MATERIALS OF CONSTRUCTION —NON-METALS.

HUGH GRIFFITHS.

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BY

HUGH GRIFFITHS

WITH NINE ILLUSTRATIONS AND EIGHT TABLES

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MATERIALS OF CHEMICAL PLANT CONSTRUCTION —NON-METALS

I

INTRODUCTORY

In the application of constructional materials to chemical plant, not only must mechanical properties and the usual influences, such as atmospheric action, weathering and rusting, be taken into account, but also the effects of wide ranges of physical conditions and corrosive action have to be considered. It is a commonplace that in many chemical plants the costs of repairs and replacements may be a very serious proportion of manufacturing charges. Nevertheless in many works one finds that there is an extraordinary state of indefiniteness in respect of knowledge of materials of construction, and frequently breakdowns result which cause serious losses of production, time, and consequently of profits. In such works very frequently the designing engineer has but little knowledge of chemistry, and relies on the chemist for information as to how the various materials will " stand up " under the special influences to which they will be subjected. If it should happen that the chemist is without plant experience, the results are disastrous. A chemist from the laboratory with experience of the behaviour of materials *in vitro* is by no means a sure guide, and the behaviour of some materials on the large scale is liable to surprise him. The chemist fresh from the laboratory is usually surprised to see that concentrated sulphuric acid can be handled when hot in iron and steel vessels, whereas it is very simple to show that in a test tube the corrosion seems fairly rapid. Likewise he will probably be new to the fact that strong nitric acid can be transported in lead bogies.

The essential knowledge of the properties of materials is therefore not likely to be secured from either the laboratory chemist or the engineer, who too often regards lead as a universal material to be used as much as possible. This essential knowledge must include all the mechanical properties and chemical properties, coupled with an economic knowledge of how long the constructions are likely to last, and also what influence the special conditions will have on the mechanical properties. It is necessary, however, for the chemist to ascertain and define, before any plant can properly be designed, the nature and amount of the impurities in the reagents employed, and also to specify special effects which constructional materials may have on the reactions it is proposed to employ. Thus, for example, if a research chemist approaches a chemical engineer with a request to provide a plant for chlorination of some organic substance, it will be necessary for him to state what catalytic effects various materials may have. In the case of chlorinating benzene to chlorbenzene an iron vessel is not merely suitable but advantageous, as the iron vessel itself acts as a catalyst, but in the case of chlorination of toluene to benzyl chloride an iron vessel would be hopeless, a lead vessel, even, having some catalytic effect in causing nucleus substitution, but not sufficient to cut out its use for some purposes where a specially pure benzyl chloride is not required. In such cases it is consequently necessary to consider what quality of product is to be manufactured.

Likewise if a pump for nitric acid were required, it would not be sufficient to state the quantity per hour, the head, the strength and the temperature, but also the impurities. If the nitric acid were strong and the temperature moderate, in the absence of chlorine compounds an aluminium pump would give good service; if, however, the acid contained chlorine compounds, stoneware might be necessary. On the other hand, if about 10 per cent. of conc. H_2SO_4 could be introduced without interfering with the process, an iron pump would serve under some circumstances. Too often plant is badly designed because such points are not properly ascertained at the outset, and unexpected failures and delays arise in consequence.

Whilst on this subject it is necessary to indicate how important it is that the research chemist, whose business consists in devising new processes, should have a chemical engineering knowledge of materials of construction, otherwise he may waste his time and efforts considerably. Consider, for example, the manufacture of sulphonic acid salts. The usual laboratory method of preparing the sodium salts of these acids from the ordinary acid reaction mixtures is by addition of salt or mixing with brine. This operation is easy enough in the laboratory, but a nuisance on the large scale, owing to the hydrochloric acid set free. The presence of this acid in the solutions generally means that metallic apparatus cannot be employed, and there is consequently some difficulty. If, however, the chemist responsible for the process knows his job, he would have endeavoured to modify his conditions so as to avoid the use of salt if possible, without some other disadvantage. Likewise one finds in the literature of organic chemistry processes described in which substances have to be heated with hydrochloric acid under pressure. Such processes are rarely used on the large scale, owing to the comparative difficulty of constructing the apparatus. It is, of course, possible to construct high pressure autoclaves for such operations, but the research chemist should not throw such a problem on to the shoulders of the chemical engineer unnecessarily.

In addition to a knowledge of the properties already mentioned, it is desirable that the chemical engineer should know the limitations of plant manufacturers in respect of various materials. Occasionally vessels are specified in stoneware, which are too large or of the wrong shape and design to be manufactured without considerable risk of "wasters." Vessels are often asked for in silicon-iron which would be impossible to make at a reasonable price, owing to the difficulty of machining this material, or the castings called for are of bad design, which would be difficult to produce in a sound condition. Workability in machine tools is often ignored altogether, but this has a very important influence on the cost of plant.

Generally it may be stated that if a piece of apparatus can possibly be constructed of a metal, the results will be better than with a non-metallic construction, the limitations not being so serious, and owing to the unequalled facilities the metals offer for sound constructional work. Nevertheless in the production of chemical plant, for reasons already mentioned, metals cannot always be used, and the non-metallic materials, if correctly used, can be fashioned into very satisfactory constructions, which will give but little trouble. In this volume a brief summary of the essential properties of the non-metallic materials will be given, in so far as possible, but it must be recognized that some of these are of indefinite composition and supplies from different sources differ considerably in properties.

II

BRICKS AND TILES

BRICKS and tiles are derived from naturally occurring clays, these consisting of impure hydrated silicate of alumina. Such clays are formed as decomposition products of rocks, and differ in qualities accordingly as they are left as residues or transported by water currents and deposited in beds. China Clay falls in the residual class, and the ordinary Brick Clays usually in the deposited class.

The essential properties of clay which are important in brickmaking are plasticity and hardening on firing at high temperatures. The latter property is due to the presence of "fluxes," i.e. impurities which assist in cementing the grains together on heating, usually by forming mixtures of lower fusing points. The plasticity is probably some sort of "colloidal" effect, and it is said that addition of vegetable matter may increase plasticity. Hence it might in some cases be impossible to "make bricks without straw." Plasticity is influenced by the treatment of the clay; weathering and grinding, but in general residual clays are non-plastic or "lean," only the sedimentary clays being plastic or "fat."

It will be obvious that the properties of such materials may differ very widely, and it is very difficult to generalise, as large differences may be produced by small differences in composition, and also by the treatment in the kilns.

In the chemical works bricks and tiles may be used for ordinary constructional purposes, and also for work in which resistance to corrosion is important. A very important class of bricks—"Firebricks"—will be considered in the chapter on "Refractories."

(*a*) **Constructional Bricks.**—Information regarding constructional bricks for ordinary uses may be obtained in detail from any of the special works on building construction, and it is sufficient to say here that the chief points in estimating the quality of a load of bricks are : regular size and shape, and freedom from flaws. The texture may be of some importance ; this should be fairly uniform and incipient vitrification should be apparent throughout the brick, even though the colour of the outer layers may be different. The bricks should give a ringing sound when struck together. Sometimes the bricks may be subjected to a test for porosity, as measured by the increase of weight after immersion in water. This may vary from about 8 per cent. to 16 per cent. Bricks are made in various shapes and sizes for special uses, the most usual being the ordinary 9 in. $\times 4\frac{1}{2}$ in. $\times$ 3 in., or sometimes, in the south of England, $8\frac{3}{4}$ in. $\times$ $4\frac{1}{4}$ in. $\times$ $2\frac{3}{4}$ in., which when set equals 9 in. $\times$ $4\frac{1}{2}$ in. $\times$ 3 in. It will be noted that the length in any case should just exceed twice the breadth by about the thickness of the mortar joint.

"Common Bricks" are made from clay alone. "Washed Bricks" have small proportion of chalk, and "Malms" a larger proportion of chalk. The name "Stocks" is given to good serviceable bricks, and the various names may be qualified by "machine-made," "wire-cut," or "pressed," indicative of the method of production. "Rubbers" and "Cutters" are soft bricks sometimes required. "Glazed Bricks" may be of two kinds : "Salt-glazed" are produced from refractory clay, salt being volatilized in the kilns which forms a thin glassy surface layer. Such bricks are not very beautiful, but serve well for chemical buildings interiors, and sometimes for tank work. "White Glazed Bricks" are well known ; they are generally coated on one or more sides with a white clay, "slip," and finally glazed. They are specially useful for reflecting light to relieve dark interiors and internal building work, and are excellent in many situations in the chemical works, but unfortunately they are expensive, and one is often reluctantly compelled to use ordinary brickwork and limewash in an endeavour to "make do."

In the chemical works, a consideration of the mechanical properties of bricks is usually sufficient for ordinary constructional work, and a summary of these is given in Table 1. Foundations, however, have to be watched as sometimes, particularly in old chemical works, the ground is saturated with soluble salts, and these may pass through the porous bricks and give trouble. This point should be investigated carefully before laying foundations for flues, boilers, etc., otherwise the soluble salts will find their way through and spoil the refractories. In such cases a specially vitrified impervious brick must be employed. Brickwork supports for apparatus may sometimes give trouble. If there should be any tendency for acids to dribble down, it is advisable to set the bricks in a mixture of fireclay and tar, or at least to "point" with such a mixture. Naturally enough, in such cases, ordinary mortar would fail quickly, but some bricks will resist weak acids fairly well, but not for very long. The writer recently dismantled an old chamber plant, and the bricks in the foundations were as soft as cheese and the mortar just like cream. This, however, represented the work of about thirty years' acid leakage from a very badly constructed plant.

Table 2 gives data for calculation of quantities for estimating purposes.

(*b*) **Acid-Resisting Bricks.**—In the selection of an acid-resisting brick for chemical plant work, composition is absolutely useless as a guide, and far more important are porosity, texture, and degree of vitrification. It is therefore to be expected that those bricks which contain appreciable proportions of oxides of iron and are fired at rather high temperatures, and consequently highly vitrified, would be very satisfactory. The hard Staffordshire Blue Bricks sold extensively for paving belong to this class, but these are generally too porous and low in acid-resisting qualities. Special kinds are manufactured in Cheshire and Flintshire, under various trade names: "Adamantine," "Metalline," "Obsidianite," etc. These are obtainable in special shapes: sections and packings for absorption towers, and Glover towers, arch blocks, etc., and as covers, basin seatings, etc., for cascade concentrators, jet blowers, nozzles, draining tiles, and in various interlocking forms, such as tank slabs.

The makers of "Obsidianite" state that, according to Messrs. Kirkaldy's tests, the composition is: SiO_2, 79·1 per cent.; alumina, 15·2 per cent.; iron oxide, 3·5 per cent.; CaO, 1·2 per cent.; MgO, 0·3 per cent. It will be seen that, apart from iron oxides, the proportion of fluxes is very small, yet this brick shows a porosity of only 0·31 per cent. by the water test.

Such bricks will last between five and twelve years in a Glover Tower, and this is a fair indication of the resistance to corrosion under practical conditions. The various qualities differ in composition according to their special application, but it may be stated that approximately "Metalline" and some others may be applied in the same way as "Obsidianite." Some of the bricks of this class are very useful refractories and will be considered later.

Whilst pipes, etc., can be obtained in most of these blue acid-resisting brick materials, it is not possible to obtain every kind in thin pieces. Another kind of acid-resisting brick is available, however, from the Accrington district, and sold commercially under the name "Nori Brick," probably of similar composition but reddish appearance. This material can be successfully applied to very difficult situations. Packings for Acid Concentration Towers, and various special parts for Vitriol Concentrators, are now produced in this brick, and give very good service. The material resists the action of most acids, even at high temperatures. A very convenient application of this brick is in the lining of iron vessels to resist corrosion, and the writer knows of no better material for lining wooden vats for containing acid liquors, or for crystallizing acid salts, if these attack lead.

In general, acid-resisting bricks will withstand the action of sulphuric and nitric acids alone or together, at all temperatures, and at most concentrations, but do not of course withstand the action of hydrofluoric acid. It should not be forgotten that phosphoric acid, when concentrated and hot, acts rapidly on some bricks, and that phosphoric acid attacks silica. In such a case vitrification is more important than composition, but a suitable brick can only be selected by experience. In the absence of experience composition is by no means a sure guide, and laboratory experiments may be misleading. Some information may be gathered by pulverizing a whole brick, sifting carefully, and determining the solubility in the corrosive material at the working temperature of a definite grist, say that passing through 16 mesh and caught on 20 mesh. The solubility value so obtained must of course be considered along with the figures obtained by a porosity test.

This procedure is of course quite useless in the case of a glazed brick, and in every case examination should be made as to the depth of vitrification. It is necessary to mention also that whilst some bricks will resist the action of cooled acids very successfully, they do not behave so well when subjected to changes of temperature. Furthermore, in many cases, for example in the case of a tower filling, resistance to crushing may be of considerable importance. In certain special cases the fillings of scrubbing towers are so deficient in mechanical strength that the packing of a tall tower would very soon fail; usually, however, acid-resisting bricks have a very high crushing strength.

It is very interesting to observe that in other countries it is frequently found that acid-resisting bricks are whitish grey, and practically free from iron oxide or lime. It will be found that such bricks are nevertheless thoroughly vitrified and of low porosity. This serves to show where the resistance lies.

(*c*) **Porous Bricks.**—Various useful porous slabs for filtration of corrosive liquids can be obtained commercially, and some of them in various grades. Particulars as to how these are manufactured are not usually given, but possibly the method consists in mixing sawdust, or some other organic substance with the clay, which volatilizes during the firing. The Bornett slabs are well known, and also McKenzie and McLaughlan's. The former firm has specially constructed filters for use with the slabs, in which pressure or suction may be applied to assist filtration. Such slabs may be used to filter weak alkaline liquids which destroy filter cloth, and some pulps filter more readily on such slabs than on cloths. A common application is the filtration of sulphuric acid after de-arsenication. An American product of this type is sold under the name "Filtros," usually in plates about 1 foot square, but in special shapes up to 16 inches square if required. This is made for filtering in seven grades, the coarsest being about fifty times as porous as the finest grade. This material is also supplied for diaphragms for electrolytic cells, under the name "Electro-Filtros." Filter plates are also obtainable in "Alundum," which is fused alumina.

TABLE 1

Properties of Bricks of Average Quality

Class.	Wt. lb. per cub. ft.	Crushing Strength. Tons per sq. ft.	Porosity.	Remarks.
Common	125	75	16	Wide variations in qualities
Firebrick	135	250	7	,,
Staffordshire Blue Pressed Brick	155	270	11	
Acid-Resisting Brick, Blue	170	400–700	·31–1·5	—
Acid-Resisting Brick, Red	165	500	·4–1·5	—

TABLE 2

Approx. Quantities of Bricks and Mortar required for Brickwork

Material.	For 1 cub. yard of Brickwork ¼ in. Joints.	
	English Standard Bricks. 8¾ in. × 4¼ in. × 2¾ in.	American Standard Bricks. 8¼ in. × 4 in. × 2¼ in.
Common Bricks	20·7 cub. ft. 380 bricks	18 cub. ft. 500 bricks
Mortar	6·3 cub. ft.	9 cub. ft.
Lime	2·16 ,,	2·6 ,,
Sand	7·5 ,,	8 ,,
Chalk Lime	3·24 ,,	
Drift	6·48 ,,	
Natural Cement	4 ,,	5 ,,
Sand	4 ,,	5 ,,
Portland Cement	2·5 ,,	2·8 ,,
Sand	7·5 ,,	8 ,,

III

REFRACTORIES

ONLY a very short description of the refractory materials can be given here. It would be possible to write a large treatise on these materials, and it is possible that no two experts would agree as to the results of their experience, so great is the complexity of the subject.

The qualities by which a refractory must be judged are: resistance to high temperature, resistance to changes of temperature, mechanical strength, texture, thermal and electrical conductivity, and these refractory properties may have to be maintained in the presence of chemical substances, which tend to react with the refractories. These properties are never found in an ideal combination, and the choice of a refractory material generally resolves itself into selection of lesser evils.

Refractory materials are generally classified under three heads: Acid, Neutral, and Basic; but it is convenient to consider Fireclays separately. Classification can, however, apply only to types, and commercial refractories may differ so much as to render classification almost impossible. The products of different makers sold under the same description will seldom have the same properties, and some makers seem to have no idea of the importance of maintaining uniform quality of their productions. Refractories therefore, unless purchased from first-class firms who have proper equipment and facilities for scientific control of manufacture, are liable to prove a source of constant trouble and irritation, and very often in a chemical works one finds a comparatively unsatisfactory material in use simply because bitter experience has taught that "better the devil you do know than the devil you don't know."

The sizes and shapes of some bricks may also differ considerably, and as a result they are wholly unsuited for first-class work. It is necessary for some purposes to have the refractories guaranteed to size, and even in shape. Occasionally the desired limits have to be obtained by grinding on abrasive wheels.

Among the fireclay bricks alone, one finds all manner of trade descriptions, supposed to indicate their suitability for various purposes. These names are frequently without foundation in the properties of the bricks, and do not in any way indicate the position of such materials in the classification given here.

(*a*) **Fireclays and Firebricks.**—A "fireclay" is a clay as previously defined, which forms a brick on firing, having a resistance to temperature not less than Seger Cone No. 26. Actually fireclays generally range between Cone 26 and Cone 36, but Cone 34 represents the upper limit for most clays. In order that the brick shall have reasonable mechanical strength, the presence of flux-forming impurities is necessary, usually less than 6 per cent. in all, or otherwise the necessary level of Cone 26 is not achieved.

Whilst the pure silica-alumina mixtures are never used in practice, it is of special interest to consider the solidifying point curve of these mixtures as shown in Fig. 1. It will be noted that pure Al_2O_3 has a solidifying point about 200° higher than pure SiO_2, and that the curve shows a sharp eutectic. This curve serves to explain why a fireclay mortar, which has the same fusing point as the bricks, may behave as a flux and diminish the refractoriness. It will not, however, do to jump at conclusions from such theoretical considerations, as silica in the uncombined state, and fluxes are found in all clays. Silica expands on heating, and therefore counteracts the tendency of clay to shrinkage. At a lower temperature it may have a favourable influence on refractory properties, whilst at the higher temperatures acting as a flux. The effect of various fluxes on the refractory properties is too complex to be considered here.

In general, it may be stated that although several methods have been suggested for drawing conclusions regarding refractoriness from chemical analyses, none of these can be so satisfactory as a direct test. A clay may be shaped into a small cone and heated with a short series of standard Seger

Cones, for comparison. If the influence of chemical action has to be ascertained, the reagents may be incorporated in the clay in various proportions in experimental cones, and the effect on refractoriness duly ascertained.

Firebrick is usually greyish in colour, density 1·8 to 2·0, porosity (water-absorption) 10–15 per cent., and crushing strength about 1,700–2,000 lb. per square inch. Most fire-bricks shrink on heating, by a linear proportion varying from

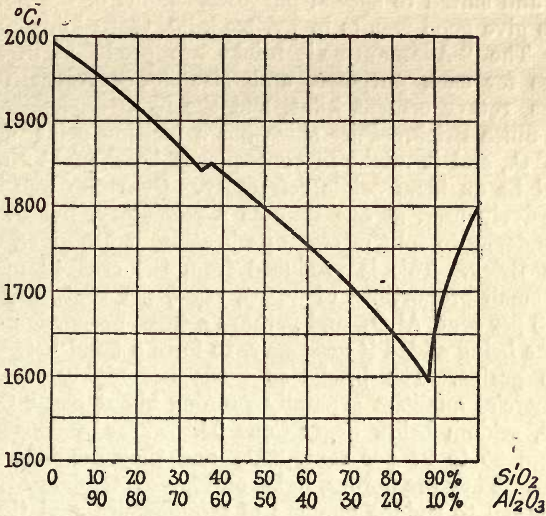

FIG. 1.—Curve showing Freezing Points of Alumina-Silica Mixtures.

½ per cent. to 3 per cent. according to the amount of free silica. Due precautions have to be exercised in laying such bricks that the clay used for mortar is of the correct composition as mentioned above, in fact most of the makers supply suitable clays for setting.

Appearance is not a good guide to refractory properties, but as a general rule the coarser grained bricks show better resistance to changes of temperature, and the finer grained better resistance to attrition and corrosion.

Regularity of shape and freedom from flaws may be very important, and in some cases, e.g. coke oven building, the firebricks are ground to true shapes and sizes, to ensure a sound gas-tight job. Such bricks are of course expensive. Among the ordinary firebricks there are many varieties, the best known being Stourbridge and Glenboig.

The "blue" firebricks are of a different nature, in that the most important fluxing ingredient appears to be oxide of iron. These are obtainable in various degrees of refractoriness, and suited to special purposes. Some of the blue firebricks give good results in pyrites kilns, Claus kilns, and the like. The "Adamantine" bricks are produced in special shapes for such purposes, and also for revolver furnace linings, rotary cement kilns, and the like.

(*b*) **Silica Brick.**—Pure silica has a melting point of about 1,750° C., and it might in consequence be thought that this would be an ideal acidic refractory. Quartzite was in fact extensively used at one time as a refractory, but owing to its tendency to split or crack on heating, it has given way to Silica Brick. This is produced from the crushed material, with small proportions of fluxes, say ½ per cent. Fe_2O_3 and 2 to 3 per cent. Al_2O_3, and perhaps a small proportion of milk of lime being added if necessary, to form a bond between the sharp grains. The bricks so made are highly refractory, commercial qualities generally running about Seger Cone 35 or 36, seldom below Seger Cone 33. These bricks generally contain 95 to 97 per cent. SiO_2, and they are brownish in colour. They are porous, light, and have a tendency to crack if exposed to sudden changes of temperature, and they also expand on heating. The mechanical properties vary with the proportion of fluxes, and the less refractory bricks have the higher compressive strength, this varying from 2,000–4,000 lb. per square inch.

The use of silica bricks has rendered possible the advance of regenerative systems of firing, and only silica bricks will withstand the action of the highest temperatures in regenerative furnaces for any considerable period. Whilst nearly all fireclay bricks lose mechanical strength rapidly above 1,300° C., i.e. perhaps as much as 300° C. below the melting point, as compared with Seger Cones, and the bricks "flow" under quite small pressures.

The melting point of clay is not definite, as in the case of a pure chemical product. Nevertheless all refractories, even silica brick, actually diminish in compressive strength as temperature rises, but the diminution in the case of silica brick is of a different character. The data given in the curve Fig. 2 are calculated from Le Chatelier's researches on "Star" Silica Brick.

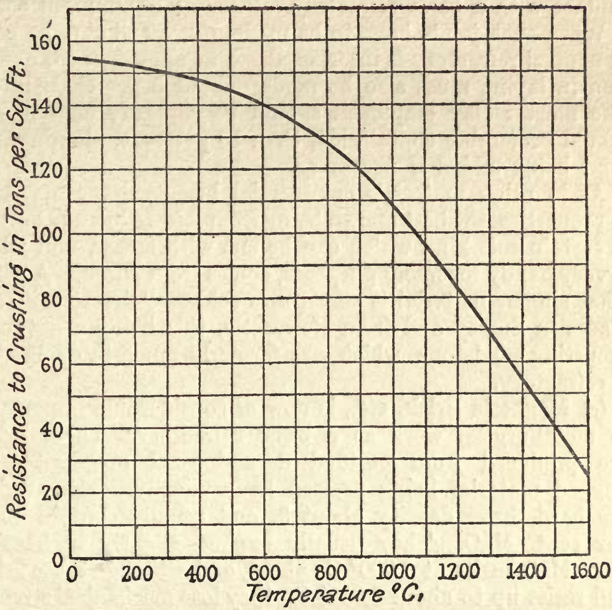

FIG. 2.—Compressive Strength of Star Silica Brick.

It will be noted that even at 1,700° C. the compressive strength would be more than ample for a furnace arch.

It might be thought that silica brick would be highly resistant to acids, and other chemical influences, but the very reverse is the case. Silica brick is porous, and does not resist the action of acids at all well, but swells and disintegrates rapidly. On the other hand it is surprising to find silica brick lining the upper part of shaft lime kilns, and sometimes

Quartzite Blocks may be so used. The reason for this is found in that the upper part of such kilns is not at a high temperature (below the fluxing temperature), and these materials withstand the action of abrasion due to the moving charge on account of their hardness.

In laying silica bricks or other acidic refractories, it is necessary to remember that they must not be laid in direct contact with a basic refractory, otherwise fluxing will occur.

When such joints have to be made, a layer of chrome brick or neutral refractory is interposed. Due allowance for expansion in laying must also be made—about 3 per cent. linear. The mortar clay employed should be carefully chosen, and should preferably contain less than 10 per cent. alumina, fine sand being added if necessary.

As in other materials commercial brands differ markedly in properties, the best known being from Kidwelly and Dowlais. A certain soft kind which can be cut with a saw, and which is very handy for many purposes, comes from Ewell. A somewhat similar material is sometimes sold as "firestone" from places in Surrey and from Newcastle, this being a naturally occurring sandstone, which was formerly much in demand as a refractory.

(*c*) **Magnesia Brick, etc.,** is now of considerable importance in metallurgical work as a basic refractory. These bricks are produced from purified dense-burned magnesite, the pugged material being pressed hydraulically. These bricks are hard, have density about 3, and usually contain 85–90 per cent. MgO. They usually expand slightly in heating. Pure MgO melts at 3,000° C., about, and although these bricks will resist up to about 2,000° C., they lose mechanical strength at about 1,500° C.

In so far as composition is a guide, it may be said that the limits of composition for satisfactory bricks are: minimum, MgO 83 per cent., Fe_2O_3 3 per cent.; maximum, 5 per cent. CaO, 2 per cent. Al_2O_3, 5 per cent. SiO_2.

It is generally stated in the literature that fused or sintered magnesia has not found application as a refractory, but for some the Norton Company have marketed such material having a density of about 3·65.

Dolomite and Dolomite Brick, lime, etc., may also be considered as basic refractories, but they do not find much application in ordinary chemical work.

(*d*) **Bauxite Brick.**—Bauxite is a material containing essenitally hydrated alumina with some SiO_2 and traces of iron oxides. It has a fairly high fusing point, usually about 1,800° C., but shrinks very considerably on heating, and is therefore only used in admixture with clays or silica. Such bricks can be obtained up to Seger Cone 38.

An interesting product prepared from Bauxite is *Alundum*, which is alumina fused in the electric furnace. It is employed as a refractory, and also as an abrasive. It is very hard, and is employed for grinding wheels, and also for crucibles.

The exact properties of Alundum depend upon the bonding material employed, the melting point generally being below that of alumina. The density is about 3·9. Specific Heat ·195. Coefficient of expansion per deg. C. ·0000071.

(*e*) **Chrome Brick.**—Chromite Blocks were formerly used to form neutral joints between acidic and basic refractories. These are now displaced almost entirely by the Chrome Bricks, which are produced from crushed chromite, suitable bonding agents being added.

This refractory is of the neutral type, and will resist some types of chemical action surprisingly well. It has a high melting point, but loses mechanical strength at about 1,300–1,400° C.

(*f*) **Miscellaneous Refractories.**—The above materials cover most ordinary chemical works requirements, but there are others of lesser importance.

Crucibles for many purposes are made of mixtures of fireclay, graphite and fine sand.

Carborundum is a silicon carbide produced in the electric furnace which will stand heating at over 2,000° C. It is remarkably resistant to corrosion, and is sometimes used as a coating in the manufacture of crucibles, and may be added to the mass. Certain modifications of this material are marketed, and crucible materials containing Carborundum are obtainable commercially. The Norton Company's Crystolon Ware is a fair example, this having a very low coefficient of expansion—per ° C. about ·0000045. This is used for some electric furnace parts and muffles. A specially interesting property of Carborundum is that it is not attacked by hydrofluoric acid.

Silicon.—A similar material can be made into small crucibles by using alumina as fluxing material, and clay can be added to form moulded pieces.

Zirconia Refractories probably have a future, but at the present time they have not come into extensive use. Pure Zirconia has a melting point of about 2,800° C., and is very inert, and resists corrosion. The ordinary commercial bricks, for example Foote Mineral Company's "Zirkite" Bricks, have the same application as Magnesia Brick, but are able to stand the action of basic materials, and show but little tendency to spall under rapid changes of temperature. The ordinary qualities usually contain silica. These refractories resist oxides of heavy metals only moderately.

Table 3 gives a summary of the properties of various refractories, and the figures will be found sufficient for all practical purposes. It should be noted that the expression "melting point" has no very definite meaning in its application to refractories, and that unless the rate of heating is specified, the figures have no definite meaning. In the table no figures have been given for crushing strength, as the available data is meagre, and the strength depends upon the temperature and method of heating. Common fireclay brick, for example, begins to flow under comparatively low pressures at temperatures 400° C. or so below the melting point, and such bricks do not give satisfaction for arches of regenerative furnaces worked at a high temperature. Silica brick behaves differently, and will withstand temperatures much nearer its melting point without commencing to flow appreciably. Magnesia Brick like firebrick also loses strength at temperatures below the melting point. These considerations coupled with the variability of commercial brands render strictly accurate data impossible in generalized form.

TABLE 3

Properties of Refractory Materials

	Specific Gravity.	Melting Point ° C.	Behaviour on Heating.	Thermal Conductivity Metre, Kilog. hour units.	Character.
Firebrick . .	1·8	1,500 upwards	Usually shrinks slightly	1·50	Variable
Blue Fire-brick { Ord. .	2·3	1,500	Usually shrinks slightly	—	Variable
Blue Fire-brick { Adamantine	—	1,700	Ditto	—	Variable
Silica Brick .	1·6	1,750	Expands 3%	·71	Acidic
Bauxite Brick	1·9	1,800	Shrinks considerably	1·19	Neutral
Alundum Brick	3·91	Below 2,050	Coeff. of exp. ·0000071	—	Neutral
Chrome Brick .	3·1	2,050	Expands	2·05	Neutral
Magnesia Brick	2·0–3·0	2,000	Shrinks	2·54	Basic
Carborundum refractories	2·0	Variable	Coeff. exp. ·0000045	8·32	Acidic
Zirconia . .	—	2,800	Commercial refractories shrink slightly	Low	Basic

IV

STONE

Of the different varieties of stone employed in chemical engineering work, we have granites, volvic stone, and pumice-stone among the igneous rocks, sandstone and limestones among the sedimentary rocks, and slate among the metamorphic rocks.

(*a*) **Granite** is by no means an acid-resisting material, but is generally employed where hardness is essential, and where wearing qualities are required. Some kinds of granite will resist the action of acid moderately, but in no case is there any great resistance to temperature. The chief application of granite is in the constructing of parts for grinding machine, as cylinders, rollers and beds for various wills.

(*b*) **Volvic Stone** is a fairly important material of construction, particularly for sulphuric acid Concentrating Plants. The great advantage of this material for such constructions is that it can be obtained from the various special firms in the South of France shaped into large blocks, and the number of joints need not be very considerable. Although Volvic Stone is essentially a lava, it is not always purely vitreous in structure, and generally contains small bubbles. In practice it will be found that Volvic Stone is not absolutely non-porous, and it is therefore customary to encase Volvic structures where acids are treated at a high temperature in thick lead casings. Volvic Stone was before the war generally regarded as the best material for the construction of acid concentration plants, and it does undoubtedly resist the action of Sulphuric Acid at the highest temperature, and this property, coupled with the circumstance that it can be obtained in large pieces, prove a great attraction. Its mechanical strength is also considerable. During the war the exportation of Volvic Stone from France was prohibited, and therefore, in this country at any rate, a tendency has arisen to find substitutes for this material among the various qualities of acid-resisting brick. These substitutes are quite satisfactory and somewhat cheap, but the great advantage of Volvic Stone is in the reduction of the number of cemented joints, as the pieces may be large.

(*c*) **Sandstone** is of many different kinds, and may be classified roughly into calcareous sandstone, in which the grains are cemented together with lime, and siliceous, in which they are cemented together by silica. Sandstone for ordinary constructional purposes and foundations need not be specially considered, but for chemical purposes it is obvious that the calcareous varieties will be of no value. For some chemical purposes very few qualities of satisfactory sandstone can be found. The various "grits," which are close-grained, homogeneous and strong, are suitable for engine foundations, but not so cheap as concrete. Various kinds of firestone have been used in the construction of boiler flues and furnace parts, these being found in Surrey and also near Newcastle. Sandstone is not now so popular as formerly for chemical work, as it is a very difficult matter to choose a really satisfactory stone, and the vessels so constructed are very heavy, and by no means cheap. From certain parts of Yorkshire and Lancashire very satisfactory stones can be obtained which have a most excellent resistance to Hydrochloric Acid and Nitric Acid. Some similar stones can be obtained in Scotland.

It is utterly useless to consider chemical analysis as a guide to the selection of a stone for acid-resisting purposes, neither is microscopic examination of any value, and visual inspection is equally useless. Certain quarries have a reputation for stone for chemical purposes, and these particular qualities only should be used. Even from these quarries occasionally bad stones will be obtained, some invisible streak of calcareous material causing a failure after the material has been put into use. In this particular direction second-hand stones are certainly better than new, as there is no knowing when a new tank or set of slabs is delivered what will happen during the first few weeks.

Formerly stone tanks were seen in chemical works in considerable numbers for storing hydrochloric acid, and also for boiling various acid solutions. These were frequently hewn out of the solid stone, the walls being anything from 6 in. to 9 in. in thickness, and such a tank, if it withstood the first few months of treatment, would generally be everlasting. It is now more usual to employ tanks built up of slabs, braced together externally by means of steel rods. Such tanks are perfectly satisfactory, and are less expensive, especially if any fault should be found, as a new slab can be put in at any time.

The advance in the manufacture of chemical stoneware has considerably diminished the popularity of stone for the construction of chemical apparatus, and it is now only employed where acid-resisting qualities have to be secured, coupled with considerable mechanical strength. Certain parts of Absorption Plant are still made of stone, and this appears to be the best material for such purpose, as stoneware will not take heavy loads, and acid-resisting brick has other disadvantages.

Usually stone slabs, tower bases and tanks are impregnated with tar before being put into use. This seems to be a doubtful practice, and should be unnecessary if the proper kind of stone is used, but in most works the tar-boiling of the stones is carried out religiously.

(*d*) **Slate** was formerly rather popular as a constructional material, apart from its use for roofing purposes. The various sizes of roofing slates are sold under names indicative of their sizes, and quantities are generally calculated in " thousands " of 1,200. Superficial area is generally expressed in " squares," these being equal to 100 sq. ft.

Quantities may be calculated roughly from the following table :—

TABLE 4

Size.	Name.	Number to cover 100 sq. feet roof area.
14 × 12	Ladies	250 approx.
20 × 10	Countesses	175 ,,
24 × 12	Duchesses	125 ,,
36 × 24	Queens	40 ,,

As a general rule smaller sizes are only required for steep roofs.

For chemical purposes it is a somewhat treacherous material, and is liable to disintegrate, although weak acids have not very much detrimental effect. In this, as in other cases, chemical analysis is no use as a guide to the quality of the slate whatsoever. It is still used for electrolytic cells in America, and was formerly employed for this purpose in England, but has been displaced by concrete.

(*e*) **Pumice-stone.**—The most important use of Pumice-stone in the chemical works is in packing absorption towers and scrubbers. Provided a good quality is obtained having the necessary mechanical strength, Pumice-stone has considerable advantages, and provided a suitable grading is adopted it is entirely suitable. Powdered pumice-stone may also be used in the preparation of certain acid-resisting cements. Pumice-stone sometimes gives trouble in scrubbing towers which are high owing to the weight of the packing crushing the lower layers, and so causing stoppages. Such packings should not be too deep, and should be carefully graded.

(*f*) **Quartzite** is probably a better material as an absorption tower or scrubber packing than either Pumice or Coke. The latter are frequently favoured, owing to their cellular porous structure, but quartzite is usually cheap and very clean in working. It is of course essential that it should be properly graded. Quartzite will stand the action of all acids of moderate strength except hydrofluoric, but is not very reliable against changes of temperature. Blocks of Quartzite laid in cement and Silex—natural flint brick—have found useful application in lining ball mills.

(*g*) **Soapstone** in quarried form has been used, especially in America, as a material for acid tanks and for furnace linings.

(*h*) **Limestone** is not very useful for chemical plant work, but may occasionally find use in buildings.

(*i*) **Asphalt** is a form of limestone which carries with it about 10–20 per cent. of bitumen. This latter—a pitchy substance—is a natural product, and has evidently originated from some organic matter which has been forced into the limestone by volcanic action. Asphalt is obtainable commercially, the various kinds generally being sold under names indicating the origins of the products: Limmer, Seyssel, Silician, Val de Travers. This material is generally laid down hot and tamped into position with heavy tools. The chief use is for making floors and rendering walls watertight. It is also useful for lining drying stoves, water tanks, and the like.

Asphalt is by no means a reliable material against the action of acids, although this is not usually realized. Even weak acids will in time make their way through fairly thick layers. Some qualities are satisfactory, but these are generally mixtures of bitumen with sand and rock other than limestone.

(*j*) **Flints, Pebbles, etc.**—It is necessary to say that flints, pebbles and the like are not suitable for packing scrubbers where acid liquids are circulated. Such materials are seldom homogeneous and wholly of amorphous silica and sometimes swell or split under the action of acids, in some cases to a large extent.

Pebbles have been very successfully used as a means of lining ball and tube mills, ribbed metal plates being provided to grip them and hold them in position by wedging action. (El Oro Lining).

(*k*) **Asbestos** is the basis of a large number of materials for chemical works: packings for pumps and pipe joints, acid-resisting cements, filter cloths, etc. It is a mineral product consisting of impure silicate of magnesia. The commercial qualities fall into two classes, the "amphibole" and the "chrysolite"; the latter containing a fair proportion of hydrated silicates. Hence, where resistance to high temperature is of the greatest importance the chrysolite asbestos is not suitable. On the other hand this quality is generally superior for woven fabrics such as filter cloth.

The essential qualities to be looked for in a supply of asbestos may be length of fibre and purity. Length of fibre is of importance in woven materials, and purity of special importance if the material is to be used in contact with acids. It is generally assumed that asbestos is quite insoluble in acids, but if commercial samples be tested it will be found that sometimes 30 to 50 per cent. dissolves away. For making acid-resisting cements, the material should invariably be extracted with acids before use, otherwise there will be trouble. For chemical purposes it is impossible to give general guidance as supplies differ in a most extraordinary manner from time to time. Some of the blue asbestos (Cape Asbestos) is very durable, and shows an extraordinary freedom from soluble impurities.

Manufactured asbestos goods include gaskets for pipe joints, sometimes incorporating rubber, metal, and in the form of sheeting. Lagging materials for pipes are built up of asbestos fibre, magnesia and kieselguhr and other materials. Partition bricks, tiles, slates, etc., are made of asbestos fibre and various cements. Such materials as Uralite and Poilite are of similar character, and serve for fireproofing partitions, roofing, and even buildings.

Occasionally in the chemical works it is necessary to produce diaphragms consisting of asbestos cloth the meshes of which are filled with a porous paste or resistant cement.

Table 5 gives the mechanical properties of the more important stones.

TABLE 5

PROPERTIES OF STONES

Kind.	Weight in lb. per cub. foot.	Crushing Strength Tons per sq. ft.	Shearing Strength Tons per sq. in.	Modulus Elasticity lb. per sq. in.	Porosity Percentage absorbed.
Granite .	165	1,200	·89	7×10^6	·3
Sandstone	150	650	·66	3×10^6	2–4
Slate . .	175	1,200	—	14×10^6	·5
Limestone	170	470	·44	7×10^6	15
Pumice .	—	10–25	—	—	—

V

ARTIFICIAL STONES

THE most important artificial stones are those derived from Portland Cement.

(*a*) **Concrete.**—The term concrete is applied to an artificial stone made by mixing a matrix of Portland cement and water with a fine aggregate of sand or stone screenings, and a coarse aggregate of broken stone, screened gravel, slag, cinders, or any hard durable material. Cinders are only used where it is desired to have a cheap light concrete of low strength, which is used chiefly in floors and low partitions.

Frequently the fine and coarse aggregates are combined by using unscreened gravel if the fine and coarse constituents are found in approximately the correct proportions. The theory of proportioning concrete correctly is that the voids or air spaces in the coarse aggregate should be filled by the fine aggregate, and the voids in the fine aggregate should be filled by the cement. The strongest concrete is obtained when these conditions are most successfully fulfilled, and porosity in the finished concrete eliminated as far as possible.

The usual method of determining voids is to measure the amount of water required to fill the voids in a given volume of aggregate, but this method is not reliable in aggregate containing much fine material. A more accurate method is given by use of formula :

$$P = \frac{1 - W}{Y(G \times 62 \cdot 5)}$$

where Y = volume of material
W = weight of material
G = specific gravity of solid stone
P = percentage of voids

If an appreciable amount of moisture is present, this must first be eliminated by drying.

Usual proportions for various kinds of work:

TABLE 6.

	Cement.	Sand.	Stone.
Reinforced columns and beams requiring great strength	1	1	2
Ordinary reinforced work columns and beams, tanks, and thin walls	1	2	4
Heavy reinforced work and piers and abutments in plain concrete.	1	3	6
Foundations and heavy retaining walls . .	1	4	8

Floors are usually made with a base 1 : 3 : 6, and a 2 in. top face of 1 part cement to 2–3 parts sand. Cinder concrete is usually of proportions 1 : 2 : 5.

Weight of stone concrete . . 145 lb. per cub. ft.
,, cinder concrete . . 110 lb. per cub. ft.

TABLE 7.

COMPRESSIVE STRENGTH OF CONCRETE.

Mixture.			Strength Tons per sq. ft.		
Cement.	Sand.	Stone.	1 month.	3 months.	6 months.
1	2	4	158	174	231
1	3	6	138	157	196
1	3	6	34	50	—

Generally speaking, a stronger concrete will be secured when mixed fairly dry, but in practice, particularly in reinforced concrete work, a wetter consistency is necessary, and the difference in strength between concretes mixed wet and that mixed fairly dry, grows less as time elapses, until in about three to four months time their strength is about equal.

Reinforced concrete is concrete in which iron or steel is embedded, and the members of a structure are so designed that metal which has a high tensile strength takes the tensile stresses, and the concrete which has high compressive strength but low tensile strength takes the compressive and direct shearing stresses. The fact that the coefficient of expansion of iron is ·000013 per ° C., and that of concrete ·000010 per ° C., render this economic combination possible.

The durability of concrete renders it an excellent fire-proof covering for steel and a protection against corrosion, so that a combination of the two materials constitutes a form of construction possessing largely the advantages of the two materials, without their disadvantages.

In this work the quality of the concrete requires to be much higher than in most plain concrete work. It must be uniform in quality and free from voids, as the stability of building is dependent on the reliability of every part. It is most important that good adhesions of the reinforcement to the concrete should be obtained, and complete protection of the metal from corrosion and fire. Owing to difficulty of placing, particularly where reinforcing members are set close together, a much finer aggregate is required than in plain concrete, but it is advisable to employ as large an aggregate as will admit of economical working. Customary maximum sizes are from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. For the same reason it is advisable to use a somewhat wetter mixture.

Reinforcement is generally used in the form of rods and bars of size varying from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in thin floors, partitions and screen walls, to $1\frac{1}{2}$ in. to 2 in. as maximum for very heavy columns and beams.

The most suitable steel for reinforcement purposes is that made by the open-hearth process, and it should be capable of being bent cold to the desired shape. Tensile strength should be not less than 45 tons per sq. in. breaking stress, as when inferior metal is used it means greater number of reinforcing members and increased difficulty and cost of placing concrete.

Plain round and square bars are most frequently used, as their adhesion to the concrete is greater than flat bars, and many special forms of bars with indentations and corrugations have been marketed whose principal object is to form a mechanical bond independent of adhesion. Expanded metal and chicken wire netting is frequently used for thin walls and floors which are designed for light loads.

Bond Strength.—This term is applied to the strength of adhesion between the reinforcement and the concrete in which it is embedded to resist the longitudinal motion of reinforcement when taking the tensile stresses. About 50 per cent. to 80 per cent. of the adhesive strength is frictional resistance, and varies greatly with the roughness of the bars. The ultimate bond strength is frequently increased by hooking the ends of the bars by a 90° or 180° bend.

Forms.—The term form is applied to the containing frame or mould in which the concrete is kept in place to desired shape until it has hardened sufficiently. The design should be as simple as possible, and as carpenter labour and timber are more costly than concrete, the labour of placing concrete, it is often advisable to modify the design, so as to simplify the form work at the expense of using more concrete. This particularly applies to standardizing sizes of columns and beams, so that some boxes can be used again and again, although it involves using larger beams or columns in some cases than the load calls for. Forms must be rigidly constructed, durable and designed to be easily removed, and to sustain a live load of about 70 lb. per sq. ft. in addition to weight of concrete. For tanks, bins, silos, and other plain repetition work, it is often economical to use moving forms which are raised step by step as the work advances.

As a material of construction reinforced concrete is becoming increasingly popular in the chemical industry, not only for buildings, but for tanks, bins, gas purifiers, chimneys, pipes, conduits, engine beds, and a variety of uses outside the scope of this manual.

The cost compares very favourably with that of structural steel, and it is stronger, more durable and a better fire-resisting material than any other form of construction. Its sole disadvantage lies in the difficulty of dismantling and moving in the case of structural alterations.

The use of concrete blocks in place of brick or stone has had considerable vogue in recent years, but their popularity is chiefly due to the high cost of bricks. If this falls, concrete blocks should not prove a serious competition to bricks, unless cheap supplies of good aggregate in the form of gravel pits or quarry refuse are available in the district where the construction is to be undertaken.

Concrete tanks are sometimes lined with acid-resisting tiles. Such acid tanks are not always satisfactory, and special care has to be taken to ensure that the acid shall not leak through the joints and into the concrete. It is therefore usually necessary to fix two layers of tiles overlapping at the joints. Sometimes concrete tanks are lead-lined, but this is corroded by the alkaline earth constituents of the concrete, particularly in presence of moist air. Lime converts lead under such conditions into calcium plumbite or plumbate.

Tanks are frequently treated with various preparations to diminish porosity and to render them watertight. Calcium chloride and silicate of soda, magnesium chloride or zinc chloride and silicate of soda, and also various proprietary mixtures, may be so employed. Tar, pitch and bitumen may also be used. These expedients are not very successful. Some attempts have also been made to produce a sort of concrete with an acid-resisting body, but up to the present without marked success.

(*b*) **Sawdust Concrete** is produced, as its name implies, from sawdust and cement. It is used somewhat extensively in Germany for the construction of danger buildings in explosives factories. It is somewhat friable, and it is stated that, in the event of an explosion, no dangerously large pieces are thrown about. The proportions are roughly 1 : 1 : 5 = cement : sand : sawdust.

(*c*) **Sorel Cements.**—These compositions are produced from magnesium chloride and sawdust, and are employed for floorings. The shrinkage in setting is sometimes considerable.

(*d*) **Miscellaneous Artificial Stones.**—From time to time various materials have been tried out, generally consisting of a mixture of ground stone or granite with silicate of soda and Portland cement. These are not important in chemical works, but several attempts have been made to produce an acid-resisting substitute for stoneware or brick, and if this were possible, such a material would be very valuable. Time and trouble in construction would be saved as compared with the regular materials, and there would be no difficulty in making replacements quickly. The writer has tried one material of this kind, but, although promising, it was not satisfactory.

VI

CERAMIC MATERIALS AND GLASS

(*a*) **Porcelain** has only a limited application in chemical engineering work, as it is expensive. It is not generally known that fairly large vessels may be obtained in porcelain, up to 100 gallons and over, and these have all the good properties of stoneware, with the additional mechanical strength and resistance to temperature.

Coils for condensation of acids can also be obtained in porcelain, but these are generally not so cheap as silica coils. Perforated plates and lutes for distilling columns in porcelain are far superior to stoneware for acid materials, and where organic scids have to be distilled they are probably the best, even when the stills may be constructed of metals, as they work very cleanly and do not choke up. The "callottes" in a Kessler Concentrator are generally made of porcelain, and these withstand the action of practically boiling sulphuric acid for very long periods.

The essential difference between porcelain and stoneware from the practical point of view is that whilst stoneware gradually depreciates under the action of acids, porcelain does not, and if it is preserved from cracking, it will last a very long time. Stoneware, on the other hand, has a very definite life.

(*b*) **Chemical Stoneware.**—Chemical stoneware includes a variety of different materials having very widely different properties. Some of the commercial brands are of comparatively coarse textures, and others fine-grained and dense. Usually these materials are buff-coloured or bluish in appearance, but there are some qualities which are white. Strictly speaking chemical stoneware should have an acid-resisting body, and should not depend upon a glaze for acid-resisting properties. Nevertheless a considerable proportion of the articles manufactured in chemical stoneware carry a glaze, and in some cases tanks are produced for acid work, which apparently owe their resistance almost entirely to the glaze.

In this as in other cases chemical composition is utterly useless as a guide to the quality of the material. A rough test of the acid-resistance of the body may be made by testing the powdered material in a similar manner to that recommended for bricks.

In spite of the large selection of different materials which are available, only few qualities are really satisfactory. Some of these materials have to stand the combined action of heat and corrosion, and as a general rule it will be found that those materials which can be manufactured in thin pieces generally give better results under stringent conditions.

One of the most difficult parts to construct in stoneware is the manifold used in the Hart Nitric Acid Condensation Plant. In this case the material must be of uneven thickness, it is subjected to corrosion and to changes of temperature, and to some mechanical stress. In such a case as this it would be almost impossible to rely upon an acid-resisting ware possessing only a surface glaze. On the other hand it is a matter of experience that some of the more dense and highly vitrified materials do not withstand these trying conditions so well as those of coarser texture.

A very interesting material has been placed upon the market by Messrs. Shanks, under the name of "Vitreon." This material is of fine grain, perfectly white, and apparently of even structure throughout. This material can be shaped into thin-walled vessels, and even carboys may be so made, and also Woulfe bottles. The mechanical strength of this material is very high. It is, however, very slightly dearer than the ordinary qualities of stoneware.

Many of the troubles encountered with stoneware apparatus result from the circumstance that it is difficult to design any piece of apparatus satisfactorily, except with a definite quality of material in view. Various qualities differ so much in mechanical strength and other characteristics that vessels made to the same drawings by different manufacturers will behave quite differently.

Very frequently in the case of chemical apparatus the designs found in the makers' catalogues have been arrived at by copying from other sources without regard to the particular material. It therefore happens that certain firms have a good reputation for pipes, others for pressure vessels, and others for nitric acid condensers and receivers, and so forth.

This circumstance has unfortunately also militated against the use of standard dimensions which were proposed a few years ago by Messrs. Nielsen & Garrow. It will be realized, however, that so far as fittings are concerned, i.e. flanges, tapered necks, spigots and sockets, it would be a great convenience to have standard dimensions adopted, as stoneware does not lend itself to alteration after manufacture, and a breakdown in the works is likely to prove a source of much delay and irritation.

In designing stoneware vessels, as a rule it is advisable to keep the thickness of the material as uniform as possible throughout, and also to choose shapes such that there is little chance of distortion during firing. A glance at any makers' catalogue will show that for a given capacity a pear-shaped vessel, such as, for example, an acid transport jar, is cheaper than a cylindrical vessel, and that a rectangular vessel is still cheaper.

It will be found that owing to the difficulty in firing large vessels, and the risk of wasters, the price generally increases somewhat rapidly after a certain size has been reached. This size varies with different manufacturers, but is generally somewhere between 300 and 500 gallons. When larger vessels are required, these have to be constructed either of slabs of stoneware ground at the edges, which are bolted together in a metal casing, or stoneware tiles may be cemented in one or two layers over the inside of a steel vessel. A good example of the former method is found in the various Marx tanks, formerly obtainable from Germany, but now not very extensively used owing to their high cost.

Pipes, centrifugal pumps, and various apparatus which have to stand pressure, may be encased in metal sheathing. These are sold under the name of armoured stoneware. This resort is really not very attractive, unless it is quite certain that the material is non-porous. Many commercial qualities of stoneware are porous and cannot be satisfactorily armoured.

In many chemical works it is the practice to cover stoneware cocks, and similar fragile pieces, with a lead casing. Quite apart from the question of leakage, in such cases some sort of protection is desirable, as in case of breakage, a little time is gained during which an accident may be prevented. In any case, however, a stoneware cock should not be used to hold back a large volume of liquid, and complexity in stoneware pipe systems should be avoided at all costs.

So far as resistance to mechanical strength is concerned, there is but little difficulty in utilizing stoneware. Fans for creating draught in absorption plants are obtainable commercially in various sizes, and for water gauges up to about 5 in.

Plunger pumps are generally obtainable for capacities up to about 40 gallons per minute. Stoneware plunger pumps for gases are also procurable, although these are of small capacity compared with metal pumps. Centrifugal pumps for acids in stoneware are generally made with iron casing, and these could formerly be obtained from Germany for a very good range of capacities up to about 30,000 gallons per hour.

The application of stoneware has recently been made to a very interesting case by Emil Passburg, Maschinenfabrik, Berlin, in the construction of a vacuum evaporating plant, all internal parts which come into contact with the liquids are made of stoneware. A number of these evaporators are in use. One of these plants is shown on the illustration Fig. 3.

An ordinary stoneware vessel of large size, used for simple storage at a definite temperature on, say, concentrated HCl would last probably four to five years at least, but if also subjected to variations of temperature, i.e. as in a still, the life would be about eight to twelve months only. Stoneware is damaged far more by changing temperatures than by corrosion, as a general rule.

A modification of stoneware, or perhaps a totally distinct ceramic material, is marketed under the name "Ceratherm." This material appears to be a carborundum-clay product, and is extremely resistant to both acids and heat. A number of very interesting pieces of plant have been constructed in this material, which has a very low coefficient of expansion, and is very indifferent to acids : electric heaters for acid liquids, fans, centrifugal pumps, and lining plates for tanks. It would be expected that such a material would be more porous than good stoneware.

(*c*) **Fused Silica.**—Fused silica has made for itself a very

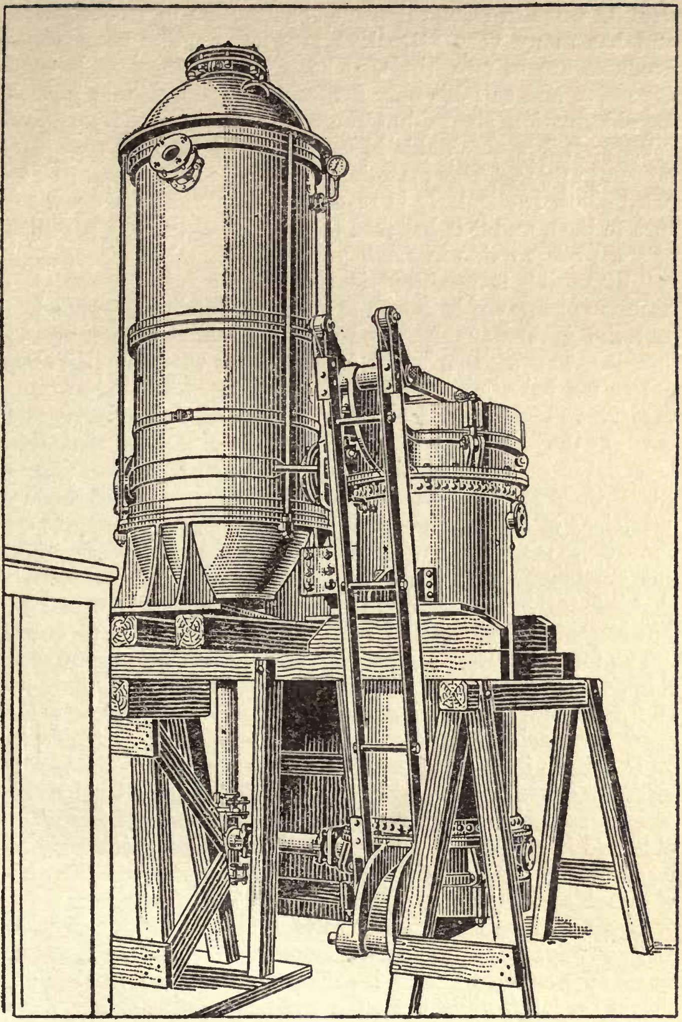

Fig. 3.

definite place in chemical plant construction in recent years, and has many very attractive properties. The commercial products are of two kinds. The clear quartz glass is very expensive and suitable only for small parts, e.g. light glasses for chlorination plants, but the opaque white variety sold as "Vitreosil" is obtainable in comparatively large pieces at a moderate price. This material is in some respects superior to fused silica, particularly in respect of devitrification on exposure to heat, and it is believed that this is due to the presence of some other oxide in small proportion.

"Vitreosil" is produced in the electric furnace, and the opaque appearance is due to the presence of bubbles, but the material is thoroughly vitrified, and quite impervious to liquids. The melting point is high, and the material does not soften below about 1,500° C. Prolonged heating at temperatures causes some devitrification, and experiments carried out at the National Physical Laboratory show that this material loses about half its strength on four hours' heating at 1,350° C. A most important property of this material is the low coefficient of expansion—·0000006 about—and in consequence the articles will stand very rapid changes of temperature without cracking. The only disadvantages of this material are that it is rather brittle, and the thermal conductivity is low. The importance of thermal conductivity is however not great.

The manufacturers of this material will supply almost anything up to fairly large sizes: pipes up to 3 ft. 6 in. long by 15 in. diameter, and vessels of 100 litres or more. Coils for condensing acids can be obtained in various sizes, running to 60 ft. length in one piece. Basins of various shapes are also made for concentrating acid liquids, and also stills, condensing towers, coolers, and in fact almost everything which can be obtained in stoneware, apart from those pieces which have to be subjected to mechanical stress. Fans, pumps, etc., are not obtainable in "Vitreosil."

It is very important to realize that changes of temperature, and not mechanical influence, generally causes failure in stoneware apparatus, whereas in the case of silica mechanical shocks are fatal, whilst corrosion and temperature change have practically no influence. "Vitreosil" fails only by fracture and not in any other way.

Fused silica will withstand the action of all acids except hydrofluoric and concentrated phosphoric acids. It is resistant even to phosphoric acid at temperatures below 400° C. Sulphuric acid can be concentrated and distilled in silica vessels, but the accumulation of sediments and "bumping" must be avoided, otherwise the mechanical shocks will cause fracture.

(*d*) **Glass.**—Glass is not of much consequence as a constructional material, as stoneware and "Vitreosil" have taken over the work formerly done by glass. Chemically, glass is a mixed silicate containing excess of silica in the form of a solid solution. It is, of course, used in windows, sight glasses, observation "lanterns," and gauges. It is occasionally used for shelves or trays in dryers, the wire-woven varieties still being popular for such purposes.

It was formerly used for a large number of purposes: in sulphuric acid "cascades," in beakers, in the form of large pipes, and with considerable success, but now the most important uses are ordinary constructional work.

Sheet glass is usually sold by the square foot, being described as regards thickness by the weight in ounces per square foot, 13 oz. per sq. ft. corresponding to about $\frac{1}{16}$ in. thickness.

Glass tubing of various kinds is fairly important for the construction of traps—for example, in nitric acid plants to make observation of rates of flow possible, and also in straight lengths for air-lifts. Gauge glasses for boilers and stills have to be made of special glass, and have to be very carefully annealed. Sight glasses also require careful selection, but trouble with these is more commonly due to incorrect fixing, the seating should be of flexible material and the glass should not touch metal at all.

Glass is fairly strong, but should not be exposed to rapid changes of temperature.

Wire-woven glass is frequently used: for drying tables and trays and windows. It should be remembered that such windows hang together and may be blown out of the frames in one piece in an explosion, and become very dangerous missiles, whereas ordinary glass can be caught on a wire gauze fixed below a roof light. Wire-woven glass should not be used for sight glasses in vessels subjected to changes of temperature.

VII

RUBBER, EBONITE, AND LEATHER

(*a*) **Rubber.**—Commercial varieties of rubber differ enormously in properties. Rubber articles differ in properties and suitability for chemical work according to the nature of the filling materials employed and the extent of vulcanization. Some manufacturers cater specially for the chemical works, and produce varieties which are surprisingly resistant to corrosive action of various materials. Gaskets, tubes and sheeting can be got in many qualities, and in all cases where rubber articles are necessary the manufacturers should be consulted and full particulars of the working conditions given.

A solution of halogenated rubber is now sold as "Duroprene," and this is useful as a coating for surfaces to resist corrosion, or to prevent contamination by metallic salts.

(*b*) **Ebonite** is a variety of hard rubber which is of great importance in chemical work, and is for many purposes an ideal material. Ebonite can be worked in almost all machine tools, and fashioned into pipes, cocks, valves, plunger and centrifugal pumps, agitators, etc. It is also comparatively easy to produce ebonite coatings and linings for metal vessels. Centrifugal baskets are also obtained ebonite lined and covered.

The selection of ebonite for chemical purposes is a matter of some difficulty. Most of the commercial qualities of acid-resisting ebonite will withstand the action of cold non-oxidizing acids perfectly, and for hydrofluoric acid are without equal. Some varieties are obtainable which will withstand the action of chlorine gas. Where hot acids have to be dealt with, the problem is different, and if the material is to be used in the form of a lining, more difficult. On maintaining many qualities at 90°–120° C. they harden and crack, and sometimes linings leave the vessels. This appears to be due to the vulcanization proceeding after the vessel is put into use, and the harder kinds used for low temperature purposes do not give satisfaction.

One of the best ebonites the writer has ever used for lining was boiled for fourteen days with hydrochloric acid, and the action was negligible.

Most manufacturing firms will coat vessels up to 5 ft. by 5 ft. with ebonite, but no larger, but some will take any size of vessel for lining.

From the above it will be seen that the material is variable in character, and it may be said that composition is not a good guide to the suitability of any material. Laboratory tests are not of great value, but a fair estimate may be sometimes made by powdering the material and testing as is done for bricks and stoneware.

(*c*) **Dexine** is a proprietary material, probably a soft vulcanized rubber, not containing graphite, but some special filling material. It resists both hot and cold non-oxidizing acids well.

(*d*) **Vulcanized Fibre.**—Various materials are sold under proprietary names, consisting of paper with a small proportion of rubber, vulcanized under hydraulic pressure. Some of these contain asbestos, and are employed as pipe-joint rings, pulleys, valve seatings, insulators, and also in pipe form. Some qualities resist high-pressure steam very well, and a few will withstand the action of non-oxidizing acids, and may be employed for flanged acid pipe joints with great success.

(*e*) **Gutta-percha.**—Unlike rubber, is not elastic, but may be vulcanized in the same way. It has been used for linings of vessels and also for centrifugal baskets, and is preferred by some engineers for such purposes.

(*f*) **Leather** also varies in properties considerably, according to the methods employed in preparation, tanning and finishing. In the chemical works it is chiefly used in the form of driving belts or in special packings. It appears to be fairly generally believed that leather belts are unsuitable for chemical works, and that vulcanized rubber and canvas belting is the best. It is possible, however, to obtain special kinds of leather belting not only waterproof, but also acid-resisting. The latter are probably impregnated with a dope containing cellulose esters, and will last in moist atmospheres even where acid fumes may be present. Such belts are joined by means of a special acid-proof and waterproof cement. A very resistant belting of this type is sold under the name "Spartan." This has practically all the advantages of good oak-tanned belting without the disadvantages. It is not suitable, however, if a "striker" has to be used, and in such cases a double belting having one layer of "Spartan" and the other of a harder quality leather should be tried. The "Spartan" belting can be boiled in water for some minutes without visible alteration and will resist moist acid fumes in most situations where a belt drive is likely to be required.

For packing pumps, hydraulic cylinders, etc., various leather goods can be obtained in blocked form : U leathers, hat leathers. These are not suitable for use in conjunction with acids, but pumps for organic liquids will give good service when packed with leather which has been impregnated with melted hard soap. Hard soaps are insoluble in most organic solvents. A metallic soap may in some cases be substituted. Packing rings of thin leather or paper similarly impregnated may be used for pipes for benzene, toluene, etc., and are without equal for such purposes.

VIII

WOOD

It is possible by studying the structure and classification of various woods to secure a scientific knowledge which enables one to judge the various properties with substantial accuracy for all practical purposes, and a knowledge of structure is the only guide to differentiating between the various kinds, and as structure generally determines all the mechanical properties accurate information on the latter could only be given after a prolonged treatment of structure which would not find proper place in this book, and for which reference should be made to the special works on this subject.

(*a*) **Classification of Woods.**—One frequently hears the terms "hardwood" and "softwood," and it should be noted that these refer respectively to the woods of broad-leaved trees and conifers, and some of the "softwoods" are in actual fact harder than some of the "hardwoods." Scientific classifications are however possible.

The mechanical properties of the various classes of wood are completely summarized in Table 6, but it should be realized that these figures vary considerably, and liberal margins should be allowed for purposes of design.

(*b*) **Seasoning of Timber.**—All timber used for constructional purposes is derived from exogenous plants, the stems of which grow outwards. The structure of any trunk is therefore made up of annual rings, and those which are last formed towards the outside carry the greater proportion of sap. Considering more accurately the structure of a trunk, there will be found a central rod of pith, covered by the medullary sheath. Surrounding this sheath is the "heartwood," and then the "sapwood," extending outwards to the bark. Radiating outwards from the centre there are formed in the course of growth "medullary rays."

The shrinkage of timber in course of seasoning follows from circumferential contraction of the sapwood, whereas shrinkage in a radial direction is prevented by the stiff medullary rays, and furthermore the heartwood does not shrink in the same proportion circumferentially as does the sapwood. Hence timber is liable to shrink if not properly seasoned.

During the process of seasoning the shrinkage may give rise to actual faults in the timber, and furthermore a variety of "shakes" may develop, consisting of splits or cracks, and occasionally honeycombing will be found. These points cannot be treated fully here, and further particulars will be found in the special works on the subject.

(*c*) **Use of Timber.**—The selection of the timber for use in a chemical works is usually a matter of cost, and most ordinary work can be done with pitchpine, although oak, teak, and to a smaller extent lignum-vitæ and boxwood, may find application.

For purely constructional purposes timber was formerly very popular in the chemical works, owing to the ease of erection without previous planning, and also, strange as it may appear, the comparative fire-proofness of such structures. It is frequently stated, and correctly, that timber is rapidly acted upon by acid fumes, and sufficient proof of this will be found on examination of a Belfast roof which has been some years subjected to such an action. On the other hand, if the wooden structure consists of thick members, and is suitably protected, the action is not very deep, and after the first attack proceeds only very slowly. For the roof of a nitric acid plant, for example, it is difficult to find anything very much better than a really thick wooden covering, say 3 in. t. and g. boards, and such a construction is substantially fire-proof, because it is very slow to get into a state of vigorous combustion.

There is an increasing tendency to dispense with the use of timber for many kinds of structural work, partly owing to the circumstance that timber is no longer cheap as a constructional material, as compared with steel, but also on account of the greater reliability of steel for complicated structures. The modern tendency in sulphuric acid plants of the chamber type is unquestionably towards steel framing, and there is also considerable indication that the lead-lined wooden tank may give place to some extent to lead-lined steel cages. In general it should be remembered that a timber structure should not be subjected to dry heat, otherwise it will depreciate rapidly, and it is also to be remembered that timber construction is very dangerous as a support where there is any likelihood of leakage of oxidizing acids. Mixed nitric acid and sulphuric acid, as used for nitration purposes, will, on falling on timber produce ignition, and any position where a possible accident would cause leakage of such a mixture there should be protection of some kind, if serious consequences are to be avoided. It would therefore be very questionable to erect a nitric acid storage vessel of stoneware on wooden staging.

It should be remembered also that a timber structure is seldom rigid, and timber framing is therefore not suitable for supporting apparatus built up of flanged stoneware sections, such as, for example, the old-fashioned Valentiner nitric acid plant. Such an apparatus is almost invariably put together with a hard inflexible cement, and if supported on a wooden framing continual trouble will be experienced with the joints. On the other hand, a wooden framework is quite suitable for supporting spigot and faucet stoneware pipes, where the jointing material may be flexible.

Apart from purely structural work, timber finds application for the production of vats and rectangular tanks, which may or may not be lead-lined. Occasionally absorption towers are constructed in a similar fashion. The most usual woods for this work are pitchpine, redwood and oak. Blunders are occasionally made through sheer thoughtlessness.

In the case of ordinary circular vats, it is usually advantageous to taper these, so that they are slightly smaller in diameter at the top. In some works vats will be found tapered downwards, and in such cases the hoops are a nuisance, and difficult to keep in position. If, however, the vats have to be lead-lined, then it is convenient to make them cylindrical and without taper, and in such cases it is recommended to provide hoops which can be tightened. Suitable types of coupling are shown in Figs. 4A, 4B and 4C.

It should not be forgotten that if slightly acid liquors are to be handled, ordinary iron hoops will be corroded. These

FIG. 4A.

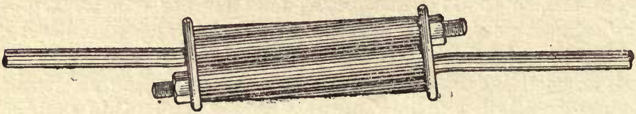

FIG. 4B.

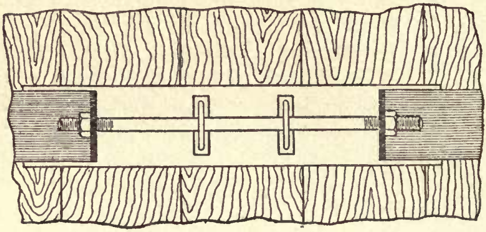

FIG. 4C.

difficulties may be overcome in some cases by using homogeneously lead-coated hoops or ebonite-coated hoops, or by passing strips of lead between the hoops and the staves. In some cases, in addition to these precautions, small wedges support the hoops away from the staves, so that in the case of a leakage the liquid does not touch the hoops.

In the construction of wooden tanks the commonest mistake is made in the case of liquids of high density. A tank of 6 ft. depth may be very satisfactory for water, but when provided with a lead lining, and containing some liquid of higher density, the flat sides may bulge badly. As soon as this trouble is discovered the tank may be strengthened, but if this is done in a slipshod manner there is likely to be trouble later on.

A very convenient method of bracing wooden tanks is shown in Fig. 5, and it will be noted that this method avoids the use of any tie-rods passing over the top of the tank. Tie-rods in such a position suffer rapidly from corrosion by acid vapours and also hinder repairs to the lead linings, if such are employed. Fig. 6 shows another method.

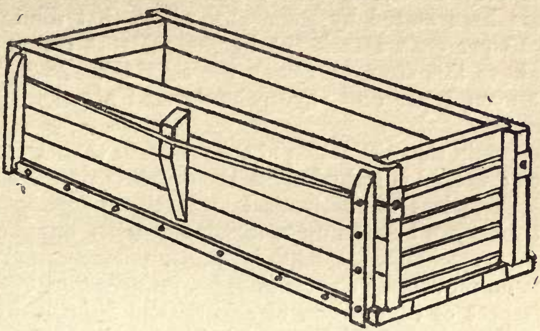

Fig. 5.

(*d*) **Resistance to Reagents.**—One of the most difficult questions to decide is the resistance of timber to corrosion by acids. Strongly oxidizing acids of course cannot be employed

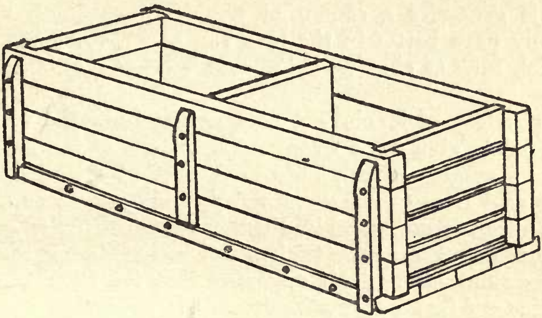

Fig. 6.

in contact with wood, neither should these acids be placed in wooden tanks lined with lead. Some serious accidents have occurred as a result of the practice of storing strong nitric acid in lead-lined wooden tanks.

Organic acids have but little action on timber, and acetic acid up to considerable strength may be stored in wooden vats without difficulty. On the other hand, the action of inorganic acids is very uncertain.

It has been stated by some authorities that dilute acids below 15 per cent. attack the lignine, whereas concentrated acids above this strength attack the cellulose. As a matter of fact even 4 per cent. hydrochloric acid attacks cellulose appreciably.

It is certain that the action of acid stronger than 4 per cent. hydrochloric acid is to hydrolyse the cellulose on the surface, and there is loss of mechanical strength. Large pieces of thick timber can be used up to higher strengths, but generally only where mechanical strength is of no importance, and where there is no movement or attrition, i.e. no agitation.

In respect of comparison of acid-resisting qualities, there is some difference of opinion, and it is very difficult to choose between the various woods. Cypress is generally acknowledged to be the best, but followed closely by yellow pine, pitchpine and teak. Redwood and oak do not give a very much inferior service. In view of the circumstance that there are other materials to choose from for resistance to cold acids, wood is generally a somewhat doubtful expedient, and it generally pays better in the long run to employ some other material, such as ebonite, if the acid is other than extremely dilute.

By courtesy of Manlove Alliott & Co., Ltd., the writer is privileged to give some quantitative results of the action of various strengths of sulphuric acid, acetic acid and hydrochloric acid from an excellent series of investigations carried out on various woods used by them in the construction of their filter presses. From these trials, which included comparisons of cross-breaking strength, it appeared that for most purposes pitchpine and teak were distinctly superior, and that American oak was not nearly so good, being unable to resist the action of even very dilute mineral acids. Sappy pine was apparently very readily acted upon even by acetic acid. One of the most remarkable results of the investigation was the difference between acetic acid and inorganic acids. Whilst even with 5 per cent. hydrochloric acid or 10 per cent. sulphuric acid the woods became brittle in time and broke without deflection; in the case of acetic acid of 50 per cent., or even 80 per cent. strength, the action was very much slower, and the wood showed deflection before fracture. In the case of acetic acid the 50 per cent. strength had a more rapid action than the 80 per cent. These results would appear to indicate that hydrogen ion concentration is a dominating factor, as in the case of the action of acids on purer forms of cellulose.

The action of sulphuric acid is more complex, and 80 per cent. strength caused immediate surface carbonization; 60 per cent. and 40 per cent. caused a rapid diminution of strength,

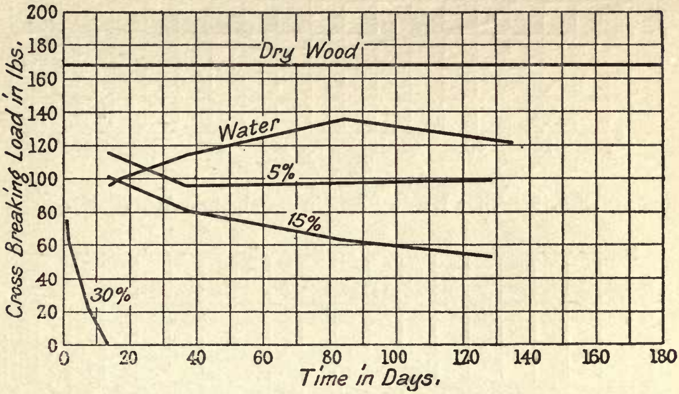

FIG. 7.—Time Load—Pitchpine—Hydrochloric Acid (Cold).

but not carbonization; 20 per cent. acid acted much more slowly; and 10 per cent. sulphuric acid appeared to cause an increase in strength of pitchpine, but even so the wood became brittle.

The following diagrams show one set of results for pitchpine in quantitative form.

The tests with hot acids gave similar indications, and showed that pitchpine was easily best, and followed closely by teak. Cypress did not figure well in any of the tests, and beech was about the worst.

Filter presses are very frequently constructed with wooden plates and frames, not merely on account of acid-resisting qualities, but also in view of the fact that such press parts are lighter and more economical in labour. Some care is required in the design and construction of such plates, and

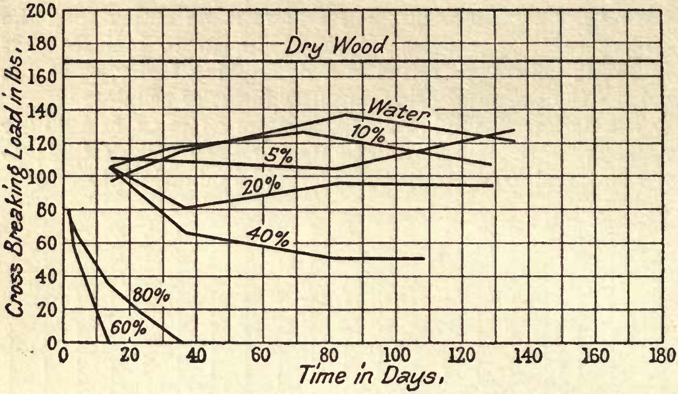

FIG. 8.—Time Load—Pitchpine—Sulphuric Acid (Cold).

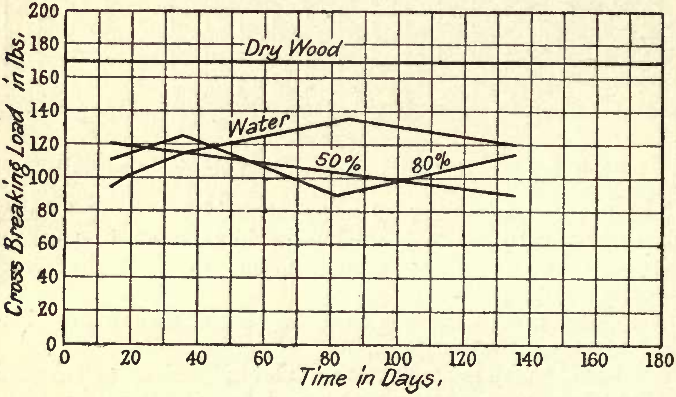

FIG. 9.—Time Load—Pitchpine—Acetic Acid (Cold).

the bracing should receive careful attention. In any case if an acid liquid is to be handled all tie-rods and bracing screws must be covered either with lead or ebonite. Further, such a press should, when not in use, be kept full of water.

Whilst on this subject it should be noted that taps for such filter presses may be constructed of lignum-vitæ and boxwood, and even larger cocks may be obtained in such materials, but these are not now so cheap as ebonite, and are gradually falling out of use.

Occasionally it is necessary to employ bearings in wooden tanks containing weakly acid liquors, and for this purpose, lignum-vitæ is without equal, and for all bearings under water, where lubrication is impossible, this material is used. For filter presses used in the treatment of oils a fairly hard wood is desirable, and hard maple is generally specified for such work.

(*e*) **Protection of Timber.**—Where timber structures have to be exposed to the weather various treatments have been proposed, the most popular in this country being impregnation with creosote. It should be remembered that this treatment is not necessarily efficacious in other climates, and there is a tendency to take into consideration various treatments with metallic salts for preserving timber. In Germany at the present time some of these processes have become of great importance, and special impregnating materials can be chosen to suit different conditions. Reference to the various special works must be made for further information on these subjects.

These treatments refer essentially to purely structural work, and in the chemical works usually some kind of protective coating is given to wooden structures, to assist in withstanding the action of acid fumes, various kinds of special varnish and tar paint. In some cases proprietary brands of fire-resisting paint are also used. In all cases it is of importance that the timber should be thoroughly dry and properly seasoned before any such coatings are applied.

In some cases tanks and vats are lined internally with asphalt or treated with a variety of different solutions calculated to improve the acid-resisting qualities. It is certainly possible to coat tanks internally with such materials, so that they may be used to handle strongly acid liquids, but these expedients must be regarded as doubtful.

In some processes where it is desired to avoid contamination by the extraction of soluble matters from the wood, it may be necessary to impregnate the wooden vessels internally with paraffin or ceresine wax. Such a method should not be relied upon as a means of imparting acid resistance, although it serves to some extent to prolong the life of the vessels so treated.

TABLE 8

Mechanical Properties of Timber

	Unit.	Hardwoods.					Softwoods.			
		Oak.	Teak.	Beech.	Box.	Lignum Vitæ.	Pitch-pine.	Red Pine.	White Pine.	Spruce.
Density	lb. per. cub. ft.	34	41	43	60	72	34	35	25	29
	Sp. gr.	·54	·66	·69	·96	1·14	·54	·55	·93	·46
Cross breaking strength: Modulus elasticity	Tons per sq. in.	930	—	—	—	—	—	720	620	750
Cross breaking strength: Apparent elastic limit	,,	6·5	—	—	—	—	—	3·4	2·8	2·8
Cross breaking strength: Ultimate strength	,,	4·4	—	—	—	—	—	4	3·5	3·5
Tensile strength .	,,	6·7	6·7	5·5	9·1	7·2	5·1	5·1	5·1	5·5
Crushing strength .	,,	4·5	5·4	4·2	4·7	4·4	4·0	2·6	2·2	3·0
Longitudinal shear .	lb. per sq. in.	1,100	—	—	—	—	500	380	400	360

IX

MISCELLANEOUS NON-METALLIC MATERIALS

Among the many and curious materials used in chemical works and not previously described only a few will be mentioned here. Such materials as laggings and filter cloth are left over and will be treated elsewhere. In many cases exact compositions are not given as these vary considerably with the special uses to which the mixtures are applied. The writer has, for example, collected a large number of compositions of acid-resisting cements, but these vary wildly and apparently without reason. In some works such cements are simply mixed by guesswork "according to individual tastes."

(*a*) **Mortar.**—There are two kinds of mortar ordinarily used for building purposes, viz., lime mortar and cement mortar.

Lime mortar usually consists of one part slacked lime and three parts of sand. The lime is slacked before mixing by placing it in the form of lumps in a water-tight box in a layer about 8 in. thick, and pouring over the lime about three times the volume of water. This forms a paste, and sand is spread evenly over the paste and the whole thoroughly mixed until of a uniform colour, a little water being added if the mortar is too stiff. The mortar is of correct constituency and of maximum strength if, when placed on a trowel, it will flow just sufficiently to make a joint.

Sand is added to mortar for the purpose of preventing excessive cracking of mortar owing to shrinkage on setting, to make the mortar more porous, to give greater strength to the mortar in compression, and to decrease the cost of mortar by decreasing amount of lime used. Mortar is only called on to resist compressive stress and should only be regarded as a packing to fill joints between bricks or stones.

Masonry and brickwork should never be designed so that mortar is subjected to tensile or shear stresses.

(*b*) **Cement Mortar** is used where work of a higher grade is required, and is a mixture of cement, sand and water. The proportioning is usually done by volume, but it is important to take the bag or barrel as the unit at some definite volume as cement will increase as much as 25 per cent. when heaped up loosely. 8 cu. ft. is usually taken as weighing 100 lb.

Proportions.—With Portland cement the proportions are usually 1 part cement to 3 parts clean sharp sand, and for natural cement equal parts of cement and sand.

The strength of a mortar naturally increases with increased proportion of cement, and for mortar of equal proportions the strength increases with the density.

Feret's well-known formula gives approximate strengths for different densities.

$$S = K \left(\frac{Vc}{1 - Vs}\right)^2$$

where K is a constant

Vc is absolute volume of cement in a unit of mortar.

Vs is " " " sand " " "

S is compressive strength of mortar.

In determining density the ratio of the actual solid material in cement and sand to the volume of hardened mortar is to be taken. About 20 per cent. water is required to produce normal consistency in neat cement paste.

(*c*) **Corrosion-Resisting Cements.**—Quite apart from the various proprietary cements which are available, the corrosion-resisting cements used in chemical works are invariably somewhat mysterious. Very frequently they contain substances which would dissolve readily in the reagents they are intended to resist, and composition is no guide whatsoever to the properties of any mixture. Systematic discussion of these cements is almost impossible, but there are some general principles which must be recognized.

Most chemical works foremen have compositions of their own, evolved by methods of trial and error, and the theorist who tries to improve on these frequently comes to grief. The subject is nevertheless one of great importance, and it is obviously quite useless to construct a plant of corrosion-resisting material unless the various parts can be fitted together with a reliable cement.

In so far as metal constructions are concerned there is but little difficulty, as flanges may be machined and the packing material reduced to the smallest dimensions, and if necessary omitted altogether. In such cases the only difficulties which are experienced are in connection with making joints tight against volatile organic liquids or against alkalies or strong acids, such as sulphuric.

Where weak acids have to be dealt with, necessitating the use of stoneware or acid-resisting brick, the problem is essentially a matter of choosing the proper kind of acid-resisting cement. Acid-resisting cements may be divided into two broad groups, namely setting cements and non-setting cements.

(1) *Setting Cements.*—The commonest acid-resisting cements are those produced by mixing a filling material such as ground barytes, ground volvic stone or asbestos fibre with sirupy silicate of soda. In this, as in many other matters, a little knowledge is a dangerous thing, and a cement of this description will, if used incorrectly, work havoc with an otherwise excellent plant.

All these cements depend for their acid-resisting properties on the formation of colloidal silica, which is set free by the action of the acid. Unfortunately the setting of these cements is attended by a very considerable expansion, and as a result they are not suitable for the packing of stoneware spigot and faucet joints. The writer inspected recently a certain chemical works in which such joints had been packed with a cement of this kind. More than one-half of these had been broken by the expansion of the cement, and in some cases entire pipes had been split lengthwise. These cements, however, set into very hard masses, and can be used for topping a softer packing of the non-setting type, so as to ensure gas-tightness.

They may also be used for very small joints without much difficulty. They must never be used for jointing silica pipes, as the expansion is absolutely fatal. In the building of structures in acid-resisting brick, these cements are almost invariably used, and in such cases it is important to use the mixture in a fairly thin condition, adding water if necessary, and the joints should be made as thin as possible.

A difficulty under such circumstances is that the cements do not set very quickly, and various methods have been proposed from time to time, one of the best being according to a recent patent in which plaster of Paris is added in a small proportion. Messrs. Chance and Hunt's " double set " cement is a very useful product of this type.

Where these cements are used for making joints between acid-resisting tiles for lining acid tanks, a certain amount of difficulty is experienced with the running of these cements at the joints. Sometimes, in order to check this trouble, the surface of the cement is treated with acid as soon as it is in place. The substitution of silicate of potash for silicate of soda gives a cement which hardens more quickly, and this is to be preferred for such purposes. It is however more expensive.

In preparing these cements it is desirable to use for the best work asbestos fibre which has been washed in acid. Various commercial qualities of asbestos powder contain cement and other impurities, these causing an increased expansion on setting. For some purposes mixtures of silicate of soda and Portland cement are employed.

(2) *Non-Setting Cements.*—The various cements of the non-setting kind are really nothing more than fillings, and the essential property is that they should harden, if at all, only with extreme slowness, and that they should not expand under the influence of heat or acids.

In nitric acid plants various modifications of the well-known litharge cement are used containing raw linseed oil, whiting, white lead, asbestos fibre, and red lead. Such a mixture hardens only very slowly, and in fact it is frequently called a putty. A similar mixture may be made using boiled linseed oil, and this will harden more rapidly, the rate of hardening being controlled by the percentage of red lead. It might be thought that a cement containing so many constituents which will dissolve readily in acids would be utterly useless for the purposes intended, but it will be recollected that a mixture of linseed oil with lead compounds gives a certain elasticity which is not easy to secure in other ways.

Cements of this kind used in modifications in which the oil is replaced partly or wholly by glycerine, and by using simply litharge or red lead and glycerine, a very hard-setting cement is obtained, but usually rather expensive. In some cheaper modifications oxide of iron replaces red lead. These are fairly satisfactory in hot situations.

A fairly common putty for spigot and faucet joints on nitric acid plant is:

	Per cent.
Raw Linseed Oil	45
Whiting	15–20
White Lead (wet)	15–20
Asbestos Fibre	15–20
Red Lead	2½

For small pipes and for good work the above is usually most satisfactory, but where a cheaper putty is required for, say, fume pipes, a large proportion of asbestos powder may be incorporated.

	Per cent.
Raw Linseed Oil	15
Whiting	10–12
White Lead (wet)	10–12
Asbestos Powder	60–65
Red Lead	2½

These mixtures should be prepared as required, and if stored at all should be protected from the action of the air.

For very large pipes these mixtures are rather expensive, and in such cases clay and oil putty covered with black varnish or silicate cement may be useful.

As an example of the litharge type may be taken a mixture of oxide of iron or carbonate of iron and red lead in equal parts, boiled linseed oil being added to make a putty. Such a mixture will resist heat, and may be used on air heaters, superheaters and the like in making metal-to-metal joints.

For non-oxidizing acids there is nothing much better than rubber, various cements having been proposed from time to time, and sold commercially, containing raw rubber and linseed oil, sometimes asbestos fibre being added to make the mixture hang together. In such situations it is better to use, if possible, the acid-resisting rubber rings which may be now obtained commercially, and for flanged pipes these are unequalled by any known acid-resisting cement of this type.

It has been suggested to fix tank linings of stoneware with rubber, and the use of sulphur chloride as a means of vulcanizing in position has been patented. It is nevertheless possible to effect the vulcanization at moderate temperatures with sulphur, but considerable care is required in using a vulcanized rubber jointing material, as, unless the mixture is very carefully proportioned, the vulcanization continues after the vessel is put into use and the joint becomes hard and brittle.

Many of the above mixtures are used on the top of a plain asbestos filling: in all such cases it is of great importance to remember that the joints will not stand any pressure, even a small hydrostatic pressure, unless the cement is of the setting kind, or the mixture is held in by flanges.

(3) *Miscellaneous Cements and Jointings.*—Probably the best known of all cements is that containing iron fillings or borings, together with ammonium chloride. There are many compositions of this kind, some containing sulphur, and in some cases it is recommended to moisten with very weak acid before use. There are also a large number of proprietary mixtures for which special advantages are claimed. The best known is that sold under the name "Smooth-On." Such mixtures are extremely useful and can be used for any iron-to-iron joints. The end covers of acid eggs are usually fixed on with such a cement, and joints may be made in nitric acid stills in this material. Frequently part of the joint is made in cement containing manganese dioxide. It is not generally known that this type of cement can be used for making repairs in directly heated vessels, but it is a comparatively simple matter to put a patch on the bottom of a nitric acid still or caustic fusion pot, consisting simply of a piece of thick steel plate covered with "Smooth-On" and held in position during setting with a few set screws.

Occasionally in making joints between cast-iron sections of vessels subjected to both heat and corrosion a sort of combination cement may be used containing asbestos, iron fillings, manganese dioxide and barium sulphate in various proportions, these being mixed with silicate of soda immediately before use. A joint so made is an attempt to combine the properties of a silicate cement and rust cement, and the results are often surprisingly good.

Some fire-resisting cements for filling cracks in brickwork, covering silica and stoneware vessels subjected to heat, and similar work, are obtainable commercially. A fairly useful mixture consists of fireclay mixed with a very weak silicate of soda solution. This will set quite hard on drying and will resist heat.

For packing glands of acid pumps and cocks there is nothing better than asbestos fibre impregnated with mineral jelly and melted paraffin wax, and finally kneaded with graphite until no more can be taken up.

(*d*) **Paints and Enamels.**—Metal tanks lined with various kinds of enamel are now commercially obtainable in almost all sizes. These are suitable for the purposes intended, but generally sooner or later mechanical damage exposes the underlying metal surface and there is a necessity to patch the surface. From time to time various mixtures have been tried to doctor up a chipped enamel lining, but without marked success. In cases where the object of the enamel is to avoid contamination with metallic salts rather than to resist corrosion the use of " Bakelite " is indicated. If Bakelite is carefully used an iron or steel vessel may be protected against a mild corrosive action, and if the coating is renewed frequently the method is a great success as a means of avoiding contamination of products. Bakelite varnishes require careful drying and should not as a rule be applied to wooden tanks unless the wood can be dried and the vessel stoved after the application, and even then the results are poor. It is also possible to apply a thick coating of Bakelite and similar products by the use of the varnish, and also the paste forms. Such work is, however, not very easy to execute satisfactorily without special equipment.

For some purposes " Duroprene " may be substituted for Bakelite. Both Bakelite and Duroprene coatings are preferably not subjected to higher temperatures than 70–80° C.

For resisting the action of corrosive fumes various bitumen mixtures are employed, but more frequently one of the proprietary mixtures on the market, and sometimes tar mixtures. It is not desirable, however, to have pipes and fittings black in every case, and lighter coloured washes for pipe lines can be prepared containing silicate of soda and Portland cement with a small proportion of mineral pigment. Such mixtures are very suitable for protecting steelwork and piping. Under very bad conditions an acid-resisting varnish has to be applied to cover these cement washes, or one of the bitumen paints must be used. Whilst coverings of this kind are adequate for resisting the action of the air in chemical works buildings which may contain a small proportion of corrosive fumes, they cannot, of course, be depended upon for resistance in actual process vessels.

For most of these miscellaneous materials quantitative data are extremely difficult to obtain and until systematic investigations have been made, trial and error can alone guide practice. Some of the proprietary materials have been thoroughly investigated by the makers, but often enough the makers' claims are not borne out by practice. It is quite common to receive offers of this or that material, stating that "it will stand any acid." Such claims are never founded on any real experience, and makers who really know the properties of their products do not make extravagant claims.

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