STANDARD BOOKS DEALING WITH CLAYWORKING.

In the following list only books dealing directly with some branch of clayworking are included. Allied subjects, as Book-keeping, Chemistry, Physics, Electricity, Steam and Mechanical Engineering, Building Construction, Geology, etc., are omitted, excepting where they treat specially of the clay industries. Many of the best books are, unfortunately, in French or German, but where English translations exist, these, and not the originals, are given.

In Column 6 the following abbreviations are employed:—

S. G. = Scott, Greenwood & Co., Ludgate Hill, London.
B. C. = Clayworker Press, Essex Street, Strand, London.
T. = Verlag der Tonindustriezeitung, Berlin.
W. = Wiley & Co., New York, or Williams & Norgate, London.

No.	Author.	Title.	Date.	Price.			Publisher.
				£	s.	d.	
1	Ansell, H.	Glazed Brick Manufacture	1898	0	7	6	B. C.
2	Ashby, H.	How to Analyse Clay	1898	0	2	6	S. G.
3	Auscher, E. S.	Technologie de la Céramique	1901	0	4	6	T.
4	,,	Les Industries Céramiques	1901	0	4	6	T.
5	Beck, A. J.	Ziegeleianlagen u. Fabrikation	1901	0	7	0	T.
6	Berling, Dr.	Meissner Porzellan (Geschichte)	...	8	8	0	T.
7	Binns, C. F.	Manual of Practical Potting	1901	0	17	6	S. G.
8	,,	Ceramic Technology	1897	0	12	6	S. G.
9	Bischoff, Prof.	Die feuerfesten Tone	1904	0	15	6	T.
10	,,	Gesammelte Analysen	1901	0	10	0	T.
11	Bock, O.	Ziegelei als landw. Gewerbe	1898	0	3	0	T.
12	,,	Ziegelfabrikation aller Arten	1901	0	14	6	T.
13	,,	Ziegeloefen Konstruktion	...	0	2	6	T.
14	Bolz, C. H.	Die Pyrometer	...	0	3	6	T.
15	Borrmann, R.	Moderne Keramik	1902	0	5	6	T.
16	Bourry, E.	Treatise on Ceramic Industries	1901	1	1	0	S. G.
17	Broemse, F.	Lehrbuch d. Tonwarenindustrie	1899	0	3	6	T.
18	,,	Ofen- u. Glasurfabrikation	1896	0	2	6	T.
19	Brongniart, A.	Colouring and Decoration of Ware	1898	0	7	6	S. G.
19A	Brown, A. E.	Brick-Drying	...	0	2	6	B. C.
19B	,,	Hand Brickmaking	...	0	2	6	B. C.
20	Buchholz, P.	Dachziegel Fabrikation	1899	0	3	0	T.
21	Christoph, J.	Der praktische Toepfer	1895	0	2	0	T.
22	Cramer, E.	Ueber feuerfeste Tone u. Quarzite	1901	0	1	3	T.
23	,,	Ueber das Ausschlages im Ofen	...	0	0	6	T.
24	Crouch, J. L.	Brick and Pottery Trades Journal	M'thly	0	5	0	29 Basinghall St., London, E.C.
				(per ann.)			
25	Deck, T.	La Faïence	1887	0	6	6	T.
26	Demmin, A.	Keramik-Studien : I. Fayence	1881	0	3	0	T.
		,, ,, II. Porzellan	1883	0	3	0	T.
		,, ,, III. Steinzeug	1885	0	3	0	T.
		,, ,, V. Terrakotten	1884	0	4	6	T.
26A	Dobson, E.	Bricks and Tiles	1903	0	3	6	Crosby Lockwood & Co.
27	Dubovszky, J.	Majolika-Malerei	...	0	1	3	T.
28	Dümmler, K.	Handbuch der Ziegelfabrikation	1900	2	4	0	T.
29	,,	Das Brennen der Ziegelsteine	1903	0	2	0	T.
30	D. V. Ton. ind.	Zur Frage der Herstellung von Ziegeln grossen Formats	1902	0	0	6	T.
31	Eckhart, A.	Bei Anlage periodischer Ziegelöfen	1883	0	2	0	T.
32	,,	Technik des Verblendsteins (2 vols.)	1884	0	2	0	T.
				(each)			
33	Fairie, J.	Notes on Pottery Clays	1901	0	4	6	S. G.
34	Furnival, W. J.	Leadless Glazes for Tiles and Faience	1904	6	6	0	W. J. Furnival, Stone, Staffs.
35	Graesse-Jaennicke	Guide de l'amateur de Porcelaines	1901	0	9	0	T.

No.	Author.	Title.	Date.	Price.			Publisher.
				£	s.	d.	
36	Griffen, H. R.	Clay Glazes and Enamels	1896	1	1	0	W.
37	Hausbrand, E.	Trocknen mit Luft und Dampf	1903	0	4	6	T.
38	Hecht, Dr.	Untersuchungen über Porzellan	...	0	2	0	T.
39	,,	Ueber verschiedene Chamottesteine	1900	0	0	6	T.
40	,,	Rohstoffe der Tonindustrie	1900	0	0	6	T.
41	Hegemann, H.	Herstellung des Porzellans	...	0	5	0	T.
42	Heinecke, Dr.	Neuere Brennöfen der k. Porzellan-Manufaktur zu Charlottenburg	...	0	1	3	T.
43	Hermann, F.	Glass, Porcelain and Enamel Painting	1897	0	10	6	S. G.
44	Heusinger, E.	Ziegel und Rohrenbrennerei	1901	1	5	0	T.
45	Hillebrand, Dr.	Analysis of Silica-earths	1898	0	2	0	W.
46	Hölzgen, F.	Herstellung holländisch Dachziegel	...	0	1	3	T.
47	Jackson, W.	Ceramic Calculations	1904	0	3	6	Longmans.
48	Jaennicke, F.	Geschichte der Keramik	1900	0	11	0	T.
49	,,	Grundriss der (Kunst) Keramik	1880	2	15	0	T.
50	,,	Marken auf Fayence, etc.	...	0	9	6	T.
51	Jochum, Dr.	Chemische Analyse als Massstab der Feuerbeständigkeit	...	0	2	0	T.
52	,,	Grenzen der Feuerbeständigkeit	...	0	2	0	T.
53	Kerl, Prof.	Handbuch der gesam. Tonindustrie	New edition shortly				T.
54	Kissling, J.	Photokeramik	1893	0	2	6	T.
55	Klassen, L.	Fabrikanlagen	1896	0	6	6	T.
56	,,	Kontroll-Apparate für Ziegeleien	...	0	1	3	T.
57	Krüger, J.	Photokeramik	1893	0	3	0	T.
58	Lang, Prof.	Schornsteinbau (3 vols.)	1901	1	0	0	T.
59	Lange, G.	Ofen-fabrikation bes. für Emaille	...	0	1	3	T.
60	Langenbeck, C.	Chemistry of Pottery	1895	0	8	4	W.
61	Le Chatelier	Mésure des températures élevées	1900	0	4	6	T.
62	Lefévre, L.	Architectural Pottery	1900	0	15	0	S. G.
63	Liebold, B.	Kontinuierlichen Brennöfen	...	0	13	0	T.
64	,,	Trockenanlagen	1877	0	6	6	T.
65	Loeser, C.	Handbucher für Studierende (2 vols.)	...	0	11	0	C. Loeser, Halle a S.
66	Mäckler, Dr.	Ausblühungen	...	0	0	6	T.
67	Mayr, M.	Die keramische Malerei	1901	0	2	0	T.
68	,,	Formen und Modellieren	1900	0	1	0	T.
69	,,	Technische Zeichnen	1903	0	2	0	T.
70	Mendheim	Brennöfen mit Gasfeuerung	1893	0	1	3	T.
71	Mercator, G.	Photokeramik und Imitationen	1900	0	3	6	T.
72	Merrill, G. P.	Non-metallic Minerals	...	1	0	0	T.
73	Michel	Ueber die keramischen Verblendstoffe	...	0	3	0	T.

No.	Author.	Title.	Date.	Price.			Publisher.
				£	s.	d.	
74	Montgomery, H. G.	British Clayworker	M'thly	0	6	0 (per ann.)	B. C.
75	Müller, Dr.	Fabrikation der Farben	1880	0	4	0	T.
76	...	Pottery Gazette	M'thly	0	7	6 (per ann.)	S. G.
77	...	Prüfung von Ziegeltonen	...	0	0	6	T.
78	Quaglio, J.	Feuerfeste Materialen	1886	0	1	3	T.
79	Randau, P.	Fabrikation der Emaille	1900	0	3	3	T.
80	Richters, Dr.	Untersuchungen ueber Feuerbest.	1897	0	2	3	T.
81	Rischer, A.	Das Glazieren der Ziegel	...	0	2	0	T.
82	Rösler, M.	Keramische Tagesfragen	1888	0	2	0	T.
83	Romanoff	Behandlung der Schmelzfarben	1887	0	1	3	T.
84	Salvetat	See Brongniart.					
85	Sandemann, E.	Manufacture of Earthenware	1901	0	7	6	Virtue & Co.
86	Schamberger, J.	Keramische Praxis	1901	0	5	0	T.
87	Schlesinger, J.	Bau der Ziegel Brennöfen	1866	0	4	6	T.
88	Schmatolla, E.	Gaserzeuger und Gasfeuerungen	...	0	3	6	Dr. Max Jaennacke, Hannover.
89	,,	Rauchplage u. Brennstoffverschwendung	1902	0	3	6	,,
90	,,	Was muss man von Feuerungstechnik wissen?	1901	0	2	3	,,
91	,,	Die Brennöfen	1903	0	5	0	,,
92	Schom, Dr.	Kunsterzeugnisse aus Ton	1887	0	1	3	,,
93	Schumacher, Dr.	Die Keramischen Tonfabrikate	1884	0	11	0	T.
94	Seger, Dr. H.	Collected Writings	1903	3	4	0	W.
95	Shaw, S.	History of Staffs. Pottery (re-issue of	1829)	0	7	6	S. G.
96	,,	Chemistry of Pottery Materials (re-issue of	1837)	0	14	0	S. G.
97	Steinbrecht, G.	Steingutfabrikation	1891	0	4	6	T.
98	Stoermer, Dr.	Untersuchungsmethoden	1902	0	6	6	T.
99	Strele, C.	Fabrikation des mit starkfeuerfarben dekorierten Feldspat-Porzellans	1868	0	8	6	T.
100	,,	Handbuch der Porzellan-Malerei	1883	0	7	6	T.
101	Swoboda, C. B.	Farben zur Dekoration von Majolika	1891	0	3	6	T.
102	,,	Grundriss der Tonwaren Industrie	1894	0	3	6	T.
103	Tenax, B.	Steingut- und Porzellan Fabrikation	1879	0	7	6	T.
104	Toldt, F.	Ueber künstlichen Zug	...	0	2	3	T.
105	Cramer, etc.	Tonindustrie Zeitung	Tri-weekly	1	0	0 (per ann.)	T.
106	Uhlenhuth, E.	Formen und Giessen	1899	0	2	2	T.
107	Ulke, R.	Katechismus der Porzellan Malerei	1894	0	3	3	T.

No.	Author.	Title.	Date.	Price.			Publisher.
				£	s.	d.	
108	Vogt, G.	La Porcelaine	1893	0	7	0	T
109	Vogt, J.	Die Silikatschmelzlösungen	1903	0	7	0	T.
110	Wheeler, H. A.	Vitrified Paving Brick	...	0	5	0	W.
111	Winkler	Lehrbuch der tech. Gasanalyse	1901	0	8	6	T.
112	Wipplinger, L.	Keramik	1897	0	5	0	T.
113	Zschokke, B.	Untersuch. über Plasticität	...	0	5	0	T.
114	,,	Untersuch. zur tech. Analyse der Ton	...	0	1	6	T.
115	Zwick.	Natur der Ziegeltone und Fabrikn.	1894	0	8	6	T.
116	...	La Céramique	M'thly		...		W.
117	Pickworth, C. H.	Indicator Diagram	...	0	3	0	Emmott, Manchester.
118	Brown, A. E.	Hand Brickmaking	...	0	2	6	B. C.

STANDARD BOOKS ON CLAYWORKING.

Arranged according to Subjects.

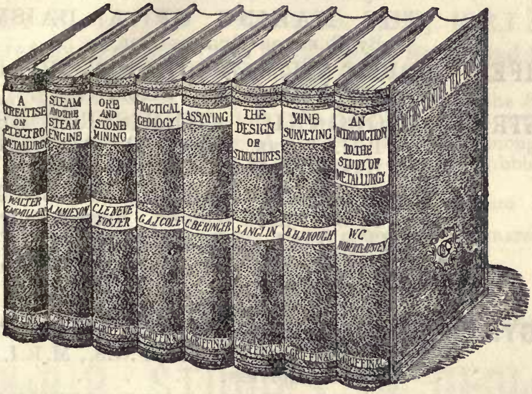
The numbers refer to those in first column of previous List.

Analysis (see 'Tests'), 2, 10, 45, 51, 52, 111, 114.
Bricks, Manufacture of (see 'Manufacture'), 1, 5, 12, 19B, 26A, 28, 30, 81, 118.
Calculations, 47.
Chemistry, 60, 96.
Chimney (see under 'Kilns'), 58.
Clays and Clayworking generally (see 'Manufacture'), 3, 7, 8, 9, 11, 15, 16, 17, 21, 22, 32, 33, 39, 40, 48, 53, 65, 72, 73, 74, 78, 82, 94, 95, 109, 112, 113, 115.
Colours (see 'Painting'), 75, 83, 101.
Drying, 19A, 37, 64.
Firing (see also 'Manufacture'), 14, 29, 44, 89, 90, 104.
Forming and Modelling, 68, 69, 106.
Glazes (see also 'Painting'), 1, 19, 34, 36, 47, 79, 81.
Kilns, 13, 18, 31, 55, 58, 59, 63, 70, 87, 88, 89, 91.
Magazines and Journals (many issued to members only are omitted), 24, 74, 76, 105, 116.
Majolica and Fayence, 25, 26, 50, 101.
Manufacture, 1, 3, 4, 5, 7, 8, 16, 20, 26A, 46, 49, 53, 62, 81, 85, 86, 93, 99, 102, 103, 110, 115.
Painting, 19, 27, 43, 54, 57, 67, 71, 92, 100, 107.
Pipes (see also 'Manufacture), 44.
Porcelain, 6, 26, 35, 38, 41, 42, 99, 103, 108.
Scum, 23, 66.
Stoneware (see also 'Manufacture' and 'Clays'), 26, 97, 103
Terracotta (see also 'Manufacture'), 26.
Tests, 14, 56, 61, 77, 80, 98, 117.
Tiles (see 'Manufacture'), 26A.

INDEX.

PRINTED BY NEILL AND CO., LTD., EDINBURGH.

A SELECTION FROM
CHARLES GRIFFIN & CO.'S PUBLICATIONS
OF
SCIENTIFIC AND TECHNICAL WORKS.



MESSRS. CHARLES GRIFFIN & COMPANY'S PUBLICATIONS may be obtained through any Bookseller in the United Kingdom, or will be sent on receipt of a remittance to cover published price and postage. To prevent delay, Orders should be accompanied by a Cheque or Postal Order crossed "UNION OF LONDON AND SMITH'S BANK, Chancery Lane Branch."

☞ **COMPLETE TECHNICAL, MEDICAL, and GENERAL CATALOGUES forwarded Post-free on Application.**

LONDON:
EXETER STREET, STRAND.

1/11/08.
C. 32.

GRIFFIN'S INTRODUCTORY SCIENCE SERIES.

FULLY ILLUSTRATED.

BOTANY.	OPEN-AIR STUDIES IN BOTANY. By R. Lloyd Praeger, B.A., M.R.I.A.,	7/6
	THE FLOWERING PLANT. By Prof. Ainsworth Davis. Third Edition,	3/6
	HOW PLANTS LIVE AND WORK. By Eleanor Hughes-Gibb,	2/6
	THE MAKING OF A DAISY. By Eleanor Hughes-Gibb,	2/6
BIRD-LIFE.	OPEN-AIR STUDIES IN BIRD-LIFE. By Charles Dixon,	7/6
CHEMISTRY.	INORGANIC CHEMISTRY. By Prof. Dupré, F.R.S., and Dr. Wilson Hake. Third Edition, Re-issued,	6/ net.
	THE THRESHOLD OF SCIENCE. By Dr. Alder Wright. Second Edition,	6/
	CHEMICAL RECREATIONS. By J. J. Griffin, F.C.S. Tenth Edition, Complete, (Or in 2 parts, sold separately.)	12/6
GEOLOGY.	OPEN-AIR STUDIES IN GEOLOGY. By Prof. G. A. J. Cole, F.G.S., M.R.I.A. Second Edition,	8/6
ENGINEERING DRAWING.	I. PRACTICAL GEOMETRY, Fifth Edition,	4/6
	II. MACHINE DESIGN, Fifth Ed. By S. H. Wells, A.M.Inst.C.E.	4/6
MAGNETISM & ELECTRICITY.	By Prof. Jamieson, late of the Glasgow and West of Scotland Technical College. Seventh Edition,	3/6
MECHANICS.	By Prof. Jamieson. Eighth Edition,	3/6
MECHANICAL ENGINEERING.	By R. S. M‘Laren,	5/ net.
THE STEAM ENGINE.	By Prof. Jamieson. Twelfth Edition,	3/6
METALLURGY.	By Prof. Humboldt Sexton, Glasgow and West of Scotland Technical College. Fourth Edition, Revised,	6/
PHYSICS.	A TEXT-BOOK OF PHYSICS: By J. H. Poynting, Sc.D., F.R.S., and J. J. Thomson, M.A., F.R.S.	
	Vol. I.—Properties of Matter. Fourth Edition,	10/6
	Vol. II.—Sound. Fifth Edition,	8/6
	Vol. III.—Heat. Third Edition,	15/
PHOTOGRAPHY.	By A. Brothers. Second Edition,	21/

LONDON: CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

"**Boys could not have a more alluring introduction** to scientific pursuits than these charming-looking volumes."—Letter to the Publishers from the Head-master of one of our great Public Schools.

Handsome Cloth, 7s. 6d. Gilt, for Presentation, 8s. 6d.

OPEN-AIR STUDIES IN BOTANY:

SKETCHES OF BRITISH WILD FLOWERS IN THEIR HOMES.

By R. LLOYD PRAEGER, B.A., M.R.I.A.

Illustrated by Drawings from Nature by S. Rosamond Praeger, and Photographs by R. Welch.

General Contents.—A Daisy-Starred Pasture—Under the Hawthorns—By the River—Along the Shingle—A Fragrant Hedgerow—A Connemara Bog—Where the Samphire grows—A Flowery Meadow—Among the Corn (a Study in Weeds)—In the Home of the Alpines—A City Rubbish-Heap—Glossary.

"**A fresh and stimulating** book . . . should take a high place . . . The Illustrations are drawn with much skill."—*The Times.*

"**Beautifully illustrated.** . . . One of the **most accurate** as well as **interesting** books of the kind we have seen."—*Athenæum.*

"Redolent with the scent of woodland and meadow."—*The Standard.*

With 12 Full-Page Illustrations from Photographs. Cloth. Second Edition, Revised. 8s. 6d.

OPEN-AIR STUDIES IN GEOLOGY:

An Introduction to Geology Out-of-doors.

By GRENVILLE A. J. COLE, F.G.S., M.R.I.A.,
Professor of Geology in the Royal College of Science for Ireland, and Examiner in the University of London.

General Contents.—The Materials of the Earth—A Mountain Hollow—Down the Valley—Along the Shore—Across the Plains—Dead Volcanoes—A Granite Highland—The Annals of the Earth—The Surrey Hills—The Folds of the Mountains.

"The **fascinating** 'Open-Air Studies' of Prof. Cole give the subject a **glow of animation** . . . cannot fail to arouse keen interest in geology."—*Geological Magazine.*

"**A charming book**, beautifully illustrated"—*Athenæum.*

Beautifully Illustrated. With a Frontispiece in Colours, and Numerous Specially Drawn Plates by Charles Whymper. 7s. 6d.

OPEN-AIR STUDIES IN BIRD-LIFE:

SKETCHES OF BRITISH BIRDS IN THEIR HAUNTS.

By CHARLES DIXON.

The Spacious Air.—The Open Fields and Downs.—In the Hedgerows.—On Open Heath and Moor.—On the Mountains.—Amongst the Evergreens.—Copse and Woodland.—By Stream and Pool.—The Sandy Wastes and Mud-flats.—Sea-laved Rocks.—Birds of the Cities.—Index.

"Enriched with excellent illustrations. A welcome addition to all libraries."—*Westminster Review.*

THIRD EDITION, Revised and Enlarged. Large Crown 8vo, with numerous Illustrations. 3s. 6d.

THE FLOWERING PLANT,

WITH A SUPPLEMENTARY CHAPTER ON FERNS AND MOSSES, As Illustrating the First Principles of Botany.

BY J. R. AINSWORTH DAVIS, M.A., F.Z.S.,

Prof. of Biology, University College, Aberystwyth; Examiner in Zoology, University of Aberdeen.

"It would be hard to find a Text-book which would better guide the student to an accurate knowledge of modern discoveries in Botany. . . . The SCIENTIFIC ACCURACY of statement, and the concise exposition of FIRST PRINCIPLES make it valuable for educational purposes. In the chapter on the Physiology of Flowers, an *admirable résumé*, drawn from Darwin, Hermann Müller, Kerner, and Lubbock, of what is known of the Fertilization of Flowers, is given."-*Journal of Botany.*

POPULAR WORKS ON BOTANY BY MRS. HUGHES-GIBB.

With Illustrations. Crown 8vo. Cloth. 2s. 6d

HOW PLANTS LIVE AND WORK:

A Simple Introduction to Real Life in the Plant-world, Based on Lessons originally given to Country Children.

BY ELEANOR HUGHES-GIBB.

⁂ The attention of all interested in the Scientific Training of the Young is requested to this DELIGHTFULLY FRESH and CHARMING LITTLE BOOK. It ought to be in the hands of every Mother and Teacher throughout the land.

"The child's attention is first secured, and then, in language SIMPLE, YET SCIENTIFICALLY ACCURATE, the first lessons in plant-life are set before it."—*Natural Science.*

"In every way well calculated to make the study of Botany ATTRACTIVE to the young."—*otsman*

With Illustrations. Crown 8vo. Gilt, 2s. 6d.

THE MAKING OF A DAISY; "WHEAT OUT OF LILIES;"

And other Studies from the Plant World.

A Popular Introduction to Botany.

BY ELEANOR HUGHES-GIBB,

Author of *How Plants Live and Work.*

"A BRIGHT little introduction to the study of Flowers."—*Journal of Botany.*

"The book will afford real assistance to those who can derive pleasure from the study of Nature in the open. . . . The literary style is commendable."—*Knowledge.*

GRIFFIN'S STANDARD PUBLICATIONS.

		PAGE
Applied Mechanics.	RANKINE, BROWNE, JAMIESON,	35, 46, 34
Civil Engineering,	PROF. RANKINE,	35
Design of Structures,	S. ANGLIN,	26
Bridge-Construction,	PROF. FIDLER,	26
Design of Beams,	W. H. ATHERTON,	26
Constructional Steelwork,	A. W. FARNSWORTH,	26
Dock and Harbour Engineering,	B. CUNNINGHAM,	27
Engineering Drawing,	S. H. WELLS,	32
Engine Design,	L. HOBBS,	27
Central Electrical Stations,	C. H. WORDINGHAM,	48
Electricity Control,	L. ANDREWS,	48
,, Meters,	H. G. SOLOMON,	48
Transformers,	H. BOHLE,	48
Telegraphic Systems,	A. CROTCH,	49
Light Railways,	W. H. COLE,	30
Sanitary Engineering,	F. WOOD,	78
Locomotive Engineering,	W. F. PETTIGREW,	30
Locomotive Compounding,	J. F. GAIRNS,	30
Marine Engineering,	A. E. SEATON,	44
The Screw Propeller,	A E. SEATON,	44
The Steam Turbine,	ALEXANDER JUDE,	28
Marine Steam Turbine,	PROF. BILES,	28
Engine-Room Practice,	J. G. LIVERSIDGE,	29
Pocket-Book,	SEATON AND ROUNTHWAITE,	44
Present Day Shipbuilding,	T. WALTON,	38
Design of Ships,	PROF. HAVARD BILES,	37
Steel Vessels,	T. WALTON,	38
Stability of Ships,	SIR E. J. REED,	37
The Steam Engine,	JAMIESON, RANKINE,	34, 35
Valves and Valve-Gearing,	CHAS. HURST,	29
Gas, Oil, and Air Engines,	BRYAN DONKIN,	28
Petrol Motors and Cars,	F. STRICKLAND,	33
Suction Gas Plants,	Prof. C. A. SMITH,	28
The Problem of Flight.	H. CHATLEY,	27
Mechanical Eng. for Beginners,	R. S. M'LAREN,	33
Boilers: Land and Marine,	T. W. TRAILL,	29
,, "Steam" and "Kitchen,"	R. D. MUNRO,	32
,, Heat Efficiency of,	BRYAN DONKIN,	28
Oil Fuel,	SIDNEY H. NORTH,	61
Pumping Machinery,	H. DAVEY,	36
Hydraulic Machinery,	PROF. ROBINSON,	36
Grinding Machinery,	R. B. HODGSON,	32
Lubrication and Lubricants,	ARCHBUTT AND DEELEY,	32
Rules and Tables,	RANKINE AND JAMIESON,	35
Practical Calculations,	C. LARARD AND H. GOLDING,	31
Bonus Tables,	H. A. GOLDING,	31
Electrical Pocket-Book,	MUNRO AND JAMIESON,	49
The Calculus for Engineers,	PROF. ROBT. H. SMITH,	45
Measurement Conversions,	PROF. ROBT. H. SMITH,	45
Traverse Tables,	R. L. GURDEN,	31

FOURTH EDITION, *Revised, with Numerous Diagrams, Examples, and Tables, and a Chapter on Foundations. In Large 8vo. Cloth.* 16s.

THE DESIGN OF STRUCTURES:

A Practical Treatise on the Building of Bridges, Roofs, &c.

BY S. ANGLIN, C.E.,

Master of Engineering, Royal University of Ireland, late Whitworth Scholar, &c.

"We can unhesitatingly recommend this work not only to the Student, as the BEST TEXT-BOOK on the subject, but also to the professional engineer as an EXCEEDINGLY VALUABLE book of reference."—*Mechanical World.*

In Large Crown 8vo. Handsome Cloth. With 201 Illustrations. 6s. net.

AN INTRODUCTION TO

THE DESIGN OF BEAMS, GIRDERS, AND COLUMNS

IN MACHINES AND STRUCTURES.

With Examples in Graphic Statics.

BY WILLIAM H. ATHERTON, M.Sc., M.I.MECH.E.

"A very useful source of information. . . . A work which we commend very highly."—*Nature.*

FOURTH EDITION, *Thoroughly Revised. Royal 8vo. With numerous Illustrations and* 13 *Lithographic Plates. Handsome Cloth.*

A PRACTICAL TREATISE ON

BRIDGE-CONSTRUCTION:

Being a Text-Book on the Construction of Bridges in Iron and Steel.

FOR THE USE OF STUDENTS, DRAUGHTSMEN, AND ENGINEERS.

BY T. CLAXTON FIDLER, M. INST. C.E.,

Prof. of Engineering, University College, Dundee.

"The new edition of Mr. Fidler's work will again occupy the same CONSPICUOUS POSITION among professional text-books and treatises as has been accorded to its predecessors. SOUND, SIMPLE, AND FULL."—*The Engineer.*

In Medium 8vo. Pp. i-xv + 248, *fully Illustrated. Price* 10s. 6*d. net.*

CONSTRUCTIONAL STEELWORK:

Being Notes on the Practical Aspect and the Principles of Design, together with an Account of the Present Methods and Tools of Manufacture.

BY A. W. FARNSWORTH,

Associate Member of the Institute of Mechanical Engineers.

"A worthy volume, which will be found of much assistance. . . . A book of particular value."—*Practical Engineer.*

In Large 8vo. Handsome Cloth, Gilt, Uniform with *Stability of Ships* and *Steel Ships* (pp. 37, 38). With 34 Folding Plates and 468 Illustrations in the Text. 30s. net.

The Principles and Practice of DOCK ENGINEERING.

By BRYSSON CUNNINGHAM.

GENERAL CONTENTS.

Historical and Discursive.—Dock Design.—Constructive Appliances.—Materials.—Dock and Quay Walls.—Entrance Passages and Locks.—Jetties, Wharves, and Piers.—Dock Gates and Caissons.—Transit Sheds and Warehouses.—Dock Bridges.—Graving and Repairing Docks.—Working Equipment of Docks.—Index.

"We have never seen a more profusely-illustrated treatise. It is a most important standard work, and should be in the hands of all dock and harbour engineers."—*Steamship.*

"Will be of the greatest service to the expert as a book of reference."—*Engineer.*

In Large 8vo. With Folding Plates and Numerous Illustrations. 16s. net.

A COMPANION VOLUME TO "DOCK ENGINEERING."

THE PRINCIPLES AND PRACTICE OF HARBOUR ENGINEERING.

By BRYSSON CUNNINGHAM.

Contents.—Introductory.—Harbour Design.—Surveying, Marine and Submarine.—Piling.—Stone, Natural and Artificial.—Breakwater Design.—Breakwater Construction.—Pierheads, Quays, and Landing Stages.—Entrance Channels.—Channel Demarcation.—Index.

"The best and most complete book we have seen on the subject."—*Steamship.*

"This is a standard work . . . sure to prove a valuable book of reference."—*Shipping World.*

In Large Crown 8vo. Handsome Cloth. 4s. 6d. net.

THE THERMO-DYNAMIC PRINCIPLES OF ENGINE DESIGN.

By LIONEL M. HOBBS,

Engineer-Lieutenant, R.N.; Instructor in Applied Mechanics and Marine Engine Design at the Royal Naval College, Greenwich.

"Serves its purpose admirably . . . should prove of invaluable service . . . well up-to-date."—*Shipping World.*

In Large 8vo. Cloth. Fully Illustrated. 10s. 6d. net.

THE PROBLEM OF FLIGHT.

By HERBERT CHATLEY, B.Sc. (Eng.), London,

Lecturer in Applied Mechanics, Portsmouth Technical Institute.

Contents.—The Problem of Flight.—The Helix.—The Aëroplane.—The Aviplane.—Dirigible Balloons.—Form and Fittings of the Airship.—Appendices (*The Possibility of Flight, Weight, A Flexible Wing, Theory of Balance, Bibliography*).—Index.

"An epitome of the knowledge available on the subject."—*Scotsman.*

In Handsome Cloth. With 252 Illustrations. 15s. net.

THE THEORY OF THE STEAM TURBINE.

A Treatise on the Principles of Construction of the Steam Turbine, with Historical Notes on its Development.

By ALEXANDER JUDE.

Contents.—Fundamental.—Historical Notes on Turbines.—The Velocity of Steam.—Types of Steam Turbines.—Practical Turbines.—The Efficiency of Turbines, Type I.—Trajectory of the Steam.—Efficiency of Turbines, Types II., III. and IV.—Turbine Vanes.—Disc and Vane Friction in Turbines.—Specific Heat of Superheated Steam.—Strength of Rotating Discs.—Governing Steam Turbines.—Steam Consumption of Turbines.—The Whirling of Shafts.—Speed of Turbines.—Index.

"One of the latest text-books . . . also one of the best . . . there is absolutely no padding."—*Sir William White* in the *Times* Engineering Supplement.

In Large Crown 8vo. Handsome Cloth. With 131 Illustrations. 6s. net.

LECTURES ON THE MARINE STEAM TURBINE.

By Prof. J. HARVARD BILES, M.Inst.N.A.,

Professor of Naval Architecture in the University of Glasgow.

"This is the best popular work on the marine steam turbine which has yet appeared."—*Steamship.*

Works by BRYAN DONKIN, M.Inst.C.E., M.Inst.Mech.E., &c.

Fourth Edition, Revised and Enlarged. With additional Illustrations.
Large 8vo, Handsome Cloth. 25s. net.

A TEXT-BOOK ON

GAS, OIL, AND AIR ENGINES.

By BRYAN DONKIN, M.Inst.C.E., M.Inst.Mech.E.

"The best book now published on Gas, Oil, and Air Engines."—*Engineer.*

In Quarto, Handsome Cloth. With Numerous Plates. 25s.

THE HEAT EFFICIENCY OF STEAM BOILERS

(LAND, MARINE, AND LOCOMOTIVE).

By BRYAN DONKIN, M.Inst.C.E.

General Contents.—Classification of Different Types of Boilers.—425 Experiments on English and Foreign Boilers with their Heat Efficiencies shown in Fifty Tables.—Fire Grates of Various Types.—Mechanical Stokers.—Combustion of Fuel in Boilers.—Transmission of Heat through Boiler Plates, and their Temperature.—Feed Water Heaters, Superheaters, Feed Pumps, &c.—Smoke and its Prevention.—Instruments used in Testing Boilers.—Marine and Locomotive Boilers.—Fuel Testing Stations.—Discussion of the Trials and Conclusions.—On the Choice of a Boiler, and Testing of Land, Marine, and Locomotive Boilers.—Appendices.—Bibliography.—Index.

"Probably the most exhaustive *resumé* that has ever been collected. A practical Book by a thoroughly practical man."—*Iron and Coal Trades Review.*

In Large Crown 8vo. Cloth. Fully Illustrated.

SUCTION GAS PLANTS.

By Prof. C. A. SMITH, of the East London Technical College.

Contents.—Introduction.—Details of Construction.—Fuel and Testing.—Application and Uses of Suction Plants.—Working the Plant.—Typical Plants.—Plants for Special Purposes.—Total H.P.—Cost of Gas Production.—The Gas Engine.—Appendices.—Index.

Fourth Edition, Revised. Pocket-Size, Leather, 12s. 6d.

BOILERS, MARINE AND LAND:

THEIR CONSTRUCTION AND STRENGTH.

A Handbook of Rules, Formulæ, Tables, &c., relative to Materials, Scantlings, and Pressures, Safety Valves, Springs, Fittings and Mountings, &c.

FOR THE USE OF ENGINEERS, SURVEYORS, BOILER-MAKERS, AND STEAM USERS.

By T. W. TRAILL, M. Inst. C. E., F. E. R. N.,

Late Engineer Surveyor-in-Chief to the Board of Trade.

"Contains an Enormous Quantity of Information arrranged in a very convenient form. . . A most useful volume . . . supplying information to be had nowhere else."—*The Engineer.*

Sixth Edition, Revised. Large Crown 8vo. With numerous Illustrations. 6s. net.

ENGINE-ROOM PRACTICE:

A Handbook for Engineers and Officers in the Royal Navy and Mercantile Marine, including the Management of the Main and Auxiliary Engines on Board Ship.

By JOHN G. LIVERSIDGE, R.N., A.M.I.C.E.

Contents.—General Description of Marine Machinery.—The Conditions of Service and Duties of Engineers of the Royal Navy.—Entry and Conditions of Service of Engineers of the Leading S.S. Companies.—Raising Steam —Duties of a Steaming Watch on Engines and Boilers.—Shutting off Steam.—Harbour Duties and Watches.—Adjustments and Repairs of Engines.—Preservation and Repairs of "Tank" Boilers.—The Hull and its Fittings.—Cleaning and Painting Machinery.—Reciprocating Pumps, Feed Heaters, and Automatic Feed-Water Regulators. — Evaporators. — Steam Boats. — Electric Light Machinery.—Hydraulic Machinery.—Air-Compressing Pumps.—Refrigerating Machines —Machinery of Destroyers.—The Management of Water-Tube Boilers.—Regulations for Entry of Assistant Engineers, R.N.—Questions given in Examinations for Promotion of Engineers, R.N.—Regulations respecting Board of Trade Examinations for Engineers, &c.

"This very useful book. . . . Illustrations are of great importance in a work of this kind, and it is satisfactory to find that special attention has been given in this respect."—*Engineers' Gazette.*

Fifth Edition, Thoroughly Revised and Greatly Enlarged. With Numerous Illustrations. Price 10s. 6d.

VALVES AND VALVE-GEARING:

A Practical Text-book for the use of Engineers, Draughtsmen. and Students.

By CHARLES HURST, Practical Draughtsman.

Part I.—Steam Engine Valves.	Part III.—Air Compressor Valves and Gearing.
Part II.—Gas Engine Valves and Gears.	Part IV.—Pump Valves.

"Mr. Hurst's valves and valve-gearing will prove a very valuable aid, and tend to the production of Engines of scientific design and economical working. . . . Will be largely sought after by Students and Designers."—*Marine Engineer.*

"As a practical treatise on the subject, the book stands without a rival."—*Mechanical World.*

Hints on Steam Engine Design and Construction. By Charles Hurst, "Author of Valves and Valve Gearing." Second Edition, Revised. In Paper Boards, 8vo., Cloth Back. Illustrated. Price 1s. 6d. net.

Contents.—I. Steam Pipes.—II. Valves.—III. Cylinders.—IV. Air Pumps and Condensers.—V. Motion Work.—VI. Crank Shafts and Pedestals.—VII. Valve Gear.—VIII. Lubrication.—IX. Miscellaneous Details —Index.

"A handy volume which every practical young engineer should possess."—*The Model Engineer.*

THIRD EDITION, Revised. With numerous Plates reduced from Working Drawings and Illustrations in the Text. 21s.

A MANUAL OF LOCOMOTIVE ENGINEERING:

A Practical Text-Book for the Use of Engine Builders, Designers and Draughtsmen, Railway Engineers, and Students.

BY WILLIAM FRANK PETTIGREW, M.INST.C.E.

Contents.—Historical Introduction, 1763-1863.—Modern Locomotives: Simple.—Modern Locomotives: Compound.—Primary Consideration in Locomotive Design.—Cylinders, Steam Chests, and Stuffing Boxes.—Pistons, Piston Rods, Crossheads, and Slide Bars.—Connecting and Coupling Rods.—Wheels and Axles, Axle Boxes, Hornblocks, and Bearing Springs.—Balancing.—Valve Gear.—Slide Valves and Valve Gear Details.—Framing, Bogies and Axle Trucks, Radial Axle Boxes.—Boilers.—Smokebox, Blast Pipe, Firebox Fittings.—Boiler Mountings.—Tenders.—Railway Brakes.—Lubrication.—Consumption of Fuel, Evaporation and Engine Efficiency.—Repairs, Running, Inspection, and Renewals.—Three Appendices.—Index.

"The work CONTAINS ALL THAT CAN BE LEARNT from a book upon such a subject. It will at once rank as THE STANDARD WORK UPON THIS IMPORTANT SUBJECT."—*Railway Magazine.*

In Large 8vo. Fully Illustrated. 8s. 6d. net.

LOCOMOTIVE COMPOUNDING AND SUPERHEATING.

BY J. F. GAIRNS.

CONTENTS.—Introductory.—Compounding and Superheating for Locomotives.—A Classification of Compound Systems for Locomotives.—The History and Development of the Compound Locomotive.—Two-Cylinder Non-Automatic Systems.—Two-Cylinder Automatic Systems.—Other Two-Cylinder Systems.—Three-Cylinder Systems.—Four-Cylinder Tandem Systems.—Four-Cylinder Two-Crank Systems (other than Tandem).—Four-Cylinder Balanced Systems.—Four-Cylinder Divided and Balanced Systems.—Articulated Compound Engines.—Triple-Expansion Locomotives.—Compound Rack Locomotives.—Concluding Remarks Concerning Compound Locomotives.—The Use of Superheated Steam for Locomotives.—INDEX.

"A welcome addition to the library of the railway engineer."—*Engineering Times.*

In Large 8vo. Handsome Cloth. With Plates and Illustrations. 16s.

LIGHT RAILWAYS AT HOME AND ABROAD.

BY WILLIAM HENRY COLE, M.INST.C.E.,

Late Deputy-Manager, North-Western Railway, India.

Contents.—Discussion of the Term "Light Railways."—English Railways, Rates, and Farmers.—Light Railways in Belgium, France, Italy, other European Countries, America and the Colonies, India, Ireland.—Road Transport as an alternative.—The Light Railways Act, 1896.—The Question of Gauge.—Construction and Working.—Locomotives and Rolling-Stock.—Light Railways in England, Scotland, and Wales.—Appendices and Index.

"Will remain, for some time yet, a STANDARD WORK in everything relating to Light Railways."—*Engineer.*

"The whole subject is EXHAUSTIVELY and PRACTICALLY considered. The work can be cordially recommended as INDISPENSABLE to those whose duty it is to become acquainted with one of the prime necessities of the immediate future."—*Railway Official Gazette.*

In Crown 8vo. Handsome Cloth. Fully Illustrated. 6s. net.

PRACTICAL CALCULATIONS FOR ENGINEERS.

BY CHARLES E. LARARD,
A.M.Inst.C.E., M.I.Mech.E., Wh.Exh.,
Head of the Mechanical Engineering Department at the Northampton Institute, London, E.C.

AND H. A. GOLDING, A.M.I.Mech.E.

CONTENTS.—SECTION I.—Contracted Methods of Calculation.—Technical Mensuration.—Practical Calculation by Logarithms.—The Slide Rule and its Applications.—Squared Paper and its Uses. SECTION II.—Pulleys and Wheels in Train.—Speed Ratios and Practical Examples.—Principle of Moments Applied to Practical Problems.—Work and Power.—Energy and Speed Fluctuations.—Transmission of Work through Machines.—Friction and Efficiency.—Transmission of Power.—Shafting.—Motion on a Circle.—Momentum, Acceleration, and Force Action. SECTION III.—Temperature Scales.—Units of Heat.—Specific Heat.—Heat and Work.—Heat Value of Fuels.—Heat Losses in Engine and Boiler Plant.—Properties of Steam.—Moisture and Dryness Fraction.—Steam and Fuel Calculations.—Boiler Efficiency.—Size of Boiler.—Engine Calculations.—Power, Indicated and Brake.—Calculations for Dimensions.—Steam Consumption and Willans Law.—Efficiencies, Comparative Costs of Power Production.—Commercial Efficiency. SECTION IV.—The Commercial side of Engineering.—Calculation of Weights.—Division of Costs, Material and Labour, Shop Charges and Establishment Charges.—Estimates.—Profit.—Use of Squared Paper in the Estimating Department and to the General Management.

"Exactly what it should be in order to make it useful to students and practitioners of engineering."—*Manchester Guardian.*

SIXTH EDITION. Folio, strongly half-bound, 21s.

TRAVERSE TABLES:

Computed to Four Places of Decimals for every Minute of Angle up to 100 of Distance.

For the Use of Surveyors and Engineers.

BY RICHARD LLOYD GURDEN,
Authorised Surveyor for the Governments of New South Wales and Victoria.

⁂ *Published with the Concurrence of the Surveyors-General for New South Wales and Victoria.*

"Those who have experience in exact SURVEY-WORK will best know how to appreciate the enormous amount of labour represented by this valuable book. The computations enable the user to ascertain the sines and cosines for a distance of twelve miles to within half an inch, and this BY REFERENCE TO BUT ONE TABLE, in place of the usual Fifteen minute computations required. This alone is evidence of the assistance which the Tables ensure to every user, and as every Surveyor in active practice has felt the want of such assistance FEW KNOWING OF THEIR PUBLICATION WILL REMAIN WITHOUT THEM."
—*Engineer*

Strongly Bound in Super Royal 8vo. Cloth Boards. 7s. 6d. net.

BONUS TABLES:

For Calculating Wages on the Bonus or Premium Systems.

For Engineering, Technical and Allied Trades.

BY HENRY A. GOLDING, A.M.I.MECH.E.,
Technical Assistant to Messrs. Bryan Donkin and Clench, Ltd., and Assistant Lecturer in Mechanical Engineering at the Northampton Institute, London, E.C.

"Cannot fail to prove practically serviceable to those for whom they have been designed."—*Scotsman.*

SECOND EDITION. Large 8vo, Handsome Cloth. With Illustrations, Tables, &c. 21s. net.

Lubrication & Lubricants:

A Treatise on the Theory and Practice of Lubrication, and on the Nature, Properties, and Testing of Lubricants.

BY

LEONARD ARCHBUTT, F.I.C., F.C.S.,
Chemist to the Mid. Ry. Co.

AND

R. M. DEELEY, M.I.Mech.E., F.G.S.
Chief Loco. Super., Mid. Ry. Co.

CONTENTS.—I. Friction of Solids.—II. Liquid Friction or Viscosity, and Plastic Friction.—III. Superficial Tension.—IV. The Theory of Lubrication.—V. Lubricants, their Sources, Preparation, and Properties.—VI. Physical Properties and Methods of Examination of Lubricants.—VII. Chemical Properties and Methods of Examination of Lubricants.—VIII. The Systematic Testing of Lubricants by Physical and Chemical Methods.—IX. The Mechanical Testing of Lubricants.—X. The Design and Lubrication of Bearings.—XI. The Lubrication of Machinery.—INDEX.

"Contains practically ALL THAT IS KNOWN on the subject. Deserves the careful attention of all Engineers."—*Railway Official Gazette.*

FOURTH EDITION. *Very fully Illustrated. Cloth*, 4s. 6d.

STEAM-BOILERS:

THEIR DEFECTS, MANAGEMENT, AND CONSTRUCTION,

BY R. D. MUNRO,

Chief Engineer of the Scottish Boiler Insurance and Engine Inspection Company,

"A valuable companion for workmen and engineers engaged about Steam Boilers, ought to be carefully studied, and ALWAYS AT HAND."—*Coll. Guardian.*

BY THE SAME AUTHOR.

KITCHEN BOILER EXPLOSIONS: Why they Occur, and How to Prevent their Occurrence. A Practical Handbook based on Actual Experiment. With Diagram and Coloured Plate. 3s.

In Crown 8vo, Cloth. Fully Illustrated. 5s. net.

EMERY GRINDING MACHINERY.

A Text-Book of Workshop Practice in General Tool Grinding, and the Design, Construction, and Application of the Machines Employed.

BY R. B. HODGSON, A.M.INST.MECH.E.

"Eminently practical . . . cannot fail to attract the notice of the users of this class of machinery, and to meet with careful perusal."—*Chem. Trade Journal.*

FIFTH EDITION. In Two Parts, Published Separately.

A TEXT-BOOK OF

Engineering Drawing and Design.

BY SIDNEY H. WELLS, WH.SC., A.M.I.C.E., A.M.I.MECH.E.

VOL. I.—PRACTICAL GEOMETRY, PLANE, AND SOLID. 4s. 6d.

VOL. II.—MACHINE AND ENGINE DRAWING AND DESIGN. 4s. 6d.

With many Illustrations, specially prepared for the Work, and numerous Examples, for the Use of Students in Technical Schools and Colleges.

"A CAPITAL TEXT-BOOK, arranged on an EXCELLENT SYSTEM, calculated to give an intelligent grasp of the subject, and not the mere faculty of mechanical copying. . . . Mr. Wells shows how to make COMPLETE WORKING-DRAWINGS, discussing fully each step in the design."—***Electrical Review***

In Three Parts. Crown 8vo, Handsome Cloth. Very Fully Illustrated.

MOTOR-CAR MECHANISM AND MANAGEMENT.

By W. POYNTER ADAMS, M.Inst.E.E.

PART I.—THE PETROL CAR. 5s. net.

Second Edition. With important new Appendix, illustrating and defining parts of actual cars in use.

Contents.—Section I.—The Mechanism of the Petrol Car.—The Engine.—The Engine Accessories.—Electrical Ignition and Accessories.—Multiple Cylinder Engines.—The Petrol.—The Chassis and Driving Gear.—Section II.—The Management of the Petrol Car.—The Engine.—The Engine Accessories.—Electrical Ignition.—The Chassis and Driving Gear.—General Management.—Appendix.—Glossary.—Index.

"Should be carefully studied by those who have anything to do with motors."—*Automobile and Carriage Builders' Journal.*

PART II.—ELECTRICAL AND PETROL ELECTRICAL MOTOR CARS.

Pp. i.-x. + 202. With 50 Illustrations. 5s. net.

PART III.—THE STEAM CAR. [*In Preparation.*

In Large 8vo. Handsome Cloth. Very Fully Illustrated. 18s. net.

A MANUAL OF PETROL MOTORS AND MOTOR-CARS.

Comprising the Designing, Construction, and Working of Petrol Motors.

By F. STRICKLAND.

General Contents.—Part I.: Engines.—Historical.—Power Required.—General Arrangement of Engines.—Ignition.—Carburettors.—Cylinders, Pistons, Valves, &c.—Crank Shafts, Crank Chambers, Cams, Runners, Guides, &c.—Pumps.—Flywheels.—Pipe Arrangements.—Silencers.—Engine Control, Balancing.—Motor Cycle Engines.—Marine Motors.—Two-Cycle Motors.—Paraffin Carburettors.—Gas Producers. Part II.: Cars.—General Arrangements.—Clutches.—Transmission.—Differential Gears.—Universal Joints.—Axles.—Springs.—Radius Rods.—Brakes.—Wheels.—Frames.—Steering Gear.—Radiator.—Steps, Mudguards, Bonnets, &c.—Lubrication.—Ball Bearings.—Bodies.—Factors of Safety.—Calculations of Stresses.—Special Change Speed Gears.—Special Cars.—Commercial Vehicles.—Racing Cars.—Index.

"Thoroughly practical and scientific. . . . We have pleasure in recommending it to all."—*Mechanical Engineer.*

In Crown 8vo. Handsome Cloth. Fully Illustrated.

OIL MOTORS.

By G. LIECKFELD. (Authorised English Edition).

Contents.—Liquid Fuels for Power Production.—Development of the Petrol and Paraffin Motors.—Working of the Later Paraffin and Petrol Engines.—Ignition Devices.—Examples of Stationary Petrol, Alcohol, Paraffin, and Crude Oil Engines.—Automobiles.—Ship, Boat, and Air-ship Engines.—Vehicles, &c., Driven by Internal Combustion Engines.—Erection and Attendance of Engines Driven with Liquid Fuel.—Correcting Irregularities in Running.

In Crown 8vo. Handsome Cloth. With 105 Illustrations. 5s. net.

MECHANICAL ENGINEERING FOR BEGINNERS.

By R. S. M'LAREN.

Contents.—Materials.—Bolts and Nuts, Studs, Set Screws.—Boilers.—Steam Raising Accessories.—Steam Pipes and Valves.—The Steam Engine.—Power Transmission.—Condensing Plant.—The Steam Turbine.—Electricity.—Hydraulic Machinery.—Gas and Oil Engines.—Strength of Beams, and Useful Information.—Index.

"The best of its kind we have seen, and should be in the hands of every apprentice."—*Steamship.*

WORKS BY

ANDREW JAMIESON, M.INST.C.E., M.I.E.E., F.R.S.E.,

Formerly Professor of Electrical Engineering, The Glas. and W. of Scot. Tech. Coll.

PROFESSOR JAMIESON'S ADVANCED TEXT-BOOKS.

In Large Crown 8vo. Fully Illustrated.

STEAM AND STEAM-ENGINES, INCLUDING TURBINES AND BOILERS. For the Use of Engineers and for Students preparing for Examinations. With 800 pp., over 400 Illustrations, 11 Plates, many B. of E., C. and G., Questions and Answers, and all Inst. C.E. Exams. on *Theory of Heat Engines.* SIXTEENTH EDITION, Revised. 10s. 6d.

"The BEST BOOK yet published for the use of Students."—*Engineer.*

APPLIED MECHANICS & MECHANICAL ENGINEERING. *Including All the Inst. C.E. Exams.* in (1) Applied Mechanics; (2) Strength and Elasticity of Materials; (3a) Theory of Structures; (ii) Theory of Machines; Hydraulics. Also B. of E.; C. and G. Questions.

Vol. I.—Comprising 568 pages, 300 Illustrations, and Questions: Part I., The Principle of Work and its Applications; Part II.: Friction, Lubrication of Bearings, &c.; Different kinds of Gearing and their Applications to Workshop Tools, &c. SIXTH EDITION. 8s. 6d.

"FULLY MAINTAINS the reputation of the Author."—*Pract. Engineer.*

Vol. II.—Comprising Parts III. to VI., with over 800 pages, 371 Illustrations; Motion and Energy, Theory of Structures or Graphic Statics; Strength and Elasticity of Materials; Hydraulics and Hydraulic Machinery. FIFTH EDITION. 12s. 6d.

"WELL AND LUCIDLY WRITTEN."—*The Engineer.*

*** *Each of the above volumes is complete in itself, and sold separately.*

PROFESSOR JAMIESON'S INTRODUCTORY MANUALS

Crown 8vo. With Illustrations and Examination Papers.

STEAM AND THE STEAM-ENGINE (Elementary Manual of). For First-Year Students, forming an Introduction to the Author's larger Work. TWELFTH EDITION, Revised and Enlarged. 3/6.

"Should be in the hands of EVERY engineering apprentice."—*Practical Engineer.*

MAGNETISM AND ELECTRICITY (Practical Elementary Manual of). For First-Year Students. With Stud. Inst. C.E. and B. of E. Exam. Questions. SEVENTH EDITION, Revised and Enlarged. 3/6.

"A THOROUGHLY TRUSTWORTHY Text-book. PRACTICAL and clear."—*Nature.*

APPLIED MECHANICS (Elementary Manual of). For First-Year Students. With B. of E., C. and G.; and Stud. Inst. C.E. Questions. EIGHTH EDITION, Revised and Greatly Enlarged. 3/6.

"The work has VERY HIGH QUALITIES, which may be condensed into the one word 'CLEAR.'"—*Science and Art.*

A POCKET-BOOK of ELECTRICAL RULES and TABLES. For the Use of Electricians and Engineers. By JOHN MUNRO, C.E., and Prof. JAMIESON. Pocket Size. Leather, 8s. 6d. NINETEENTH EDITION. [See p. 49.

WORKS BY W. J. MACQUORN RANKINE, LL.D., F.R.S.

Thoroughly Revised by W. J. MILLAR, C.E.

A MANUAL OF APPLIED MECHANICS: Comprising the Principles of Statics and Cinematics, and Theory of Structures, Mechanism, and Machines. With Numerous Diagrams. Crown 8vo, Cloth. SEVENTEENTH EDITION. 12s. 6d.

A MANUAL OF CIVIL ENGINEERING: Comprising Engineering Surveys, Earthwork, Foundations, Masonry, Carpentry, Metal Work, Roads, Railways, Canals, Rivers, Waterworks, Harbours, &c. With Numerous Tables and Illustrations. Crown 8vo, Cloth. TWENTY-THIRD EDITION. 16s.

A MANUAL OF MACHINERY AND MILLWORK: Comprising the Geometry, Motions, Work, Strength, Construction, and Objects of Machines, &c. With nearly 300 Illustrations. Crown 8vo, Cloth. SEVENTH EDITION. 12s. 6d.

A MANUAL OF THE STEAM-ENGINE AND OTHER PRIME MOVERS. With a Section on GAS, OIL, and AIR ENGINES, by BRYAN DONKIN, M.Inst.C.E. With Folding Plates and Numerous Illustrations. Crown 8vo, Cloth. SEVENTEENTH EDITION. 12s. 6d.

USEFUL RULES AND TABLES: For Architects, Builders, Engineers, Founders, Mechanics, Shipbuilders, Surveyors, &c. With APPENDIX for the use of ELECTRICAL ENGINEERS. By Professor JAMIESON, M.Inst.C.E., M.I.E.E. SEVENTH EDITION. 10s. 6d.

A MECHANICAL TEXT-BOOK: A Practical and Simple Introduction to the Study of Mechanics. By Professor RANKINE and E. F. BAMBER, C.E. With Numerous Illustrations. Crown 8vo, Cloth. FIFTH EDITION. 9s.

⁂ *The* "MECHANICAL TEXT-BOOK" *was designed by* Professor RANKINE *as an* INTRODUCTION *to the above Series of Manuals.*

MISCELLANEOUS SCIENTIFIC PAPERS. Part I. Temperature, Elasticity, and Expansion of Vapours, Liquids, and Solids. Part II. Energy and its Transformations. Part III. Wave-Forms, Propulsion of Vessels, &c. With Memoir by Professor TAIT, M.A. With fine Portrait on Steel, Plates, and Diagrams. Royal 8vo. Cloth. 31s. 6d.

"No more enduring Memorial of Professor Rankine could be devised than the publication of these papers in an accessible form. . . . The Collection is most valuable on account of the nature of his discoveries, and the beauty and completeness of his analysis." —*Architect.*

THIRD EDITION, *Thoroughly Revised and Enlarged. With 60 Plates and Numerous Illustrations. Handsome Cloth.* 34*s.*

HYDRAULIC POWER
AND
HYDRAULIC MACHINERY.

BY

HENRY ROBINSON, M. INST. C.E., F.G.S.,

FELLOW OF KING'S COLLEGE, LONDON; PROF. EMERITUS OF CIVIL ENGINEERING, KING'S COLLEGE, ETC., ETC.

CONTENTS —Discharge through Orifices.—Flow of Water through Pipes.—Accumulators.—Presses and Lifts.—Hoists.—Rams.—Hydraulic Engines.—Pumping Engines.—Capstans.—Traversers.—Jacks.—Weighing Machines.—Riveters and Shop Tools.—Punching, Shearing, and Flanging Machines.—Cranes.—Coal Discharging Machines.—Drills and Cutters.—Pile Drivers, Excavators, &c.—Hydraulic Machinery applied to Bridges, Dock Gates, Wheels and Turbines.—Shields.—Various Systems and Power Installations—Meters, &c.—INDEX.

"The standard work on the application of water power."—*Cassier's Magazine.*

Second Edition, Greatly Enlarged. With Frontispiece, several Plates, and over 250 Illustrations. 21*s. net.*

THE PRINCIPLES AND CONSTRUCTION OF
PUMPING MACHINERY
(STEAM AND WATER PRESSURE).

With Practical Illustrations of ENGINES and PUMPS applied to MINING, TOWN WATER SUPPLY, DRAINAGE of Lands, &c., also Economy and Efficiency Trials of Pumping Machinery.

BY HENRY DAVEY,

Member of the Institution of Civil Engineers, Member of the Institution of Mechanical Engineers, F.G.S., &c.

CONTENTS —Early History of Pumping Engines—Steam Pumping Engines—Pumps and Pump Valves—General Principles of Non-Rotative Pumping Engines—The Cornish Engine, Simple and Compound—Types of Mining Engines—Pit Work—Shaft Sinking—Hydraulic Transmission of Power in Mines—Electric Transmission of Power—Valve Gears of Pumping Engines—Water Pressure Pumping Engines—Water Works Engines—Pumping Engine Economy and Trials of Pumping Machinery—Centrifugal and other Low-Lift Pumps—Hydraulic Rams, Pumping Mains, &c.—INDEX.

"By the 'one English Engineer who probably knows more about Pumping Machinery than ANY OTHER.' . . . A VOLUME RECORDING THE RESULTS OF LONG EXPERIENCE AND STUDY."—*The Engineer.*

"Undoubtedly THE BEST AND MOST PRACTICAL TREATISE on Pumping Machinery THAT HAS YET BEEN PUBLISHED."—*Mining Journal.*

In Large 8vo. Handsome Cloth. Profusely Illustrated. In Two Volumes, Each Complete in itself, and Sold Separately.

THE DESIGN
AND
CONSTRUCTION OF SHIPS.

By JOHN HARVARD BILES, M.Inst.N.A.,

Professor of Naval Architecture in Glasgow University.

Volume I.—CALCULATIONS AND STRENGTH. With 36 Folding Plates, and 245 other Illustrations. Complete in itself, with Index. 25s. net.

Contents.—Part I.—Areas, Volumes, and Centres of Gravity. Part II.—Ship Calculations. Part III.—Strength of Ships.

Volume II. is in active preparation, and will be ready very shortly.

BY PROFESSOR BILES.

LECTURES ON THE MARINE STEAM TURBINE.

With 131 Illustrations. Price 6s. net.

See page 28.

Royal 8vo, Handsome Cloth. With numerous Illustrations and Tables. 25s.

THE STABILITY OF SHIPS.

BY

SIR EDWARD J. REED, K.C.B., F.R.S., M.P.,

KNIGHT OF THE IMPERIAL ORDERS OF ST. STANILAUS OF RUSSIA; FRANCIS JOSEPH OF AUSTRIA; MEDJIDIE OF TURKEY; AND RISING SUN OF JAPAN; VICE-PRESIDENT OF THE INSTITUTION OF NAVAL ARCHITECTS.

"Sir Edward Reed's 'Stability of Ships' is invaluable. The Naval Architect will find brought together and ready to his hand, a mass of information which he would otherwise have to seek in an almost endless variety of publications, and some of which he would possibly not be able to obtain at all elsewhere."—*Steamship.*

In Crown 8vo. Handsome Cloth. Fully Illustrated.

HYDROGRAPHIC SURVEYING.

For the Use of Beginners, Amateurs, and Port and Harbour Masters.

By COMMANDER S. MESSUM, R.N.,

Instructor in Nautical Surveying, R.N. College, Greenwich.

Contents.—Sextant.—Protractor.—Station Pointer.—Theodolite.—Projections.—Symbols and Abbreviations.—Plotting and Triangulation of a Small Plan.—Mast-head Angle Survey.—Meridian Distances.—Appendix.—Index.

WORKS BY THOMAS WALTON,
NAVAL ARCHITECT.

FOURTH EDITION. Illustrated with Plates, Numerous Diagrams, and Figures in the Text. 18s. net.

STEEL SHIPS:
THEIR CONSTRUCTION AND MAINTENANCE.

A Manual for Shipbuilders, Ship Superintendents, Students, and Marine Engineers.

BY THOMAS WALTON, NAVAL ARCHITECT,
AUTHOR OF "KNOW YOUR OWN SHIP."

CONTENTS.—I. Manufacture of Cast Iron, Wrought Iron, and Steel.—Composition of Iron and Steel, Quality, Strength, Tests, &c. II. Classification of Steel Ships. III. Considerations in making choice of Type of Vessel.—Framing of Ships. IV. Strains experienced by Ships.—Methods of Computing and Comparing Strengths of Ships. V. Construction of Ships.—Alternative Modes of Construction.—Types of Vessels.—Turret, Self Trimming, and Trunk Steamers, &c.—Rivets and Rivetting, Workmanship. VI. Pumping Arrangements. VII. Maintenance.—Prevention of Deterioration in the Hulls of Ships.—Cement, Paint, &c.—INDEX.

"So thorough and well written is every chapter in the book that it is difficult to select any of them as being worthy of exceptional praise. Altogether, the work is excellent, and will prove of great value to those for whom it is intended."—*The Engineer.*

In Handsome Cloth. Very fully Illustrated. 7s. 6d. net.

PRESENT-DAY SHIPBUILDING.

For Shipyard Students, Ships' Officers, and Engineers.

BY THOS. WALTON.

GENERAL CONTENTS.—Classification.—Materials used in Shipbuilding.—Alternative Modes of Construction.—Details of Construction.—Framing, Plating, Rivetting, Stem Frames, Twin-Screw Arrangements, Water Ballast Arrangements, Loading and Discharging Gear, &c.—Types of Vessels, including Atlantic Liners, Cargo Steamers, Oil carrying Steamers, Turret and other Self Trimming Steamers, &c.—INDEX.

"Simple language . . . clear and easily followed illustrations."—*Times Engineering Supplement.*

"We heartily recommend it to all who have to do with ships."—*Steamship.*

NINTH EDITION. *Illustrated. Handsome Cloth, Crown 8vo. 7s. 6d.*

The Chapters on Tonnage and Freeboard have been brought thoroughly up to date, and embody the latest (1906) Board of Trade Regulations on these subjects.

KNOW YOUR OWN SHIP.

BY THOMAS WALTON, NAVAL ARCHITECT.

Specially arranged to suit the requirements of Ships' Officers, Shipowners, Superintendents, Draughtsmen, Engineers, and Others,

CONTENTS. — Displacement and Deadweight. — Moments. — Buoyancy. — Strain. — Structure. — Stability. — Rolling. — Ballasting. — Loading.—Shifting Cargoes.—Effect of Admission of Water into Ship.—Trim Tonnage.—Freeboard (Load-line).—Calculations.—Set of Calculations from Actual Drawings.—INDEX.

"The work is of the highest value, and all who go down to the sea in ships should make themselves acquainted with it."—*Shipping World* (on the new edition).

GRIFFIN'S NAUTICAL SERIES.

EDITED BY EDW. BLACKMORE,
Master Mariner, First Class Trinity House Certificate, Assoc. Inst. N.A.;
AND WRITTEN, MAINLY, by SAILORS for SAILORS.

"THIS ADMIRABLE SERIES."—*Fairplay.* 'A VERY USEFUL SERIES."—*Nature.*

"EVERY SHIP should have the WHOLE SERIES as a REFERENCE LIBRARY. HANDSOMELY BOUND, CLEARLY PRINTED and ILLUSTRATED."—*Liverpool Journ. of Commerce.*

The British Mercantile Marine: An Historical Sketch of its Rise and Development. By the EDITOR, CAPT. BLACKMORE. 3s. 6d.

"Captain Blackmore s SPLENDID BOOK . . . contains paragraphs on every point of interest to the Merchant Marine. The 243 pages of this book are THE MOST VALUABLE to the sea captain that have EVER been COMPILED."—*Merchant Service Review.*

Elementary Seamanship. By D. WILSON-BARKER, Master Mariner, F.R.S.E., F.R.G.S. With numerous Plates, two in Colours, and Frontispiece. FOURTH EDITION, Thoroughly Revised. With additional Illustrations. 6s.

"This ADMIRABLE MANUAL, by CAPT. WILSON BARKER, of the 'Worcester,' seems to us PERFECTLY DESIGNED."—*Athenæum.*

Know Your Own Ship: A Simple Explanation of the Stability, Construction, Tonnage, and Freeboard of Ships. By THOS. WALTON, Naval Architect. NINTH EDITION. 7s. 6d.

"MR. WALTON'S book will be found VERY USEFUL."—*The Engineer.*

Navigation: Theoretical and Practical. By D. WILSON-BARKER and WILLIAM ALLINGHAM. SECOND EDITION, Revised. 3s. 6d.

"PRECISELY the kind of work required for the New Certificates of competency. Candidates will find it INVALUABLE."—*Dundee Advertiser.*

Marine Meteorology: For Officers of the Merchant Navy. By WILLIAM ALLINGHAM, First Class Honours, Navigation, Science and Art Department. With Illustrations and Maps, and *facsimile* reproduction of log page. 7s. 6d.

"Quite the BEST PUBLICATION on this subject."—*Shipping Gazette.*

Latitude and Longitude: How to find them. By W. J. MILLAR, C.E. SECOND EDITION, Revised. 2s.

"Cannot but prove an acquisition to those studying Navigation."—*Marine Engineer.*

Practical Mechanics: Applied to the requirements of the Sailor. By THOS. MACKENZIE, Master Mariner, F.R.A.S. THIRD EDITION, Revised. 3s. 6d.

"WELL WORTH the money . . . EXCEEDINGLY HELPFUL."—*Shipping World.*

Trigonometry: For the Young Sailor, &c. By RICH. C. BUCK, of the Thames Nautical Training College, H.M.S. "Worcester." THIRD EDITION, Revised. Price 3s. 6d.

"This EMINENTLY PRACTICAL and reliable volume."—*Schoolmaster.*

Practical Algebra. By RICH. C. BUCK. Companion Volume to the above, for Sailors and others. SECOND EDITION, Revised. Price 3s. 6d.

"It is JUST THE BOOK for the young sailor mindful of progress."—*Nautical Magazine.*

The Legal Duties of Shipmasters. By BENEDICT WM. GINSBURG, M.A., LL.D., of the Inner Temple and Northern Circuit; Barrister-at-Law. SECOND EDITION, Thoroughly Revised and Enlarged. Price 4s. 6d.

"INVALUABLE to masters. . . . We can fully recommend it '—*Shipping Gazette.*

A Medical and Surgical Help for Shipmasters. Including First Aid at Sea. By WM. JOHNSON SMITH, F.R.C.S., Principal Medical Officer, Seamen's Hospital, Greenwich. THIRD EDITION, Thoroughly Revised. 6s.

"SOUND, JUDICIOUS, REALLY HELPFUL."—*The Lancet.*

GRIFFIN'S NAUTICAL SERIES.

Introductory Volume. Price 3s. 6d.

THE

British Mercantile Marine.

BY EDWARD BLACKMORE,

MASTER MARINER; ASSOCIATE OF THE INSTITUTION OF NAVAL ARCHITECTS;
MEMBER OF THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS
IN SCOTLAND; EDITOR OF GRIFFIN'S "NAUTICAL SERIES."

GENERAL CONTENTS.—HISTORICAL: From Early Times to 1486—Progress under Henry VIII.—To Death of Mary—During Elizabeth's Reign—Up to the Reign of William III.—The 18th and 19th Centuries—Institution of Examinations — Rise and Progress of Steam Propulsion — Development of Free Trade—Shipping Legislation, 1862 to 1875—"Locksley Hall" Case—Shipmasters' Societies—Loading of Ships—Shipping Legislation, 1884 to 1894—Statistics of Shipping. THE PERSONNEL: Shipowners—Officers—Mariners—Duties and Present Position. EDUCATION: A Seaman's Education: what it should be—Present Means of Education—Hints. DISCIPLINE AND DUTY—Postscript—The Serious Decrease in the Number of British Seamen, a Matter demanding the Attention of the Nation.

"INTERESTING and INSTRUCTIVE . . . may be read WITH PROFIT and ENJOYMENT."—*Glasgow Herald.*

"EVERY BRANCH of the subject is dealt with in a way which shows that the writer 'knows the ropes' familiarly."—*Scotsman.*

"This ADMIRABLE book . . . TEEMS with useful information—Should be in the hands of every Sailor."—*Western Morning News.*

FOURTH EDITION, *Thoroughly Revised. With Additional Illustrations. Price 6s.*

A MANUAL OF

ELEMENTARY SEAMANSHIP.

BY

D. WILSON-BARKER, MASTER MARINER; F.R.S.E., F.R.G.S., &C., &C.
YOUNGER BROTHER OF THE TRINITY HOUSE.

With Frontispiece, Numerous Plates (Two in Colours), and Illustrations in the Text.

GENERAL CONTENTS.—The Building of a Ship; Parts of Hull, Masts, &c.—Ropes, Knots, Splicing, &c. — Gear, Lead and Log, &c. — Rigging, Anchors — Sailmaking — The Sails, &c. — Handling of Boats under Sail — Signals and Signalling—Rule of the Road—Keeping and Relieving Watch—Points of Etiquette—Glossary of Sea Terms and Phrases—Index.

⁂ The volume contains the NEW RULES OF THE ROAD.

"This ADMIRABLE MANUAL, by CAPT. WILSON-BARKER of the 'Worcester,' seems to us PERFECTLY DESIGNED and holds its place excellently in 'GRIFFIN'S NAUTICAL SERIES.' . . . Although intended for those who are to become Officers of the Merchant Navy, it will be found useful by ALL YACHTSMEN."—*Athenæum.*

⁂ For complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

GRIFFIN'S NAUTICAL SERIES.

SECOND EDITION, *Revised and Illustrated. Price 3s. 6d.*

NAVIGATION:
PRACTICAL AND THEORETICAL.

BY DAVID WILSON-BARKER, R.N.R., F.R.S.E., &c., &c.,

AND

WILLIAM ALLINGHAM,

FIRST-CLASS HONOURS, NAVIGATION, SCIENCE AND ART DEPARTMENT.

With Numerous Illustrations and Examination Questions.

GENERAL CONTENTS.—Definitions—Latitude and Longitude—Instruments of Navigation—Correction of Courses—Plane Sailing—Traverse Sailing—Day's Work — Parallel Sailing — Middle Latitude Sailing — Mercator's Chart—Mercator Sailing—Current Sailing—Position by Bearings—Great Circle Sailing—The Tides—Questions—Appendix: Compass Error—Numerous Useful Hints &c.—Index.

"PRECISELY the kind of work required for the New Certificates of competency in grades from Second Mate to extra Master. . . . Candidates will find it INVALUABLE."—*Dundee Advertiser*.

"A CAPITAL LITTLE BOOK . . . specially adapted to the New Examinations. The Authors are CAPT. WILSON-BARKER (Captain-Superintendent of the Nautical College, H.M.S. 'Worcester,' who has had great experience in the highest problems of Navigation), and MR. ALLINGHAM, a well-known writer on the Science of Navigation and Nautical Astronomy."—*Shipping World.*

Handsome Cloth. Fully Illustrated. Price 7s. 6d.

MARINE METEOROLOGY,
FOR OFFICERS OF THE MERCHANT NAVY.

BY WILLIAM ALLINGHAM,

Joint Author of "Navigation, Theoretical and Practical."

With numerous Plates, Maps, Diagrams, and Illustrations, and a facsimile Reproduction of a Page from an actual Meteorological Log-Book.

SUMMARY OF CONTENTS.

INTRODUCTORY.—Instruments Used at Sea for Meteorological Purposes.—Meteorological Log-Books.—Atmospheric Pressure.—Air Temperatures.—Sea Temperatures.—Winds.—Wind Force Scales.—History of the Law of Storms.—Hurricanes, Seasons, and Storm Tracks.—Solution of the Cyclone Problem.—Ocean Currents.—Icebergs.—Synchronous Charts.—Dew, Mists, Fogs, and Haze.—Clouds.—Rain, Snow, and Hail.—Mirage, Rainbows, Coronas, Halos, and Meteors.—Lightning, Corposants, and Auroras.—QUESTIONS.—APPENDIX.—INDEX.

"Quite the BEST publication, AND certainly the MOST INTERESTING, on this subject ever presented to Nautical men."—*Shipping Gazette.*

*** For Complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

GRIFFIN'S NAUTICAL SERIES.

THIRD EDITION, REVISED. With Numerous Illustrations. Price 3s. 6d.

PRACTICAL MECHANICS:

Applied to the Requirements of the Sailor.

BY THOS. MACKENZIE, *Master Mariner, F.R.A.S.*

GENERAL CONTENTS.—Resolution and Composition of Forces—Work done by Machines and Living Agents—The Mechanical Powers: The Lever; Derricks as Bent Levers—The Wheel and Axle: Windlass; Ship's Capstan; Crab Winch—Tackles: the "Old Man"—The Inclined Plane; the Screw—The Centre of Gravity of a Ship and Cargo — Relative Strength of Rope: Steel Wire, Manilla, Hemp, Coir—Derricks and Shears—Calculation of the Cross-breaking Strain of Fir Spar—Centre of Effort of Sails—Hydrostatics: the Diving-bell; Stability of Floating Bodies; the Ship's Pump, &c.

"WELL WORTH the money . . . will be found EXCEEDINGLY HELPFUL."—*Shipping World.*

"NO SHIPS' OFFICERS' BOOKCASE will henceforth be complete without CAPTAIN MACKENZIE'S 'PRACTICAL MECHANICS.' Notwithstanding my many years' experience at sea, it has told me *how much more there is to acquire.*"—(Letter to the Publishers from a Master Mariner).

WORKS BY RICHARD C. BUCK,

of the Thames Nautical Training College, H.M.S. 'Worcester.'

A MANUAL OF TRIGONOMETRY:

With Diagrams, Examples, and Exercises. Price 3s. 6d.

THIRD EDITION, Revised and Corrected.

⁂ Mr. Buck's Text-Book has been SPECIALLY PREPARED with a view to the Examinations of the Board of Trade, in which Trigonometry is an obligatory subject.

"This EMINENTLY PRACTICAL and RELIABLE VOLUME."—*Schoolmaster.*

A MANUAL OF ALGEBRA.

Designed to meet the Requirements of Sailors and others.

SECOND EDITION, Revised. Price 3s. 6d.

⁂ These elementary works on ALGEBRA and TRIGONOMETRY are written specially for those who will have little opportunity of consulting a Teacher. They are books for "SELF-HELP." All but the simplest explanations have, therefore, been avoided, and ANSWERS to the Exercises are given. Any person may readily, by careful study, become master of their contents, and thus lay the foundation for a further mathematical course, if desired. It is hoped that to the younger Officers of our Mercantile Marine they will be found decidedly serviceable. The Examples and Exercises are taken from the Examination Papers set for the Cadets of the "Worcester."

"Clearly arranged, and well got up. . . . A first-rate Elementary Algebra."—*Nautical Magazine.*

SECOND EDITION, Revised. With Diagrams. Price 2s.

LATITUDE AND LONGITUDE: How to Find them.

BY W. J. MILLAR, C.E.,

Late Secretary to the Inst. of Engineers and Shipbuilders in Scotland.

"CONCISELY and CLEARLY WRITTEN . . . cannot but prove an acquisition to those studying Navigation."—*Marine Engineer.*

"Young Seamen will find it HANDY and USEFUL, SIMPLE and CLEAR."—*The Engineer.*

⁂ For complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

GRIFFIN'S NAUTICAL SERIES.

SECOND EDITION, Revised and Extended. In Crown 8vo. Price 4s. 6d.

THE LEGAL DUTIES OF SHIPMASTERS.

BY BENEDICT WM. GINSBURG, M.A., LL.D. (CANTAB.),
Of the Inner Temple and Northern Circuit; Barrister-at-Law.

General Contents.—The Qualification for the Position of Shipmaster—The Contract with the Shipowner—The Master's Duty in respect of the Crew: Engagement; Apprentices; Discipline; Provisions, Accommodation, and Medical Comforts; Payment of Wages and Discharge—The Master's Duty in respect of the Passengers—The Master's Financial Responsibilities—The Master's Duty in respect of the Cargo—The Master's Duty in Case of Casualty—The Master's Duty to certain Public Authorities—The Master's Duty in relation to Pilots, Signals, Flags, and Light Dues—The Master's Duty upon Arrival at the Port of Discharge—Appendices relative to certain Legal Matters: Board of Trade Certificates, Dietary Scales, Stowage of Grain Cargoes, Load Line Regulations, Life-saving Appliances, Carriage of Cattle at Sea, &c., &c.—Copious Index.

"No intelligent Master should fail to add this to his list of necessary books. A few lines of it may SAVE A LAWYER'S FEE, BESIDES ENDLESS WORRY."—*Liverpool Journal of Commerce.*

FIRST AID AT SEA.

THIRD EDITION, Revised. With Coloured Plates and Numerous Illustrations, and comprising the latest Regulations Respecting the Carriage of Medical Stores on Board Ship. Price 6s.

A MEDICAL AND SURGICAL HELP
FOR SHIPMASTERS AND OFFICERS
IN THE MERCHANT NAVY.

BY WM. JOHNSON SMITH, F.R.C.S.,
Principal Medical Officer, Seamen's Hospital, Greenwich.

⁂ The attention of all interested in our Merchant Navy is requested to this exceedingly useful and valuable work. It is needless to say that it is the outcome of many years PRACTICAL EXPERIENCE amongst Seamen.

"SOUND, JUDICIOUS, REALLY HELPFUL."—*The Lancet.*

NINTH EDITION. *Revised, with Chapters on Trim, Buoyancy, and Calculations. Numerous Illustrations. Handsome Cloth, Crown 8vo. Price 7s. 6d.*

KNOW YOUR OWN SHIP.

BY THOMAS WALTON, NAVAL ARCHITECT.

Specially arranged to suit the requirements of Ships' Officers, Shipowners, Superintendents, Draughtsmen, Engineers, and Others.

This work explains, in a simple manner, such important subjects as:—Displacement.—Deadweight.—Tonnage.—Freeboard.—Moments.—Buoyancy.—Strain.—Structure.—Stability.—Rolling.—Ballasting.—Loading.—Shifting Cargoes.—Admission of Water.—Sail Area.—&c.

"The little book will be found EXCEEDINGLY HANDY by most officers and officials connected with shipping. . . . Mr. Walton's work will obtain LASTING SUCCESS, because of its unique fitness for those for whom it has been written."—*Shipping World.*

BY THE SAME AUTHOR.

STEEL SHIPS: Their Construction and Maintenance.

(See page 38.)

⁂ For Complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

SIXTEENTH EDITION, *Thoroughly Revised. Large 8vo, Cloth. pp.* i-xxiv+712. *With* 250 *Illustrations, reduced from Working Drawings, and* 8 *Plates.* 21*s. net.*

A MANUAL OF
MARINE ENGINEERING:

COMPRISING THE DESIGNING, CONSTRUCTION, AND WORKING OF MARINE MACHINERY.

By A. E. SEATON, M.I.C.E., M.I.Mech.E., M.I.N.A.

GENERAL CONTENTS. — PART I.—Principles of Marine Propulsion. PART II. — Principles of Steam Engineering. PART III. — Details of Marine Engines: Design and Calculations for Cylinders, Pistons, Valves, Expansion Valves, &c. PART IV.— Propellers. PART V. — Boilers. PART VI.—Miscellaneous.

"The Student, Draughtsman, and Engineer will find this work the MOST VALUABLE HANDBOOK of Reference on the Marine Engine now in existence."—*Marine Engineer.*

NINTH EDITION, Thoroughly Revised. Pocket-Size, Leather. 8s. 6d.

A POCKET-BOOK OF
MARINE ENGINEERING RULES AND TABLES,

FOR THE USE OF

Marine Engineers, Naval Architects, Designers, Draughtsmen, Superintendents and Others.

BY A. E. SEATON, M.I.C.E., M.I.Mech.E., M.I.N.A.,
AND
H. M. ROUNTHWAITE, M.I.Mech.E., M.I.N.A.

"The best book of its kind, and the information is both up-to-date and reliable."—*Engineer.*

In Large 8vo. Handsome Cloth. Fully Illustrated.

THE SCREW PROPELLER

And other Competing Instruments for Marine Propulsion.

BY A. E. SEATON, M.INST.C.E., M.I.MECH.E., M.I.N.A.

In Pocket Size. With 368 Pages. 3s. 6d. net.

ENGLISH-SPANISH and SPANISH-ENGLISH.

SEA TERMS AND PHRASES.

BY FLEET-PAYMASTER GRAHAM-HEWLETT.

"Most complete . . . useful . . . we can heartily recommend it."—*Steamship.*

In Crown 8vo. Handsome Cloth. Many Diagrams. 2s. 6d. net.

DEFINITIONS IN NAVIGATION AND NAUTICAL ASTRONOMY.

BY P. GROVES-SHOWELL,
Head of the Navigation Department, L.C.C. School, Poplar.

This Volume consists of Explanatory Diagrams, together with Description of all Instruments used, and Tables of Weights and Measures, and Formulæ for Determination of Areas and Volumes.

WORKS BY PROF. ROBERT H. SMITH, Assoc.M.I.C.E.,

M.I.Mech.E., M.I.El.E., M.I.Min.E., Whit. Sch., M.Ord.Meiji., Em. Prof. of Eng.

SECOND EDITION, *Revised. In Crown 8vo, extra, with Diagrams and Folding-Plate.* 7s. 6d. net.

THE CALCULUS FOR ENGINEERS AND PHYSICISTS,

INTEGRATION AND DIFFERENTIATION,

With Applications to Technical Problems;

AND

CLASSIFIED REFERENCE LIST OF INTEGRALS.

By PROF. ROBERT H. SMITH.

"PROF. R. H. SMITH'S book will be serviceable in rendering a hard road AS EASY AS PRACTICABLE for the non-mathematical Student and Engineer."—*Athenæum.*

"Interesting diagrams, with practical illustrations of actual occurrence, are to be found here in abundance. THE VERY COMPLETE CLASSIFIED REFERENCE TABLE will prove very useful in saving the time of those who want an integral in a hurry."—*The Engineer.*

In 4to, Boards. 7s. 6d.

MEASUREMENT CONVERSIONS

(English and French):

43 GRAPHIC TABLES OR DIAGRAMS, ON 28 PLATES.

Showing at a glance the MUTUAL CONVERSION of MEASUREMENTS in DIFFERENT UNITS

Of Lengths, Areas, Volumes, Weights, Stresses, Densities, Quantities of Work, Horse Powers, Temperatures, &c.

For the use of Engineers, Surveyors, Architects, and Contractors.

⁂ Prof. SMITH'S CONVERSION-TABLES form the most unique and comprehensive collection ever placed before the profession. By their use much time and labour will be saved, and the chances of error in calculation diminished. It is believed that henceforth no Engineer's Office will be considered complete without them.

THIRD EDITION. Pocket Size, Leather Limp, with Gilt Edges and Rounded Corners, printed on Special Thin Paper, with Illustrations, pp. i-xii + 834. Price 18s. net.

(THE NEW "NYSTROM")

THE MECHANICAL ENGINEER'S REFERENCE BOOK

A Handbook of Tables, Formulæ and Methods for Engineers, Students and Draughtsmen.

BY HENRY HARRISON SUPLEE, B.Sc., M.E.

"We feel sure it will be of great service to mechanical engineers."—*Engineering.*

SECOND EDITION. In Large 8vo. Handsome Cloth. 16s.

CHEMISTRY FOR ENGINEERS.

BY

BERTRAM BLOUNT, F.I.C., F.C.S., A.I.C.E. AND A. G. BLOXAM, F.I.C., F.C.S.

GENERAL CONTENTS.—Introduction—Chemistry of the Chief Materials of Construction—Sources of Energy—Chemistry of Steam-raising—Chemistry of Lubrication and Lubricants—Metallurgical Processes used in the Winning and Manufacture of Metals.

"The authors have SUCCEEDED beyond all expectation, and have produced a work which should give FRESH POWER to the Engineer and Manufacturer."—*The Times.*

By the same Authors, "CHEMISTRY FOR MANUFACTURERS," see p. 71, *General Catalogue.*

THE ELEMENTS OF CHEMICAL ENGINEERING. By J. GROSSMANN, M.A., Ph.D., F.I.C. With a Preface by Sir WILLIAM RAMSAY, K.C.B., F.R.S. In Handsome Cloth. With nearly 50 Illustrations. 3s. 6d. net. [See page 50.

In Demy Quarto. With Diagrams and Worked Problems.
2s. 6d. net.

PROPORTIONAL SET SQUARES

APPLIED TO GEOMETRICAL PROBLEMS.

BY LIEUT.-COL. THOMAS ENGLISH, Late Royal Engineers.

WORKS BY WALTER R. BROWNE, M.A., M.INST.C.E.

THE STUDENT'S MECHANICS:

An Introduction to the Study of Force and Motion.

With Diagrams. Crown 8vo. Cloth, 4s. 6d.

"Clear in style and practical in method, 'THE STUDENT'S MECHANICS' is cordially to be recommended from all points of view."—*Athenæum.*

FOUNDATIONS OF MECHANICS.

Papers reprinted from the *Engineer.* In Crown 8vo, 1s.

Demy 8vo, with Numerous Illustrations, 9s.

FUEL AND WATER:

A Manual for Users of Steam and Water.

BY PROF. FRANZ SCHWACKHÖFER OF VIENNA, AND WALTER R. BROWNE, M.A., C.E.

GENERAL CONTENTS.—Heat and Combustion—Fuel, Varieties of—Firing Arrangements: Furnace, Flues, Chimney—The Boiler, Choice of—Varieties—Feed-water Heaters—Steam Pipes—Water: Composition, Purification—Prevention of Scale, &c., &c.

"The Section on Heat is one of the best and most lucid ever written."—*Engineer.*

AUTHORISED ENGLISH TRANSLATION.

In Large 8vo. Cloth. With about 147 Illustrations. 15s. net.

A MANUAL OF

THE PRINCIPLES OF SEWAGE TREATMENT.

BY PROF. DUNBAR,

Director of the Institute of State Hygiene, Hamburg.

TRANSLATED BY HARRY T. CALVERT, M.SC., PH.D., F.I.C.,

Chief Chemical Assistant, West Riding of Yorkshire Rivers Board.

CONTENTS.—Growth of River Pollution.—Legal Measures taken by Central and Local Authorities.—Rise and Development of Methods of Sewage Treatment.—Earlier Views on Methods of Treatment.—Characteristics of Sewage.—Objects of Purification Works.—Methods for the Removal of Suspended Matters.—For the Removal of Putrescibility.—Disinfection.—Supervision and Inspection of Works.—Utility and Cost.—INDEX.

Beautifully Illustrated, with Numerous Plates, Diagrams, and Figures in the Text. 21s. net.

TRADES' WASTE:

ITS TREATMENT AND UTILISATION.

Handbook for Borough Engineers, Surveyors, Architects, and Analysts.

BY W. NAYLOR, F.C.S., A.M.INST.C.E.,

Chief Inspector of Rivers, Ribble Joint Committee.

"There is probably no person in England to-day better fitted to deal rationally with such a subject."—*British Sanitarian.*

In Handsome Cloth. With 59 Illustrations. 6s. net.

SMOKE ABATEMENT.

A Manual for the Use of Manufacturers, Inspectors, Medical Officers of Health, Engineers, and Others.

BY WILLIAM NICHOLSON,

Chief Smoke Inspector to the Sheffield Corporation.

"We welcome such an adequate statement on an important subject."—*British Medical Journal.*

SECOND EDITION. In Medium 8vo. Thoroughly Revised and Re-Written. 15s. net.

CALCAREOUS CEMENTS:

THEIR NATURE, PREPARATION, AND USES.

With some Remarks upon Cement Testing.

BY GILBERT R. REDGRAVE, ASSOC. INST. C.E.,

Assistant Secretary for Technology, Board of Education, South Kensington,

AND CHARLES SPACKMAN, F.C.S.

"We can thoroughly recommend it as a first-class investment."—*Practical Engineer.*

In Handsome Cloth. 5s. net.

A HANDBOOK FOR CEMENT WORKS' CHEMISTS.

BY FRANK B. GATEHOUSE, F.C.S.

GENERAL CONTENTS.—Introduction.—Chemicals and Apparatus.—Books.—Analysis and Calculations of Raw Materials.—Analysis of Fuel, Kiln Gases, Lubricants and Water.—Cement Analysis.—Gypsum, Plaster, &c., Burnt Lime.—APPENDICES.—INDEX.

Will be of great use in Cement Works."—*Architect.*

ELECTRICAL ENGINEERING.

SECOND EDITION, *Revised. In Large 8vo. Handsome Cloth. Profusely Illustrated with Plates, Diagrams, and Figures.* 24*s. net.*

CENTRAL ELECTRICAL STATIONS:

Their Design, Organisation, and Management.

BY CHAS. H. WORDINGHAM, A.K.C., M.INST.C.E., M.INST.MECH.E.,
Late Memb. of Council Inst. E. E., and Electrical Engineer to the City of Manchester;
Electrical Engineer-in-Chief to the Admiralty.

"One of the MOST VALUABLE CONTRIBUTIONS to Central Station literature we have had for some time."—*Electricity.*

In Large 8vo. Handsome Cloth. Profusely Illustrated. 12s. 6d. net.

ELECTRICITY CONTROL.

A Treatise on Electric Switchgear and Systems of Electric Transmission.

BY LEONARD ANDREWS,
Associate Member of the Institution of Civil Engineers, Member of the Institution of Electrical Engineers, &c

General Principles of Switchgear Design.—Constructional Details.—Circuit Breakers or Arc Interrupting Devices.—Automatically Operated Circuit Breakers.—Alternating Reverse Current Devices.—Arrangement of 'Bus Bars, and Apparatus for Parallel Running.—General Arrangement of Controlling Apparatus for High Tension Systems.—General Arrangement of Controlling Apparatus for Low Tension Systems.—Examples of Complete Installations.—Long Distance Transmission Schemes.

"Not often does the specialist have presented to him so satisfactory a book as this. . . . We recommend it without hesitation to Central Station Engineers, and, in fact, to anyone interested in the subject."—*Power.*

Large 8vo, Cloth, with 334 Pages and 307 Illustrations. 16s. net.

ELECTRICITY METERS.

BY HENRY G. SOLOMON, A.M.Inst.E.E.

CONTENTS.—Introductory.—General Principles of Continuous-Current Meters.—Continuous-Current Quantity Meters.—Continuous-Energy Motor Meters.—Different Types.—Special Purposes, *i.e.*, Battery Meters, Switchboard Meters, Tramcar Meters.—General Principles of Single- and Polyphase Induction Meters.—Single-phase Induction Meters.—Polyphase Meters.—Tariff Systems.—Prepayment Meters.—Tariff and Hour Meters.—Some Mechanical Features in Meter Design.—Testing Meters.—INDEX.

"An earnest and successful attempt to deal comprehensively with modern methods of measuring current or power in electrical installations."—*Engineering.*

In Large 8vo. Handsome Cloth. Fully Illustrated.

TRANSFORMERS.

BY HERMANN BOHLE, M.I.E.E.,
Prof. of Electrotechnics, S.A. College, Cape Town,
AND PROFESSOR DAVID ROBERTSON, B.SC., A.I.E.E., OF BRISTOL.

CONTENTS.—General Principles.—Magnetising and No-Load Currents.—Losses in Transformers.—Iron Losses.—Copper Losses.—Temperature Rise.—Magnetic Leakage.—Leakage Inductance.—Vector Diagrams for Transformers.—Systematic Testing of Transformers.—Insulating Materials.—Examples of Construction.—Design of Transformers.—Applications of Transformers.—Regulating and Phase-Changing Transformers.—INDEX.

In Large Crown 8vo. Handsome Cloth. Fully Illustrated. 5s. net.

TELEGRAPHIC SYSTEMS,

AND OTHER NOTES.

A Handbook of the Principles on which Telegraphic Practice is Based.

By ARTHUR CROTCH,
Of the Engineer-in-Chief's Department, G.P.O.

CONTENTS.—Batteries, Primary and Secondary.—Universal Battery Working.—Duplex Telegraphy.—Duplex and Quadruplex Telegraphy.—Automatic Telegraphy.—Multiplex Telegraphy.—The Hughes Type Printing Instrument.—The Baudot System.—The Murray Type Printing Telegraph.—Test and Battery Boxes.—Circuit Concentration, &c.—Repeaters.—Submarine Telegraphy.—Wireless Telegraphy.—INDEX.—LIST OF DIAGRAMS OF CONNECTIONS.

In Large 8vo. Profusely Illustrated. 8s. 6d. net.

WIRELESS TELEGRAPHY.

By GUSTAVE EICHHORN, PH.D.

CONTENTS.—Oscillations.—Closed and Open Oscillation Systems.—Coupled Systems.—The Coupling Compensating the Aerial Wire.—The Receiver.—Comparative Measurement in the Sender.—Theoretical Results and Calculations in respect of Sender and Receiver.—Close- and Loose-Coupled Sender and Receiver.—Formulæ.—The Ondameter.—Modern Apparatus and Methods of Working.—Conclusion.—Bibliography.—INDEX.

"Well written . . . and combines with a good deal of description a careful investigation of the fundamental theoretical phenomena."—*Nature.*

NINETEENTH EDITION. Leather, Pocket Size, with 810 pages. 8s. 6d.

A POCKET-BOOK OF ELECTRICAL RULES & TABLES

FOR THE USE OF ELECTRICIANS AND ENGINEERS.

By JOHN MUNRO, C.E., & PROF. JAMIESON, M.INST.C.E., F.R.S.E.

"WONDERFULLY PERFECT. . . . Worthy of the highest commendation we can give it."—*Electrician.*

GRIFFIN'S ELECTRICAL PRICE-BOOK: For Electrical, Civil, Marine, and Borough Engineers, Local Authorities, Architects, Railway Contractors, &c. Edited by H. J. DOWSING. SECOND EDITION. 8s. 6d.

ELECTRIC SMELTING AND REFINING. By Dr. W. BORCHERS and W. G. McMILLAN. [See page 67 *General Catalogue.*

ELECTRO-METALLURGY, A Treatise on. By WALTER G. McMILLAN, F.I.C., F.C.S., and W. R. COOPER. [See page 67 *General Catalogue.*

ELECTRICAL PRACTICE IN COLLIERIES. By D. BURNS, M.E., M.Inst.M.E. [See page 57 *General Catalogue.*

ELECTRICAL SIGNALLING IN MINES. By GERALD J. HOOGWINKEL, M.I.E.E., &c. [*In Active Preparation.*

THIRD EDITION, Revised, Enlarged, and Re-issued. Price 6s. net.

A SHORT MANUAL OF

INORGANIC CHEMISTRY.

BY A. DUPRÉ, Ph.D., F.R.S.,

AND WILSON HAKE, Ph.D., F.I.C., F.C.S.,

Of the Westminster Hospital Medical School.

"AN EXAMPLE OF THE ADVANTAGES OF THE SYSTEMATIC TREATMENT of a Science over the fragmentary style so generally followed. BY A LONG WAY THE BEST of the small Manuals for Students."—*Analyst.*

In Handsome Cloth. With nearly 50 Illustrations. 3s. 6d. net.

THE ELEMENTS OF CHEMICAL ENGINEERING.

BY J. GROSSMANN, M.A., PH.D., F.I.C.

WITH A PREFACE BY

SIR WILLIAM RAMSAY, K.C.B., F.R.S.

CONTENTS.—The Beaker and its Technical Equivalents.—Distilling Flasks, Liebig's Condensers.—Fractionating Tubes and their Technical Equivalents.—The Air-Bath and its Technical Equivalents.—The Blowpipe and Crucible and their Technical Equivalents.—The Steam Boiler and other Sources of Power.—General Remarks on the Application of Heat in Chemical Engineering.—The Funnel and its Technical Equivalents.—The Mortar and its Technical Equivalents.—Measuring Instruments and their Technical Equivalents.—Materials Used in Chemical Engineering and their Mode of Application.—Technical Research and the Designing of Plant.—Conclusion.—Chemicals and Materials.—INDEX.

"Excellent. . . . Every student of chemistry attending a technical course should obtain a copy."—*Chemical News.*

LABORATORY HANDBOOKS BY A. HUMBOLDT SEXTON.

Professor of Metallurgy in the Glasgow and West of Scotland Technical College.

OUTLINES OF QUANTITATIVE ANALYSIS.

FOR THE USE OF STUDENTS.

With Illustrations. FIFTH EDITION. Crown 8vo, Cloth, 3s.

"A COMPACT LABORATORY GUIDE for beginners was wanted, and the want has been WELL SUPPLIED. . . . A good and useful book."—*Lancet.*

OUTLINES OF QUALITATIVE ANALYSIS.

FOR THE USE OF STUDENTS.

With Illustrations. FOURTH EDITION, Revised. Crown 8vo, Cloth, 3s. 6d.

"The work of a thoroughly practical chemist."—*British Medical Journal.*

"Compiled with great care, and will supply a want."—*Journal of Education.*

ELEMENTARY METALLURGY:

Including the Author's Practical Laboratory Course.

[See p. 36 *General Catalogue.*

Griffin's Chemical and Technological Publications.

		GENERAL CATALOGUE, PAGE
Inorganic Chemistry,	PROFS. DUPRÉ AND HAKE,	70
Analysis,	PROF. HUMBOLDT SEXTON,	70
Chemical Engineering,	DR. J. GROSSMANN,	46
Chemistry,	BLOUNT AND BLOXAM,	46, 71
Foods and Poisons,	A. WYNTER BLYTH,	72
Tables for Chemists,	PROF. CASTELL-EVANS,	79
Dairy Chemistry, &c.,	H. D. RICHMOND,	73
Milk,	E. F. WILLOUGHBY,	73
Agricultural Chemistry,	H. INGLE,	73
Flesh Foods,	C. A. MITCHELL,	72
Practical Sanitation,	DR. G. REID,	78
Sanitary Engineering,	F. WOOD,	78
Sewage Treatment,	DUNBAR AND CALVERT,	76
Lessons on Sanitation,	J. W. HARRISON,	78
Technical Mycology,	LAFAR AND SALTER,	74
Soil Bacteria,	J. CLARK,	73
Ferments; and Toxines,	C. OPPENHEIMER,	74
Brewing,	DR. W. J. SYKES,	75
Trades' Waste,	W. NAYLOR,	76
Smoke Abatement,	WM. NICHOLSON,	76
Cements,	G. R. REDGRAVE,	76
Handbook for Cement Works' Chemists,	F. B. GATEHOUSE,	76
Clayworkers' Handbook,	———	75
Peat,	BJÖRLING AND GISSING,	75
Water Supply,	R. E. MIDDLETON,	77
Road Making,	THOS. AITKEN,	79
Gas Manufacture,	W. ATKINSON BUTTERFIELD,	77
Acetylene,	LEEDS AND BUTTERFIELD,	77
Fire and Explosion Risks,	DR. SCHWARTZ,	77
Petroleum,	SIR BOVERTON REDWOOD,	61
——— (Handbook),	THOMSON AND REDWOOD,	61
Ink Manufacture,	MITCHELL AND HEPWORTH,	81
Paper Technology,	R. W. SINDALL,	75
Glue, Gelatine, &c.,	THOS. LAMBERT,	81
Leather Trades Chemistry,	S. R. TROTMAN,	81
Oils, Soaps, Candles,	WRIGHT AND MITCHELL,	71
Lubrication and Lubricants,	ARCHBUTT AND DEELEY,	32
India Rubber,	DR. CARL O. WEBER,	81
Rubber Goods Manufacture,	HEIL AND ESCH,	81
Colour Manufacture,	ZERR, RUBENKAMP, MAYER,	80
Painters' Colours, Oils, &c.,	G. H. HURST,	80
Painters' Laboratory Guide,	" "	80
Painting and Decorating,	W. J. PEARCE,	80
Manual of Dyeing,	KNECHT AND RAWSON,	82
Dictionary of Dyes,	RAWSON AND GARDNER,	82
The Synthetic Dyestuffs,	CAIN AND THORPE,	82
Spinning,	H. R. CARTER,	83
Cotton Weavers' Handbook,	H. B. HEYLIN,	83
Textile Printing,	SEYMOUR ROTHWELL,	83
Textile Fibres of Commerce,	W. I. HANNAN,	83
Dyeing and Cleaning,	F. J. FARRELL,	84
Bleaching, Calico-Printing,	GEO. DUERR,	84

LONDON: CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

Geological, Prospecting, Mining, and Metallurgical Publications.

		GENERAL CATALOGUE, PAGE
Geology, Stratigraphical,	R. ETHERIDGE, F.R.S.,	52
,, Practical Aids,	PROF. GRENVILLE COLE,	52
,, Open Air Studies,	,, ,,	85
Mining Geology,	PROF. JAMES PARK, F.G.S.,	56
Prospecting for Minerals,	S. HERBERT COX, A.R.S.M.,	53
Theodolite Surveying,	PROF. JAMES PARK, F.G.S.,	56
Ore and Stone Mining,	FOSTER AND BROUGH,	54
Elements of Mining,	SIR C. LE NEVE FOSTER,	54
Coal Mining,	H. W. HUGHES, F.G.S.,	55
Practical Coal Mining,	G. L. KERR, M.Inst.M.E.,	55
Elementary ,,	,, ,,	55
Elect. Colliery Practice,	D. BURNS,	57
Mine Surveying,	BENNETT H. BROUGH, A.R.S.M.,	56
Mine Air, Investigation of,	FOSTER AND HALDANE,	54
Elect. Signalling in Mines,	G. J. HOOGHWINKEL,	58
Mining Law,	C. J. ALFORD,	57
Blasting and Explosives,	O. GUTTMANN, A.M.I.C.E.,	58
Testing Explosives,	BICHEL AND LARSEN,	58
Shaft Sinking,	RIEMER AND BROUGH,	58
Mine Accounts,	J. G. LAWN, A.R.S.M.,	57
Mining Eng. Report Book,	E. R. FIELD, M.Inst.M.M.,	57
Petroleum,	SIR BOVERTON REDWOOD,	61
A Handbook on Petroleum,	THOMSON AND REDWOOD,	61
Oil Fuel,	SIDNEY H. NORTH,	61
Mineral Oil Testing,	J. HICKS,	61
Metallurgical Analysis,	MACLEOD AND WALKER,	60
Microscopic Analysis, Metals,	F. OSMOND AND J. E. STEAD, F.R.S.,	60
Metallurgy (General),	PHILLIPS AND BAUERMAN,	60
,, (Elementary),	PROF. HUMBOLDT SEXTON,	66
,, Intro. to Practical,	PROF. THOS. TURNER, A.R.S.M.,	66
Getting Gold,	J. C. F. JOHNSON, F.G.S.,	59
Gold Seeking in S. Africa,	T. KASSNER,	59
Cyanide Process,	PROF. JAMES PARK, F.G.S.,	59
Cyaniding,	JULIAN AND SMART,	59
Electric Smelting,	BORCHERS AND McMILLAN,	67
Electro-Metallurgy,	W. G. McMILLAN, F.I.C.,	67
Assaying,	J. J. AND C. BERINGER,	66
Metallurgical Analysis, Tables,	J. J. MORGAN, F.C.S.,	66
Metallurgy (Introduction to),	SIR. W. ROBERTS-AUSTEN, K.C.B.,	63
Gold, Metallurgy of,	DR. KIRKE ROSE, A.R.S.M.,	63
Lead and Silver, Metallurgy of,	H. F. COLLINS, A.R.S.M.,	64
Iron, Metallurgy of,	PROF. THOS. TURNER, A.R.S.M.,	65
Steel, ,,	F. W. HARBORD,	65
Alloys, Industrial Appl.,	ED. F. LAW, A.R.S.M.,	64
Metallic Alloys (Structure),	G. H. GULLIVER, B.Sc.,	60
Antimony,	C. Y. WANG,	67
General Foundry Practice,	McWILLIAM AND LONGMUIR,	68
Iron-Founding,	PROF. THOMAS TURNER, A.R.S.M.,	68
Precious Stones,	DR. MAX BAUER,	68
Spanish Mining Terms,	ED. HALSE, A.R.S.M.,	57

LONDON: CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

Jacl
V3d nul