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THE ELEMENTS OF CHEMICAL ENGINEERING.

BY

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WITH A PREFACE BY

SIR WILLIAM RAMSAY, K.C.B., F.R.S.

With 50 Illustrations.



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1906.

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GENERAL

A. I. L.

PREFACE

BY

SIR WILLIAM RAMSAY, K.C.B., F.R.S.

THE students who throng our laboratories are, for the most part, well taught so far as scientific chemistry is concerned. The study of the science, however, demands at least three years; indeed, a young man of more than average abilities is not at home in the subject until he has spent a fourth year in laboratory work. If it is required that a young chemist should not merely know facts and theories, but should also be able to help forward the science either in its theoretical or its industrial side, a considerable part of the time must be devoted to research. But at the end of his four or five years' training, when he has probably graduated, and has been awarded a degree, or a diploma showing that he is an associate of the Institute of Chemistry, he is almost always woefully ignorant of the properties of the materials required to carry out operations on a large scale, which are perfectly familiar to him on the laboratory scale, when glass and porcelain and platinum, water pumps and mercury pumps are available. The most that can be expected of him is that he shall have a fair knowledge of the science, and that he shall have some notion of how to tackle a new problem. It is with the view of attempting in some measure to remedy this state of affairs that this work has been written. It may be said that in Britain there is, for the most part, a gulf fixed between the technical and the

scientific chemist; a gulf which our Continental competitors have managed to bridge; for abroad it is by no means infrequent for the technical chemist to become professor, or *vice versa*; and works problems often find their solution in University and Polytechnicum laboratories, while the facilities of the works are often extended to the scientific chemist. And abroad, the works afford a training school for scientifically trained chemists, such as are practically unknown in England. It is to be hoped that the simple and lucid statement which Dr Grossmann has given of the difficulties met with, and the methods of their solution, in proceeding from the scale of laboratory to that of manufacturing operations, may awaken the interest of many chemical students, and lead them to demand tuition on these lines; and even if this work only induces teachers to pay attention to the problem of cost, it will have contributed much to the progress of the teaching of chemistry.

WILLIAM RAMSAY.

May 1906.

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ELEMENTS OF CHEMICAL ENGINEERING.

INTRODUCTION.

THE student who has gone through a course of study in analytical and theoretical chemistry often finds great difficulty in adapting himself to the altered circumstances which regulate chemical work when carried out on a large scale, and therefore fails to grasp the principles of chemical technology. It may be laid down as a fundamental difference between theoretical and practical work that whilst the question of cost does not enter into theoretical work, it is the fundamental basis of all technical work. Thus, if it were necessary to prepare nitrate of ammonia in the laboratory in an extremely pure state, the cost of materials, the amount of time spent, the labour, the breakage of vessels, cost of heating, evaporating, and drying, the initial cost of the apparatus, and final cost of packing in bottles or jars, would be of no consequence so long as the object in view had been attained. But if the problem were put to a student to make nitrate of ammonia in the cheapest manner on a large scale, the conditions in which the work would have to be carried on would be fundamentally different. He would have to choose, amongst a number of possible processes, the one which, when all the above conditions are taken into account, enables the

manufacturer to produce the article required in the cheapest manner, not only as regards the cost of the raw materials, but also as regards the initial cost of the plant, and the consequent interest on capital expended, the depreciation of the plant, the labour, the fuel, and the cost of packing, as well as incidental charges in the management of the works and office.

But, apart from these questions, there is a great difficulty in understanding the apparatus which is used on a large manufacturing scale. Without any intermediate stage, the student must at once accommodate his ideas, which have been trained by using extremely small quantities, to the use of extremely large quantities; and whilst he would be quite capable of understanding how to mix nitric acid and ammonia to produce nitrate of ammonia in a beaker or a basin, he would be totally at sea if he were asked to construct the apparatus necessary to carry this operation out on a large scale. I have endeavoured in the first few chapters to make the transition from the small laboratory scale to the large manufacturing scale not abrupt, as it is now to the student, but gradual; and for this purpose I have tried, where possible, to represent the operations which are carried out on a large scale as almost natural evolutions arising from the work with the laboratory apparatus, to which the student has been accustomed.

CHAPTER I.

THE BEAKER AND ITS TECHNICAL EQUIVALENTS.

ONE of the commonest appliances used in the laboratory is the beaker, made of glass or porcelain, and it will be instructive to follow its evolution in working on a large scale.

Ordinary laboratory beakers are made in different sizes to hold any quantity from an ounce or less to half a gallon or more. They are applied for different purposes: for storing or mixing liquors; for dissolving solids in liquids, either in the cold or by heat; and in some cases, though not often, for boiling down, concentrating, and crystallising. For the latter purposes porcelain basins are preferred. As the uses of both beakers and basins are almost identical, we may, where convenient, include the evolution of the basin in that of the beaker.

One of the simplest operations is that of mixing two liquids. Suppose we had to make 100 c.c. or more of a solution of sulphuric acid, containing approximately one part of H_2SO_4 to ten of water. We should measure 100 c.c. of water into a beaker or dish, and add slowly about 10 c.c. of H_2SO_4 , stirring all the time with a glass rod. Suppose, now, that we have to prepare the same mixture on a large scale, say 100 gallons at a time. The first question to decide would be, what material should the vessel be made of? We know that glass would not do; earthenware would stand the acid, but would be liable to be broken; lead would stand cold acid of that dilution well, and would not be liable to breakage; therefore lead would be

the best material for the purpose ; and in order to save expense, the vessel would be made of comparatively thin lead, surrounded with a wooden casing. The shape of the vessel would be pre-determined, for the only practicable shape for casing would be a figure in straight lines ; *i.e.* either a cube or an oblong box. As regards the size, it is clear that as we have to mix the acid and water, we must allow for splashing, and therefore make the box about 25 per cent. larger, that is, to hold at least 125 gallons. Now the bulk of 125 gallons equals 20 cubic feet ; we might therefore have it either

$$\begin{array}{l} 2' 0'' \times 2' 6'' \times 4' \quad \text{high} \\ \text{or } 2' 0'' \times 2' 0'' \times 5' \quad \text{,,} \\ \text{,, } 2' 0'' \times 3' 6'' \times 3' \quad \text{,,} \\ \text{,, } 2' 0'' \times 3' 0'' \times 3\frac{1}{2}' \quad \text{,,} \end{array}$$

whichever dimensions may appear to strike our fancy, or to be the most suitable for other purposes.

The mixing of the acid could be done with a wooden paddle, which might be covered with lead ; and as, in using the paddle, it might knock with greater force against the bottom of the vessel than against the sides, it will be advisable to have the bottom of the vessel made of stronger lead than the sides. Considerable latitude is permissible in choosing the thickness of the lead ; the choice depends upon the number of years that one would require the vessel to stand wear and tear. The sides might be made of lead, .068 inch thick, the bottom .119 inch thick. In practice it is not usual to express lead measurements in that way, the custom being to take the weight of sheet lead per square foot ; thus lead .068 inch thick is termed four pound lead, and lead .119 inch thick seven pound lead. Therefore in this case the way to express the quality of lead which should be used would be four pound lead for the sides and seven pound lead for the bottom. The joints where the lead sheets meet in making the box would have to be burned by the hydrogen flame

as is the case in all chemical work, for it is clear that solder could not be used for that purpose. The top should overlap the casing.

We will now suppose that instead of being required to mix weak vitriol, the problem was put to us to make a cold 10 per cent. solution of soda-ash. In that case, if only a quantity of 100 c.c. were required, one would measure 100 c.c. of water into a beaker or dish, and weigh into it 10 grammes of soda-ash, and stir up until it is all dissolved; this would take considerably longer to stir than the mixing of two liquids. Now if this operation is extended, and if it should be necessary to prepare a solution of this kind regularly on a large scale, say 200 gallons at a time, the problem is, what vessel would be most suitable for the purpose? First of all, what is the material which could be used for the vessel employed? As soda-ash does not attack iron, and iron, after all, is the cheapest material which can be used on a large scale, it is evident that the vessel should be made of iron. Cast- or wrought-iron could be used; as a rule, however, cast-iron is cheaper than wrought-iron, and also offers the advantage of having a smoother surface, free from joints. In this particular instance, however, it might be as cheap, and perhaps cheaper, to have an ordinary wrought-iron water-cistern 4' 0" \times 3' 0" \times 3' 3", and use it for the purpose. Two hundred gallons of water might be put into this box, and 200 pounds of soda-ash weighed and gradually put into it, the whole being stirred up with an iron or wooden paddle until dissolved. But it will be found that the labour on this would be considerable, and it would therefore be advisable to construct an arrangement by which the stirring could be done automatically by a machine. The simplest form of a stirrer of this kind would be a centre shaft with revolving cross pieces. It is clear that in that case the vessel would have to be of cylindrical shape, which might be a cylinder with a flat bottom. Most iron vessels are made with a round bottom, and in this case it would be an advantage to have

a round bottom, so that none of the soda-ash could lodge in the crevices between the side and the bottom of the cylindrical vessel. We should, therefore, construct a vessel shaped like a wash kitchen boiler, only larger, with a flange on which we could screw a plate to hold the gearing.

Figs. 1 and 2 show a complete arrangement of such an apparatus, Fig. 1 in section and Fig. 2 in perspective. A is a

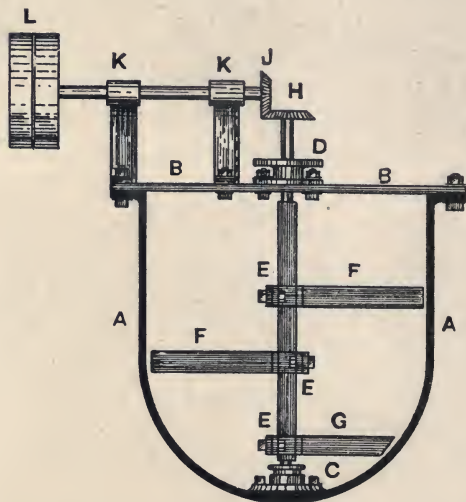


FIG. 1.—Sectional elevation of iron vessel and stirrers, for dissolving soda-ash in water.

cast-iron pot with flange, across which is an iron plate B about 6" wide, bolted on to the flange; through the middle of this plate goes a shaft which rests on the bottom in a footstep C, and passes through the collar D, which is fixed on plate B. The shaft is best made square, and only rounded at the top and bottom part so as to revolve in C and D. F and G are stirrers at right angles to each other, either clamped round or fastened through slots in E. H and J are spur wheels which change the

vertical motion into a horizontal one. *KK* are the axle bearers, while *LL* are fast and loose pulleys, which are worked from the shafting above by means of an endless belt.

There are cases when it is not convenient to employ this kind of stirrer, which, moreover, is not always very reliable, as in revolving round in large quantities of liquids, particularly those of a viscous nature, the liquor is apt to go round with the agitator without properly mixing. In such cases, and where it

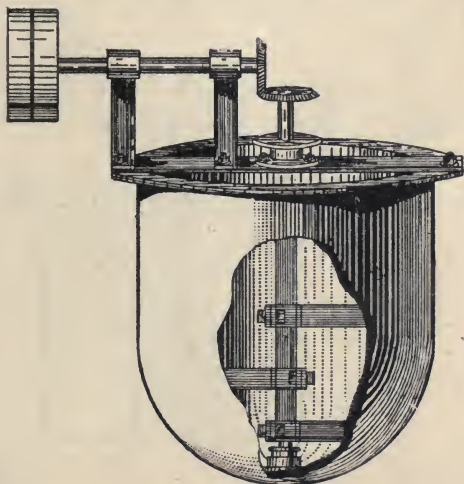


FIG. 2.—Perspective view of vessel represented in section in Fig. 1.

is desirable to employ a rectangular vessel, another kind of agitation may be used, based on the working of a ship's screw. Figs. 3 and 4 show such an arrangement.

A is a square tank, and *B* is a vertical shaft which moves in footstep and collar as in Fig. 2, the latter being fastened on a plate *N*. *D* is an Archimedean screw surrounded by a pipe *C*, which is fastened to the bottom of the tank; the bottom of it is perforated so that the screw can draw the liquor from the bottom of the tank, pump it up in the direction of the arrows,

and deliver it at the outlet of the pipe. In this way every part of the liquor is pumped through the pipe, and a thorough mixing ensured.

The next step that we have to consider is the conditions under which these operations would have to be carried on if it were necessary to heat the liquid at the same time as it is being mixed. Three ways are open to us to do this. The first way is by simply blowing live steam into the liquid; in that case the volume of the liquid will become larger as the steam

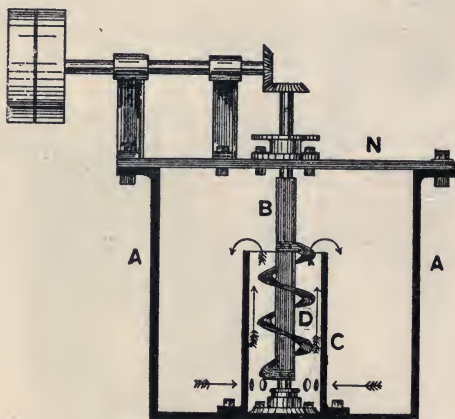


FIG. 3.—Sectional elevation of vessel for mixing liquids by means of an Archimedean screw.

condenses in it. Where this does not matter, it is the simplest way of heating the liquid. The next arrangement would be to pass steam through a coil contained in the tank and heat the liquid in that way. The third way would be to heat the pot by a coal or coke fire. Going back to Fig. 2, it can be easily seen that if the pot were to be heated by open steam the arms of the agitator would have to be cut shorter so as to allow of the steam pipe going down at the side of the pot, as otherwise, if they were brought near to the sides of the pot, they would knock against the pipe at each revolution. Of course the pipe could

be brought along the outside and taken in at the bottom of the pot through a hole bored through, but this would be an awkward arrangement, as with any differences of temperature the liquor might be drawn back into the steam pipe. In heating by means of closed steam, an agitating arrangement like that described in Fig. 2 would be awkward, unless the coil were specially made to fit close to the sides of the pot, and such a coil would be expensive. It will now be seen why it is sometimes advisable

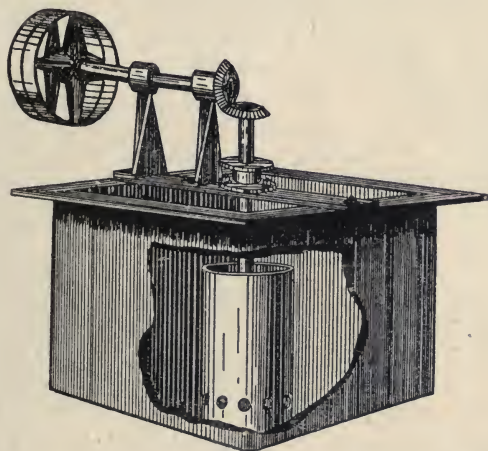


FIG. 4.—Perspective view of vessel represented in Fig. 3.

to have a rectangular tank for purposes of this kind, and why the agitating arrangement described in Fig. 3 is sometimes preferable. In that arrangement it would be easy to use either a steam pipe or a steam coil. The steam coil could be placed at the bottom, and both the inlet of steam and the outlet for the condensed water could be regulated by taps.

If the pot is to be heated by open fire, some new principles which do not come into consideration in laboratory work will have to be considered. When we heat a beaker in the laboratory from a gas jet, it is simply placed on the wire gauze net and

the flame applied underneath. It is natural that in that way a great deal of the heat is lost by radiation; and on a large scale, where it is necessary to consider the question of economy very carefully, it would not be advisable to heat the bottom of the pot only. The arrangement should be such as to allow of the heat being supplied to a much more extensive surface. The simplest and most efficient way is to convey the hot gases from the burning coal round the pot by means of the wheel flue shown in Figs. 5 and 6.

Fig. 5 represents a vertical section, and Fig. 6 a plan of the

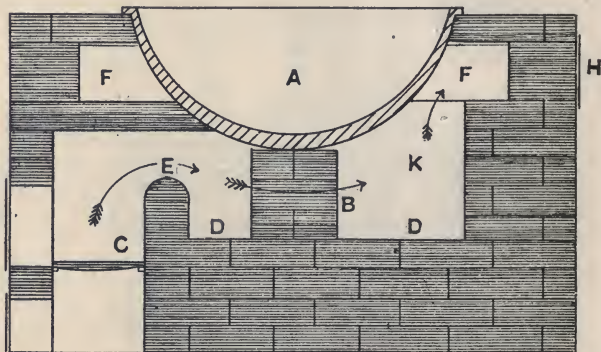


FIG. 5.—Vertical section of Wheel Flue.

arrangement. A is a cast-iron pot which rests on a solid brick pillar B. The fire grate C is separated from the bed D of the furnace by the bridge E, which also prevents the fuel from being carried over. The gaseous products of combustion pass over the bridge under the pot, then upwards through the flue K into the flue F, where they are taken round from left to right through G into a flue which conveys them to the chimney. The chimney draught is controlled by a damper H. Even with an arrangement like the above, a great deal of the available heat is still lost. It is in many cases more economical to put two or three furnaces together, working them from only one fireplace

under the front pot. The waste gases in that case pass from the exit flue of the first pot, which otherwise would lead into the chimney, under the second pot; they are then made to circulate first round the second pot, then round the third pot, and then into the chimney. In arrangements of this kind cold liquor is fed into the coldest pot, namely, the third pot, and syphoned automatically first into the second pot, and then into

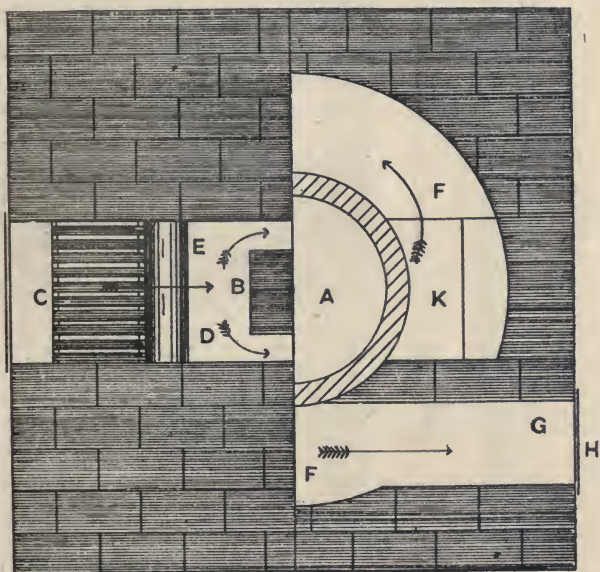


FIG. 6.—Plan of Wheel Flue.

the first pot, which will always contain the most concentrated liquor.

It is evident that one of the principal points to be considered in the construction of an evaporating plant is that the products of combustion should be used to the greatest advantage, that is, that as large a surface as possible of the evaporating vessel should be exposed to their action; hence, the surface of the vessel should be a maximum with regard to its volume. The

instances which we have given so far are, theoretically,

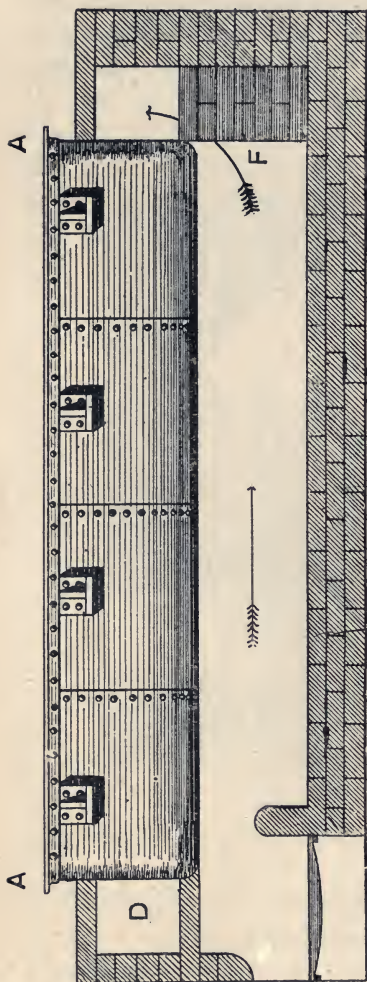


FIG. 7.—Side elevation of semi-cylindrical evaporating vessel.

not adapted to fulfil these conditions. It is well known that the half section of a sphere offers the least surface with regard to its volume. It would be possible to increase the ratio between surface and volume by making the pot shallower, but it will be more difficult then to build a flue round it. It is evident that there is no reason why differently shaped evaporating vessels should not be used; for instance, one which would resemble a bath, such as is used for domestic purposes, or a cylinder cut in two. The latter would give more surface in proportion to its length. If, for instance, the length were four times the radius of the corresponding cylinder, we should gain 25 per cent. in surface, as compared with a half sphere of equal volume; if it were eight times longer than the radius, we should gain 40 per cent. As the flues follow

straight lines instead of curves, they will be easier to build, easier to clean, and more economical to construct.

Figs. 7 and 8 represent such an arrangement.

The pan A A, which in this case is made of wrought-iron, rests on the brick walls E E. The fire gases travel underneath the pan, then upwards, and are divided by the pillar F; they then pass through the right and left flues B and C simultaneously, join up again in the front at D, and are taken from this into the main flue. Dampers are provided in the flues B and C to regulate the draft in each of the side flues, in case it should be stronger on one side than it is on the other. The question will

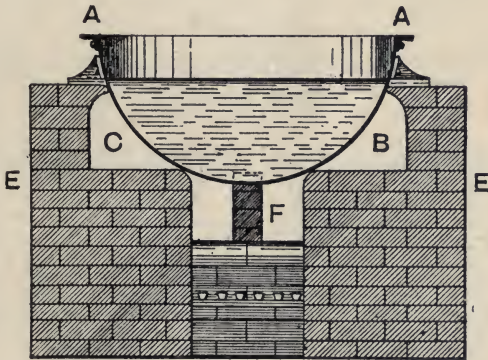


FIG. 8.—Transverse section of semi-cylindrical evaporating vessel.

be asked: Why not always use a long pan? The answer to this will be apparent if drawings are made of a pot and of a pan, the latter having a length eight times the radius of the corresponding cylinder, each capable of holding 100 gallons. It will then be noticed that for small quantities of liquid there is no advantage in a long pan, as the side flues become so shallow that the surface cannot be utilised to its best advantage in economising heat. The question of cost of plant will also often determine the shape of the evaporating vessel; for whilst, weight for weight, cast-iron is cheaper than wrought-iron, vessels made of the former have to be constructed in much

thicker metal, and therefore may become more expensive than wrought-iron apparatus, always provided that in the latter the cost of shaping and riveting is not excessive. A small cast-iron pot may be cheaper than a wrought-iron pan, and a large cast-iron pan may be dearer than a pot or pan made of wrought-iron.

In the boiling down of solutions it often happens that solid matters separate out and settle on the sides of the evaporating

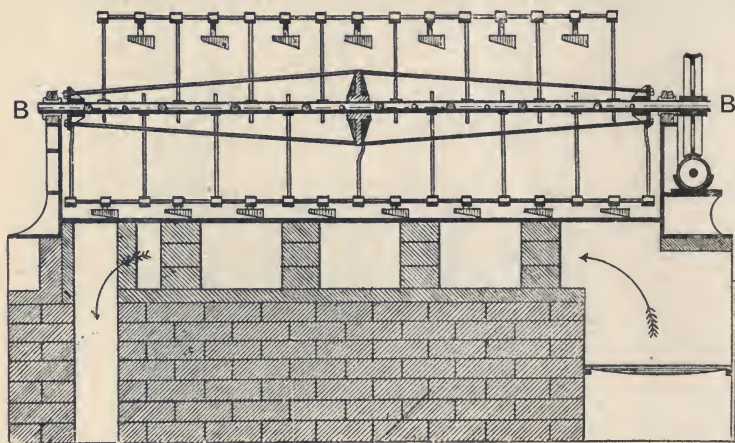


FIG. 9.—Side view of Thelen Pan.

vessel. The crusts which are thus formed are dried by the heat of the flue gases, and being in every case worse conductors of heat than iron or metal of any kind, prevent the heat from passing to the liquid, and thus doing its work economically. In consequence of this, the evaporating vessel is unequally heated, so that, where incrustation occurs, the undue rise of temperature may tend to alter the shape of the vessel or to burn through the iron. It is therefore in many cases advisable to have a mechanical arrangement which keeps the sides of the evaporating vessel free from incrustations. This purpose may be

effected by means of an agitator, the arms of which are arranged in such a manner that they traverse every part of the sides of the pot. A better arrangement would be one which would at the same time remove the precipitated matter altogether from the liquid. Such a design is shown in Figs. 9 and 10, and is known by the name of a Thelen pan.

A is a pan similar to the one last described. A shaft B B works in bearings at each end and is provided with arms, each carrying a small movable shovel at its end. The arms are arranged in such a manner that the little shovels push all deposit towards the end of the pan, where it is taken up by another shovel and lifted bodily out of the pan into a draining vessel, from which the liquor can drain straight back into the pan. Several of these pans may be so arranged that the waste heat from one pan heats the succeeding one.

A natural consequence of the foregoing remarks is that an evaporating pan should always be filled with liquor above the highest point of the surrounding flues, otherwise these parts would become overheated, and would soon deteriorate.

In the above-described apparatus the liquor to be concentrated has been placed in a suitable vessel, and the fire gases produced from the combustion of fuel have been passed under and round the vessel without coming into contact with the liquor to be evaporated. But an arrangement could be designed by

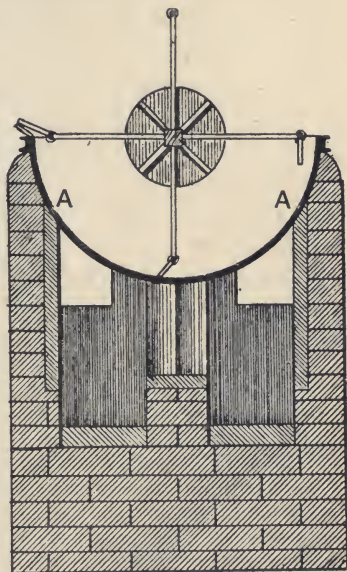


FIG. 10.—Transverse section of Thelen Pan.

which the products of combustion would be passed over the surface of the liquor which has to be concentrated. Such an arrangement is occasionally used, but it has the great drawback that naturally the liquor becomes contaminated with dust and objectionable impurities, such as sulphurous acid, which is almost always present in the products formed by the combustion of coal. This device is therefore not often used, though it is possible that with the extension of gas for fuel it may be found useful in certain cases in which it has hitherto not been applied. An ingenious apparatus, termed a Porion evaporator, is built on these lines, and is constructed in such a manner that whilst the fire gases pass over the liquid, the latter is converted into a fine spray by means of paddles revolving at great speed.

We have, so far, considered such technical evaporating arrangements as have a close structural resemblance to the Bunsen burner placed under a beaker or basin filled with liquid as commonly used in laboratory practice. It is often found more advisable in laboratory work not to use the naked flame for these operations, but to use a water, sand, metal, oil, or air bath, in order to obtain lower or higher and fairly constant temperatures. Where similar results have to be obtained on a large scale, there should be no difficulty, after the preceding remarks, to elaborate arrangements of this kind suitable for technical work, bearing in mind all the time that in working on a large scale we have an important auxiliary in steam, which, with few exceptions, chiefly found in experimental dye-houses, is not to any great extent made available in college laboratories. As a matter of fact, it is often more difficult to put together a small laboratory apparatus with closed-in steam than it is to construct a large apparatus in the works. As steam can be produced at different pressures, and consequently at different constant temperatures; as it can, moreover, be superheated to still higher temperatures than those which belong to it at its relative pressure, we have a ready means of producing and

maintaining constant temperatures ranging from 100° C. to about 400° C.

Where a sand-bath, oil-bath, or metal-bath is used, the arrangement will be almost identical with that used for the same purpose in the laboratory. If we use vessels of pot shape, it will only be necessary to place one pot inside a larger one, and fill in the empty space between the two with either sand, oil, lead, or any alloy which will give the required temperature. When steam is used, a similar arrangement may be resorted to, but with this difference, that the two pots will have to be jointed together steam-tight. Such an arrangement is shown in Fig. 11.

It is necessary to let the steam enter at the top, and to remove the condensed water and superfluous steam at the bottom, so as to give the waste steam and water a free passage. In order to use the steam most economically, it is necessary to take care that no more

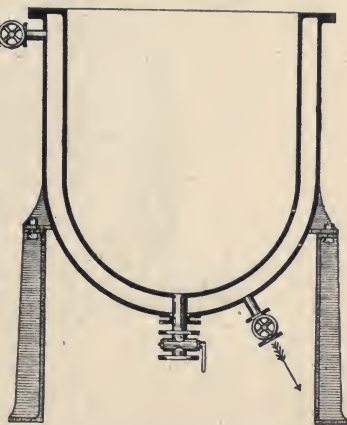


FIG. 11.—Steam-jacketed vessel.

steam is used than will conveniently condense, so that only hot water may leave the apparatus. This may be either used for feeding the boiler or for other purposes where hot water is required, or it may be taken through suitable coils placed in the liquid which feeds the boiling-down pan, and thus serve to give that liquid a preliminary heating.

In constructing jacket pans, care must be taken to make sufficient allowance in the strength and shape of the vessels to stand the pressure of the steam, and it will in many cases be found advisable to make the surrounding or outside jacket of

wrought-iron, which will resist a greater amount of pressure for the same thickness of metal than cast-iron. All apparatus of this kind—in fact, all apparatus which has to stand exterior or interior pressure—should be designed so as to present as little surface of a plane shape as possible; all surfaces should represent curves. This precaution need not be taken if we pass the steam through a coil placed in a suitably shaped evaporating vessel; in that manner the initial expense is reduced; and as it is possible to obtain welded coils of wrought-iron of almost any shape, vessels of different material, and of pot, pan, or box shape,

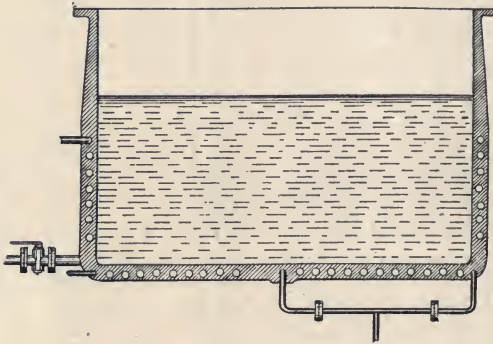


FIG. 12.—Steam-jacketed Bath.

may be used in conjunction with steam heating coils. The objection to coils is, that where solids are apt to be deposited, they are troublesome to keep clean, and when covered with incrustation they become inefficient. An ingenious device has been resorted to to overcome this objectionable feature, and one which combines the advantages of a jacket and coil pan. It has been found possible to cast molten iron round coils of wrought-iron pipes, so that a cast-iron vessel may be obtained which can be heated by steam passing through the sides which define its shape. Fig. 12 shows such an arrangement, which requires no further explanation.

Care should be taken in all cases to minimise radiation from the evaporation vessel; this is done either by surrounding it with several courses of brickwork, or by coating it with compositions which have little conductivity for heat, such as the well-known compositions which are used for steam-boiler coverings. In using coils for evaporating purposes, there is one point which must be particularly watched. If steam is passed through a coil which is slightly leaking, two things may happen: the steam may escape into the surrounding liquid and cause unnecessary dilution, or the surrounding liquid may be drawn through that fine opening, and in that way loss may be caused. Wherever a coil is used for evaporating purposes, it is therefore necessary to test the condensed water from time to time, to see that it is free from any of the substance which is placed in the boiling-down vessel.

In special cases it will be found that the waste steam from the steam engines may be utilised for evaporating purposes, and wherever this is possible it should be done. We shall have occasion to refer to this again.

We have, so far, only dealt with the commonest forms of apparatus for evaporation, not only for the reason that they are used more extensively than others, but because they illustrate most clearly the principles on which such apparatus is constructed. In the space at our disposal, it is impossible to deal with every kind of known apparatus, and special modes of evaporation, such as Brine towers, the Glover towers, and others, have therefore not been mentioned. These and many other kinds of apparatus may be, and have been, constructed for special purposes, but there is no necessity to describe every one in detail. They are all based on the principles which we have explained,—that is, to give as much surface to the evaporating vessel as possible, and to use up waste heat.

Cases arise in which the vapours evolved from the boiling liquids have to overcome a greater pressure than that of the

atmosphere, or in which the pressure under which they are evolved is less than that of the surrounding atmosphere, *i.e.* about 15 lbs. per square inch. These cases may be considered as processes of evaporation or of distillation, for no hard-and-fast line can be drawn between the two. For our purposes it will be most convenient to treat all processes of evaporation which take place in a closed system as processes of distillation, and thus include in that category evaporation under increased or diminished pressure. Taking that view, we proceed to the next chapter, in which we will deal with apparatus used for distillation and condensation, including the important subject of evaporation in a vacuum.

CHAPTER II.

DISTILLING FLASKS, LIEBIG CONDENSERS, FRACTIONATING TUBES, AND THEIR TECHNICAL EQUIVALENTS.

WE have mentioned in the preceding chapter that evaporation may be carried on under either increased or diminished pressure. Practically speaking, all the apparatus which has been described so far for evaporating can be easily converted into part of an apparatus for boiling down under a pressure, or in a vacuum, by simply putting a lid on the top of either the pots or pans described. Evaporation under pressure will be dealt with later on, when describing the construction and function of a steam boiler. Before describing the form of apparatus used for evaporation in a vacuum on a manufacturing scale, we will consider the apparatus used in the laboratory for similar purposes.

In its simplest form, this consists of a flask or retort into which the liquid to be evaporated is placed. This vessel is connected with a Liebig condenser, from which the condensed distillate passes into a Woulfe bottle. If the latter is joined up to a Bunsen pump, the distillation may take place in a vacuum. It is well known that with diminished pressure the boiling point of all liquids is considerably lowered, and that it is therefore possible to distil or evaporate liquids at a lower temperature in a partial vacuum than would be the case at ordinary pressure. In laboratory work this is chiefly done when the liquid which is to be evaporated would become

partially or wholly decomposed if evaporated at its normal boiling point. A solution of sugar, for instance, will partially decompose and become discoloured if evaporated under atmospheric pressure, whereas in a vacuum it yields pure white crystals. But whilst in the chemical laboratory the above is almost in all cases the only reason for which evaporation in a vacuum is resorted to, it is found in practical work that, even where one has to deal with stable substances, evaporation in a vacuum may offer such advantages as to counterbalance the extra cost of the apparatus, cost of condensing, and other incidentals.

We will now attempt to evolve, from the laboratory apparatus which we have described, the simplest form of apparatus suitable for technical purposes. We have first to consider how to transform the flask which holds the liquid, and which in the laboratory would be heated by means of a water-bath or similar arrangement; this we can replace by any of the pot-shaped boiling-down appliances which we have mentioned, particularly by a jacket pan, such as is shown in Fig. 11. We should simply provide this pan with a lid, which, as it has to stand pressure, would be of spherical or similar shape, and would contain a pipe at the top for the purpose of carrying away the steam which is given off.

In the laboratory apparatus the steam from the boiling liquid would be taken through a Liebig condenser; on a large scale the latter might be replaced by an upright pipe, which may be cooled from the outside by a stream of water trickling round its circumference; or the cooling water may be injected into the pipe by a spray arrangement, and, mingling with the steam, condense it. The Bunsen pump which would be used in the laboratory arrangement would be replaced by a mechanical vacuum pump, of which there are two kinds. If constructed for keeping up a vacuum by drawing out the air only, it is termed a dry air pump; if it draws the condensed steam and condensing water as well, it is termed a wet vacuum pump.

Fig. 13 shows such a simple arrangement, and represents the principles underlying the construction of vacuum apparatus.

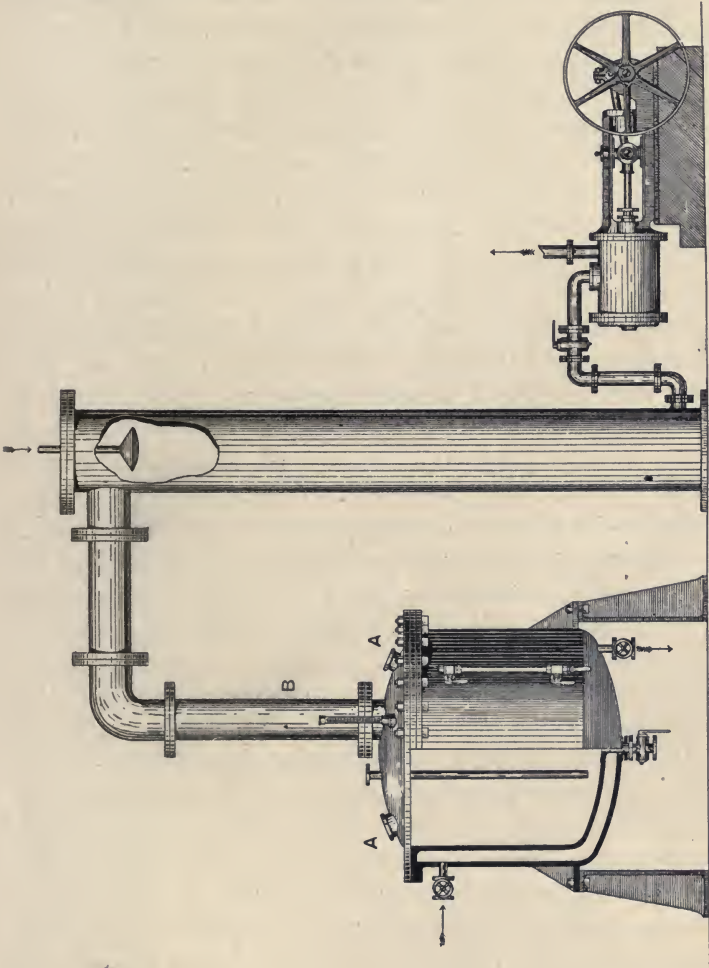


FIG. 13.—Vacuum Distilling Plant.

Alterations and additions naturally occur in improved working apparatus.

Thus it is advisable to have sight glasses A, one opposite to the other, on the lid, so as to be able to watch the progress of the operation. It is also necessary to make provision against boiling over by means of a dome B, or otherwise, in the case of liquids which produce a great amount of froth. There are many minor details of construction which distinguish different makes of vacuum apparatus made by different reputed firms. Some vacuum pans are supplied with pipes through which the liquid can circulate, and which, therefore, offer a greater surface to the heating steam; some have means of discharging salts which separate out without breaking the vacuum. All these improvements add to the efficiency of the apparatus, but they also add to its cost, and sometimes, by their complication, cause frequent breakdowns. Where the condensing water is sprayed into the condensing tower, it will be advisable to ensure that the water enters the tower under as little pressure as possible, as otherwise a back pressure will be produced, which will reduce the vacuum, or at any rate will render it more expensive to keep up a good vacuum. As the temperature at which a liquid will boil varies with the pressure, or, to put it more clearly, but less scientifically, as it is to some extent inversely proportionate to the vacuum, it follows that the better the vacuum which is kept up in the apparatus, the lower will be the temperature at which the evaporation will take place, and the higher the efficiency of the whole apparatus. It also follows that as water will boil at 50° C. with a moderate vacuum, the steam which is used for heating the vacuum apparatus will do its work as long as it is above that temperature, so that, whilst in an open apparatus it would be necessary to work with steam of over 100° C., with vacuum apparatus, steam even at 50° C. will produce a sensible evaporating effect. It is here, therefore, where the exhaust steam from engines, which in most cases has a temperature not much over 100° , will be found particularly effective and

economical. As the boiling point of every liquid is lowered in a vacuum, it is possible to distil substances by means of steam which otherwise would not be amenable to that agent; one could, *e.g.*, distil a substance boiling at 200° with steam of 150° C. On the other hand, one has to be careful, on evaporating liquids containing substances which decompose at certain temperatures, not to use the steam at too high a temperature, otherwise these substances, notwithstanding that the operation is performed in a vacuum apparently kept below the decomposing temperature, may partially decompose. The reason for this is, that the sides of the vessel become temporarily heated nearly to the temperature of the heating steam, and though the liquor in the pan would be exposed to that temperature only for a very short time, a slight decomposition would take place at the contact points, and in the time required for an operation might cause serious loss. In such cases, again, evaporation in a vacuum often enables us to utilise waste steam with great advantage. Where waste steam is not available, and where the steam which comes direct from the boiler has to be reduced in pressure, and consequently in temperature, this is done by an apparatus which is called a reducing valve—a simple contrivance which consists of a valve which regulates the flow of the steam so that it expands at such a ratio as to reduce its temperature and pressure.

If we heat a liquid by means of closed-in steam, that is, by means of a jacket, coil, or similar arrangement, steam is ultimately evolved from that liquid. There is no reason why this steam should not be conducted into the jacket of another pan or through a steam coil or similar arrangement, and made to heat up a further quantity of liquid and produce steam again, though of lower temperature and pressure. An arrangement of such a system is practically feasible, and is known as 'multiple-effect evaporation.' Two apparatus coupled together represent what is termed double-effect; three, triple-effect; four, quadruple-effect, etc. It is possible thus to utilise heat for

the purpose of evaporation more efficiently than by any other system, but it does not follow that an arrangement of this kind will be always the most economical in work. The cost of evaporation in every case is composed of a number of factors, including the cost of coal required to evaporate the liquid, the cost of labour in attending to the boiling down, the interest and depreciation on the outlay for plant, the repair for the same, and other general charges which we need not consider at present. If, for instance, we found that in order to boil down a certain quantity of water, say 1000 gallons per day, we required one ton of coal at 10s., if the labour in attending to the pan came to 4s., and if the total cost of the apparatus were £100, and the wear and tear of this, including interest on the money laid out, came to £15 per annum, which is 1s. per day, the total cost of evaporation would come to 15s. per thousand gallons. If, on the other hand, we found that the original cost of the installation in multiple evaporation were £1000, which at 15 per cent. would represent £150 per annum, or 10s. per day, we should find that, even if the labour and other expenses were the same as with an ordinary boiling-down pan, the cost of evaporation would be still higher by that system, although the amount of coal, or rather its equivalent in steam, used for evaporation might only come to three or four shillings per day, against the 10s. which we had to spend on fuel in evaporation in open pans by direct fire. These calculations do not represent actual facts, but are intentionally exaggerated so as to show the necessity of not being misled by only taking one factor into consideration when the cost of an operation has to be considered. There is little doubt that the principle of multiple evaporation will in the future play an important part in the construction of evaporating apparatus. At present the apparatus in many cases is still too complicated and too costly, and is therefore not used to the extent which it deserves.

We may now proceed to consider the construction of an apparatus used for what is generally understood as distilling. A convenient example of such an apparatus is presented in the manufacture of nitric acid. In the laboratory nitric acid is generally prepared by mixing sodium nitrate and sulphuric acid in a glass retort connected with a receiver which, being cooled, condenses the vapours of nitric acid which are given off. It is well known to the student of chemistry that this method of preparing nitric acid is capable of various modifications. To start with, one may aim from the outset at obtaining a very strong nitric acid, one approaching HNO_3 as near as possible; or one may be satisfied with obtaining a weaker acid, say one containing only 66 per cent. of HNO_3 . In the one case it would be necessary to use pure dried sodium nitrate and strong sulphuric acid containing at least 98 per cent. of H_2SO_4 . In the other case ordinary commercial nitrate and sulphuric acid of commercial quality of a specific gravity of 1.75, and equal to about 80 per cent. of H_2SO_4 in strength, may be employed. Moreover, the quantity of acid may be chosen so as to yield a product in the retort which may be either Na_2SO_4 or NaHSO_4 , or a mixture of the two. If the proportions between sulphuric acid and nitrate of soda are chosen in such a way that they may be represented by the equation $2\text{NaNO}_3 + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{HNO}_3$, then the remaining mass in the retort will be sodium sulphate in such a form that it will be impossible to remove it from the retort without breaking the latter. If the operation is carried on in such a manner that it may be represented by the equation $2\text{NaNO}_3 + 2\text{H}_2\text{SO}_4 = 2\text{NaHSO}_4 + 2\text{HNO}_3$, then the mass formed in the retort will melt at the comparatively low temperature which is necessary to produce the liberation of nitric acid, and it will be possible to pour out the molten sodium hydrogen sulphate at the end of the operation without breaking the retort. One difficulty will have presented itself in putting

together the distilling apparatus, and that is how to make the connection with the retort and the receiver tight, as hot nitric acid will attack cork, rubber, or any other of the materials which are generally used for the purpose of making joints in ordinary laboratory work. With the facilities which one has now in getting glass apparatus of this kind, this difficulty is often overcome by having the retort neck ground into the neck of the receiver.

If we now consider how we may construct an apparatus suitable for manufacturing large quantities of nitric acid, we must bear in mind all the points which we have explained in connection with the laboratory process, and decide if the work is to be done in accordance with the first or the second of the equations given above. In practice, it is not usual to go as far as $2\text{H}_2\text{SO}_4$ in the second equation; generally one and a quarter or a little more is taken, *i.e.* just sufficient to form a compound which will melt at the temperature at which the retort is kept, and which, therefore, will enable us to run off the charge in the retort when the operation is finished. If the proportions chosen are two NaNO_3 to one H_2SO_4 , so that Na_2SO_4 results as the end product in the retort, it will be necessary to use such an apparatus as will enable us to chip out the contents of the retort after each operation. For this purpose a cylindrical vessel is generally used, about 5 feet long and about 2 feet in diameter, provided with a cover in front, which is taken off after each operation, so as to enable the workman to chip the sodium sulphate, or salt-cake, as it is generally termed, out of the retort. Apart from the extra labour which this involves, it is also necessary to cool the apparatus for about twenty-four hours before it can be opened and emptied and got ready again for another charge. In this mode of working there is a saving in sulphuric acid, and the product obtained is commercially more valuable, but the relative charges for labour and interest on installation, and the loss in fuel caused by the heating up and cooling down of

the apparatus between the charges, are considerable. For this reason it is often preferable to use such an excess of sulphuric acid as to produce a mixture of sodium sulphate and hydrogen sodium sulphate in the retort, which, being liquid at the end of the operation, can be let off through a convenient tap-hole, leaving the still ready for another charge without loss of time and with little expense for labour. In an apparatus which is designed for this purpose, the still will have the shape of an ordinary pot with a round cover on it, similar to the one shown in Fig. 13; the dimensions of these pots vary considerably, the charges they will hold ranging from a few cwt. to one ton and more of nitrate of soda. They are provided with a pipe going through the lid, through which the sulphuric acid is passed into the still; there is also a charging hole, sufficiently large to enable the workman to throw in the nitrate of soda with a shovel; there is, further, a connecting piece on the top to which the earthenware pipe conveying the nitric acid vapours to the condensing plant is secured. We have already mentioned that there is a convenient tap-hole at the bottom of the still for letting off the molten residue. The still and all these parts are made of cast-iron, as this resists the action of sulphuric acid down to acid of 80 per cent. fairly well. But there is some action, and it is necessary to allow for the gradual eating away of the iron, and to make the bottom part of the still, as far as it is touched by the sulphuric acid and the acid sulphate, of sufficient thickness, say 2 inches or more. It is further necessary to brick in a still of this description in such a manner that the nitric acid vapours cannot condense in the upper part of the still and on the lid, as the fumes of nitric acid do not act nearly so strongly on the iron as the condensed acid does. The fire gases are therefore conducted round the pot as we have shown in previous examples, and in many cases taken over the lid of the still, though this complicates the matter considerably, and the same effect can be obtained by other means.

Having settled the form which our laboratory retort would have to take to enable us to prepare nitric acid on a large scale, and the material of which it would have to be constructed, we may now consider how to deal with nitric acid vapours so as to get them condensed. First of all we must ascertain the material of which the condensing part will have to be constructed. Iron is naturally out of the question, as it would be destroyed, and at the same time would reduce the nitric acid to lower oxides; no other metal could be used except platinum, which would be too expensive. We are therefore compelled to use earthenware. Fig. 14 shows different kinds of apparatus used for the purpose; a number of receivers A A may be combined with a plate tower B and an earthenware worm C, or receivers only may be used, and the last traces of nitric acid may be washed out in a tower filled with earthenware solid or hollow balls, over which water or sulphuric acid is passing. Here we meet with the difficulty which we have mentioned in discussing the process as carried on in the laboratory, viz. the joining up of the different parts. This in practical work is effected by means of lutes or cements which are filled into the interstices at the junctions; thus the socket D would be filled in with cement as far as it would hold the latter after the pipe E had been placed in position. Naturally, it will be necessary to choose such a lute as will resist the action of nitric acid vapour, and a number of these lutes or cements are recommended for the purpose. It will be sufficient to mention only a few. Thus, where it is desirable to allow a certain amount of play on account of expansion by heat or for other reasons, a plastic lute which does not set hard is advisable; for instance, one made by heating up linseed oil with sulphur and old india-rubber cuttings, and incorporating in the resulting mass barium sulphate and asbestos fibre. Where a hard setting cement is required, a mixture of sodium silicate and ground glass may be used.

The principle of condensation is analogous to that of evaporation. One may cool by air or by water, or by freezing mixtures,

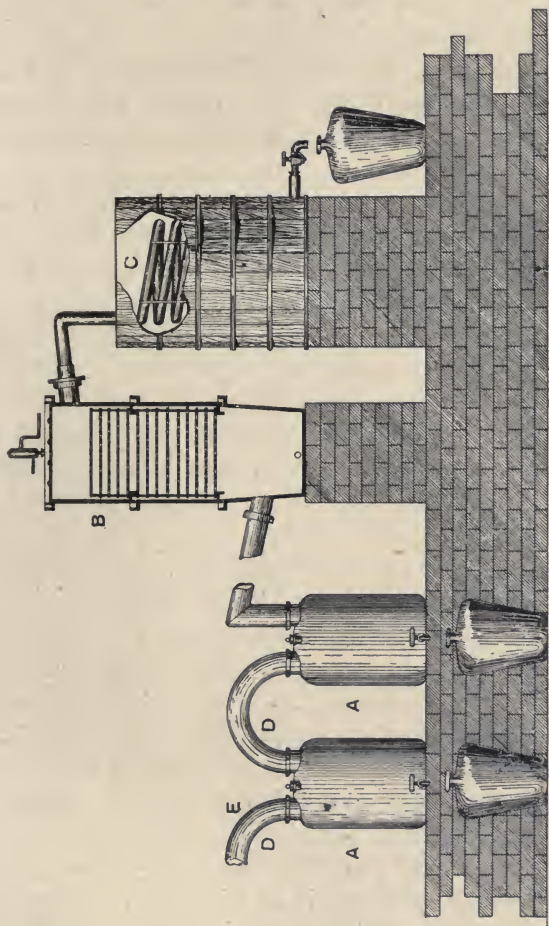


FIG. 14.—Receiving apparatus used in producing nitric acid.

but in every instance the apparatus, to be efficient, must be constructed in such a manner that the largest surface is presented to the cooling medium.

The example on which we have demonstrated distillation shows how important it is to carefully study the chemical reactions which take place, so as to design the apparatus accordingly; how necessary it is to consider the action of the chemicals used and produced on the material of which the separate parts of the plant are composed, and how even the smallest details, as in this instance suitable jointings, must be attended to.

Fractionating distillation is a process by which mixtures of liquids containing several constituents which boil at different temperatures are separated. The general view is, that at the boiling point of a mixture of liquids, the more volatile constituent evaporates first, and carries with it only a certain quantity of the higher boiling constituents. If, therefore, the part which passes over is cooled, a product is obtained which consists chiefly of the lower boiling parts of the mixture. As the distillation proceeds, the residue in the retort will gradually be freed from the more volatile part of the mixture, and its boiling point will accordingly be raised. It is not possible to separate every mixture by fractionating. Cases occur where the mixtures at a certain point of the distillation form groups which may be considered as combinations, and in that case, although the distillate will pass over at a fixed temperature, it will not be a pure compound, but a mixture or combination of fixed boiling point. Thus a mixture of 8 per cent. of water and 92 per cent. of alcohol cannot be separated by fractionating. On boiling a weak aqueous solution of hydrochloric acid, water will be given off until the residual product contains a mixture of 20 per cent. of HCl and 80 per cent. H₂O; and on boiling a strong solution of hydrochloric acid in water, hydrochloric acid gas will be given off until the remainder in the still is again composed of 20 per cent. of hydrochloric acid and 80 per cent. water; and in both cases the boiling point will be found to be 110° C.

The ordinary apparatus which is used for fractionating in the laboratory consists of a flask provided with a fractionating tube, which is connected with a Liebig condenser. Many different designs of these fractionating tubes have been proposed, though all are based on the principle of giving the vapours a certain amount of resistance in passing through, and of increasing the cooling surface, and thus effecting the condensation of the higher boiling vapours, whilst the lower boiling vapours pass on through a Liebig condenser. On a large scale the principle is exactly the same. The mixture of the liquids which have to be separated is placed in a still of suitable shape, made of such material as will not be attacked by the substance which has to be manipulated. It is sometimes most difficult to find a suitable substance from which to construct the still, and the most varied materials are used, including cast-iron, wrought-iron, copper, silver, lead, enamelled iron, earthenware, and even glass. According to the nature of the substances and the temperature they require for separation, the still may be heated by open fire, by steam, or by hot water; wherever inflammable liquids have to be treated which give off vapours at comparatively low temperatures, it is a fixed rule that no open fire must be used. Fig. 15 shows the general arrangement of a fractionating plant.

The vapours which come from the still pass through a separator A, which corresponds to the fractionating tube as used in the laboratory model. This separator generally consists of a metal tube A, which may be divided horizontally into a number of compartments by sieves, as shown in Fig. 16, or by plates provided with lutes covered by balls, as shown in Fig. 17. Provision is made at the sides for tubes so that condensed liquid may run back into the still. The distillation is regulated in such a manner that if the separator is kept at the proper temperature, only vapours pass from it into the vessel B above. This vessel really represents the Liebig condenser of the

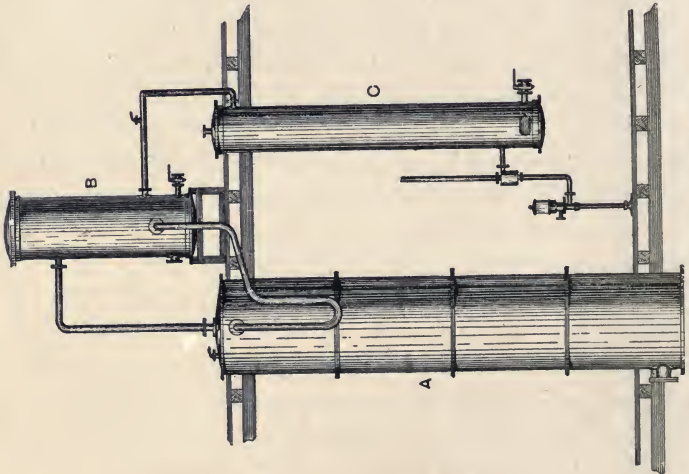
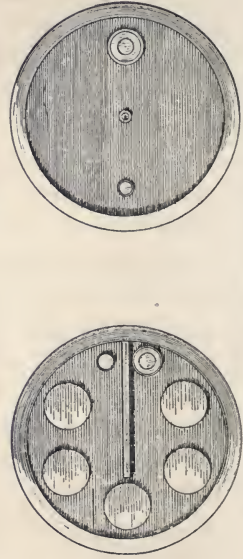
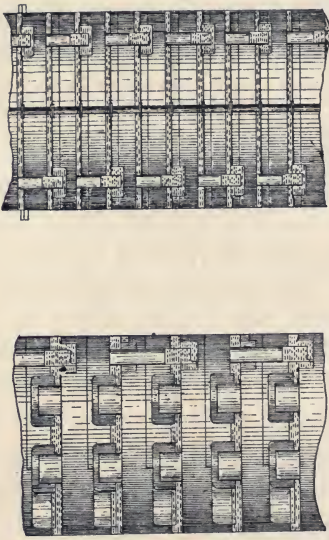


FIG. 15.—To show general arrangement of Fractionating Plant.



FIGS. 16 and 17.—Two different types of Separator.

laboratory apparatus, but inverted, so that whatever condenses in it first goes back in the separator, and the more volatile constituents pass on into the receiver C, where they are completely condensed. It may not be unnecessary to point out that in a system of this kind the distillation and separation of the constituents take place partly in the still, but to a great extent in the separator, and that the success of the operation depends largely upon the proper management of the cooler B, which regulates the quantity of liquid which runs back into the separator.

CHAPTER III.

THE AIR-BATH AND ITS TECHNICAL EQUIVALENTS.

THE air-bath is used in the laboratory for drying substances at different temperatures. It may be heated directly by gas, or the heat may be transferred to its interior through a water jacket. The purpose of the drying operation is in most cases to expel water from solids, though cases occur in which other liquids have to be separated in this manner from solids, or from liquids which boil at a higher temperature. As the problem of expelling superfluous water from solids is the one which most frequently occurs in practice, we will confine our remarks to this particular case.

It must be clearly understood that the operation of drying is not identical with that of ordinary evaporation. In ordinary evaporation we produce, by the application of heat and by the evolution of steam, currents which enable the particles of the liquid to move about freely, and thus to conduct the heat fairly well. Although, therefore, water, and many compounds which dissolve in it, are in themselves exceedingly bad conductors of heat, yet in the process of evaporation, as it is generally understood, the bad conductivity is overcome by the mobility of the liquids. But whenever the problem before us consists in drying a mixture of a solid and a liquid, in which the particles cannot freely move, we have to take into consideration and allow for the fact that the heat has to be transferred through a bad conductor. We know that without

special mechanical arrangements 1 pound of coal will evaporate from 5 to 10 pounds of water from a liquid which remains such during the process, but it will be impossible to expel anything like that quantity of water from a pasty mass, and the best mechanical arrangements will not enable us to obtain results which in ordinary evaporation would be considered barely satisfactory.

In using the air-bath in the laboratory, we may either use it with only an opening at the top through which the vapours evolved may pass, or we may have an opening at the bottom as well, and thus produce a current of air during the drying process. If we adopt the latter arrangement, we shall find that we obtain the desired results in a shorter time, as the moist substance, instead of being in a stagnant atmosphere saturated with moisture, will be exposed to a constant current of air, which not being fully saturated with water, will take up moisture in its passage. The same applies to work on a large scale; but whilst the small quantities manipulated in the laboratory are generally left undisturbed in the air-bath, the large quantities dealt with on a manufacturing scale have to be stirred up by hand or by mechanical means, or they may have to be moved about and transported from one part of the drying machine to another.

In the first instance it is necessary to deprive those goods which have subsequently to be dried by heat of as much moisture as possible by such means as will be explained in Chapter VII. Crystals should be drained and, where possible, dried by a centrifugal machine; precipitates should be deprived of as much water as possible by means of filter-presses or other pressing machinery. Only after such preliminary treatment should the process of drying by heat be resorted to.

As it is often necessary to make use of mechanical arrangements which recur in different forms of drying apparatus, it may be advisable to give a description of some mechanical

arrangements which we have, so far, not had occasion to consider, and a study of which will render the subsequent explanations of drying machinery more lucid and easier to understand.

Supposing we had many tons of crystals which had to be transported from one end of a room to the other, we could do so by placing them in a wheelbarrow and wheeling them from one end to the other; but the same object could be obtained by having a roller fixed at either end of the room, over which a sheet of calico of the width of the rollers was stretched in such a manner that it would form an endless belt. By turning the rollers, that endless belt, through friction, would, according to the speed of the rollers, move at whatever speed we desired to give it, and any substance placed upon the top part of the endless belt would travel from one end and be discharged at the other end. Instead of a belt made of calico, we could use an arrangement made of metal, consisting of thin metal laths, wire netting, or similar appliances, to effect the same purpose. Such an arrangement is largely used for transporting goods in works, and is known as a carrier conveyor, and shown in Fig. 18.

Another way of effecting the same purpose would be to place a long Archimedean screw in a trough, when, on turning the screw, any suitable substances placed in the trough would be moved in a horizontal direction. Such an arrangement is known as a screw conveyor, and is shown in Fig. 19. It works remarkably well with dry or comparatively dry substances, but is not so efficient in the case of pasty masses, which are apt to stick. In such contingencies, an arrangement may be used in which an endless chain travels over sprocket wheels: bars, which act as scrapers, are fixed to the chain at convenient intervals, and thus, as the chain revolves, take up and carry forward any substances which they may meet. An arrangement of this kind is called a drag plate conveyor, and is represented by Fig. 20.

The arrangements which we have so far discussed enable us

to transport goods in a horizontal or slightly inclined direction. If it is desirable to transport goods in a vertical direction or at

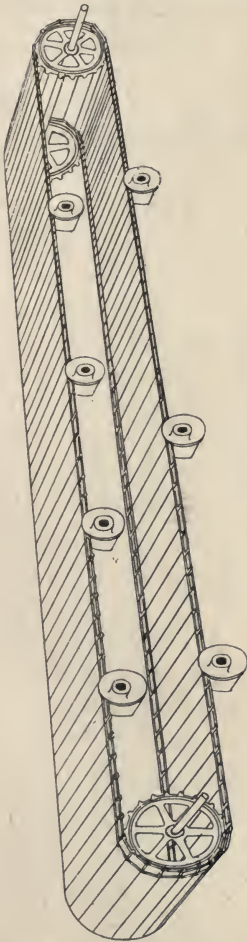


FIG. 18.—Carrier Conveyor.

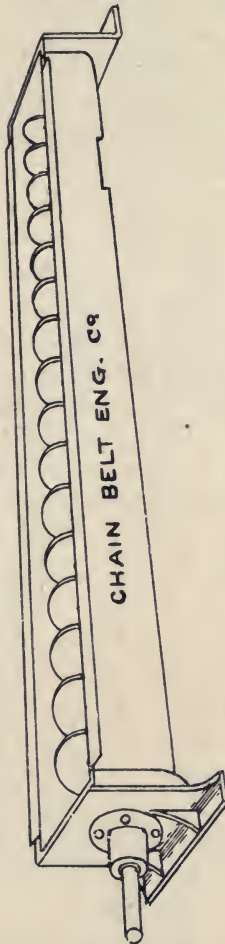


FIG. 19.—Screw Conveyor.

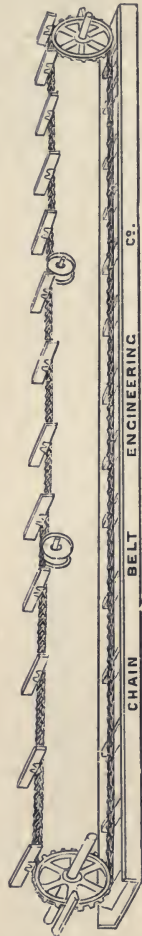


FIG. 20.—Drag Plate Conveyor.

an obtuse angle, we may make use of an endless chain to which buckets are attached at convenient intervals. As the chain is made to revolve, these buckets dip at the lowest point into the

mass which has to be transported from a lower to a higher level, and get filled. In travelling upwards they will, on passing the highest point, gradually turn over and discharge the mass which they contain. Such an arrangement goes by the name of the bucket elevator, and is shown in Fig. 21.

All these arrangements are largely made use of in the construction of drying plant, and we may now proceed to describe some systems in detail.

The nearest approach to the air-bath as used in the laboratory would be a chamber built of wood, brick, or other suitable material, well isolated against radiation, through which hot air was made to circulate. Such an arrangement is frequently used, and various details of construction are applied to it. The heating may take place inside the chamber by means of steam pipes, or the air may be heated before it enters the chamber, or a mixture of air and the products of combustion from a coke fire may be passed through the drying chamber in cases where the presence of carbonic acid would not be injurious. Again, air may be either drawn through the system or it may be forced into it. The latter arrangement is the better of the two, as it prevents cold air from being drawn into the apparatus if there should be any leakage in it. A number of such chambers may be placed on the top of each other, forming a high building, and each story may be heated separately, or may receive its heat from the story below it. The goods which have to be dried may be placed on racks or trays which are fixtures in the drying chambers, or a number of trays may be built up above each other into a set of shelves, and placed on bogies so that they may be easily wheeled into or out of the drying chambers for the purpose of filling and emptying. It is difficult in these arrangements to obtain an even distribution of heat, so that the goods in different parts of the system do not finish drying in the same time.

The simplest form of drying apparatus would appear to be

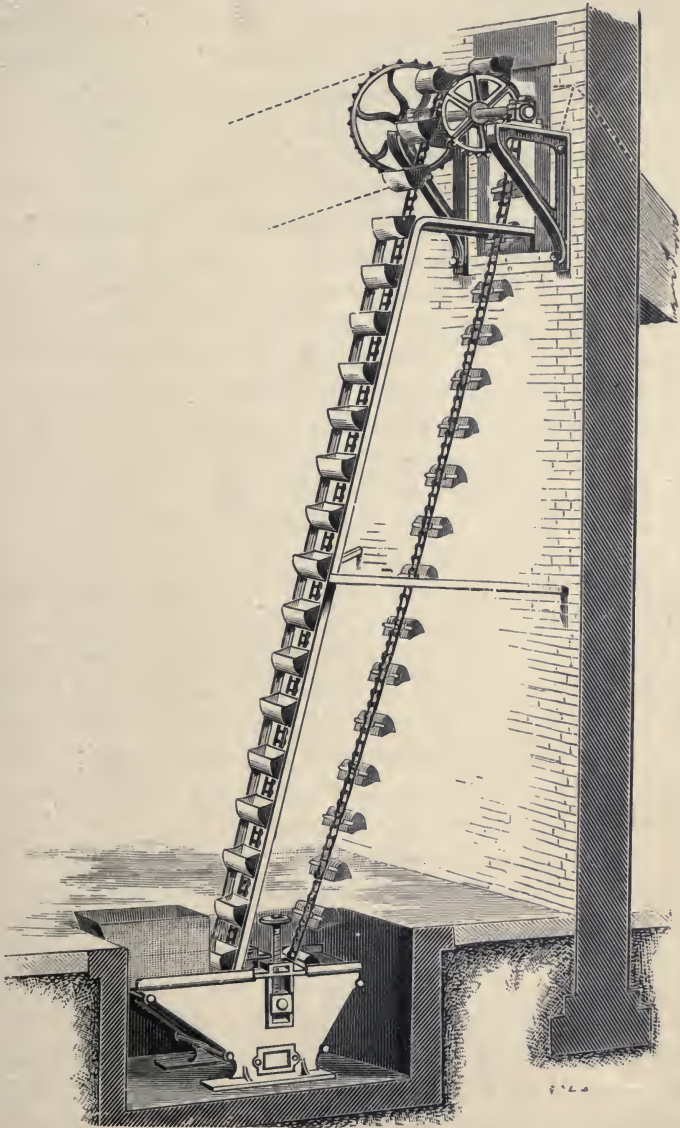


FIG. 21.—Bucket Elevator.

one which consisted of a long plate or a shallow pan, and heated by means of an ordinary fire in such a manner that the flue gases would pass along channels underneath the plate or pan. Various metals, enamelled iron, or earthenware tiles could be used for constructing the drying bed. The heat of the bed would be greatest near the fireplace, and least at the end furthest from it, and the material to be dried might be placed on the cold end and moved gradually by rakes towards the hottest end. In such an arrangement, however, it would be impossible to keep the temperature within a narrow range, and it would be quite impracticable in the case of compounds which decompose above 100° C. or thereabouts. In such cases a steam-jacketed shallow pan might be used, care being taken that the flat bed be made of sufficiently strong material to stand the pressure of the steam without bulging. Or an arrangement might be used in which the heat was transmitted to the bottom of the tray by means of steam pipes. The writer has found that the efficiency of this construction can be increased by imbedding the steam pipes in dry iron filings and placing the bed closely on the top layer. As the iron filings conduct well, this is a fairly economical way of transmitting the heat of the steam. We may mention that a similar design also furnishes an excellent sand-bath in laboratories in which steam is available. Steam coils are placed in a square box of about 4 inches depth made of wood or sheet iron; the box is filled up within half an inch above the coils with dry iron filings, and a layer of 1 inch of sand is placed on the top of this.

According to the pressure and temperature of the steam, which can be regulated at any time by means of a reducing valve, the sand-bath may be kept at a uniform heat of from 100° C. to 120° C.; and with superheated steam a temperature up to 300° C. or more may be obtained. Instead of steam pipes or steam coils, advantage could be taken of the arrangement

which we have shown in Fig. 12, p. 18, in which wrought-iron pipes are cast into iron plates.

In the arrangements described, the air has free access to the goods which have to be dried. In some cases it may be desirable to carry on the drying in a closed system: this could easily be effected by providing any of the before-mentioned apparatus with a lid. In that case it will be necessary to carry off the vapours by means of a mechanical arrangement, such as a pump, a fan, or an ejector.

From the remarks made at the beginning of this chapter it will appear that in many cases the drying operation will not proceed on economical lines unless the mass is frequently agitated and turned over. In other cases the goods have to be gradually moved from the coldest to the hottest part of the system. This, if done by hand, requires constant attention and labour, and therefore involves extra cost; wherever it is practicable, mechanical appliances are therefore employed. There are many ways in which the work involved in turning over substances whilst drying can be effected by machinery. One of the simplest would be to have a shallow trough, at the bottom of which an endless screw worked, such as we have described. This could be heated in either of the ways which we have mentioned, and the speed of the screw could be arranged in such a manner that the goods were carried from end to end in the time required to reduce them from the wet to the dry state. Instead of spiral conveyors, drag plates could be made to move on a flat plate and thus to carry the substance forward, but in that case the amount of stirring in many cases would be inconsiderable, and pasty substances would be liable to be carried along in almost solid blocks.

Drying apparatus are constructed, and have been found efficient, consisting of long cylinders in which the material, by means of large screws, is gradually and slowly moved from end to end, whilst at the same time little buckets fixed on the

revolving axle lift the stuff from the bottom and in carrying it round drop it again, thus producing a thorough mixing and separating. It is evident that here again many ways of heating the apparatus may be applied; thus in one arrangement the coal or coke fire is made to heat the air which is passed through the drum whilst the products of combustion are taken round the drum, thus heating it from the outside; or the drum may be double-cased and heated by steam, and so on. In another type of drying machinery, a long chamber provided with doors at opposite ends may be heated by any of the means described above. The goods to be dried are placed in little waggons which run on a tramway along the chamber, and these little waggons are placed in the chamber by means of long rods, and left in it for the necessary time. Where space has to be economised the chamber may be built vertically, and in that case the little waggons are raised or lowered by means of chains.

Another arrangement which is largely used consists of a drying chamber in which carrier conveyors are arranged in such a manner, one above the other, that the substances which are fed in at the top pass along the highest band and are made to drop on the one below, which projects at that end and moves in an opposite direction, and so on from the higher to the lower until the goods are discharged at the bottom of the apparatus. The use of machinery in drying installations to economise hand labour is not restricted to the drying chamber itself. The wet stuff or finished material can be moved away or towards the place by means of bucket elevators, and the other arrangements mentioned may be used for the same purpose. Economy of labour and economy of heat are the two main principles which underlie the construction of such installations. As regards the former, the problem has been solved very efficiently; but with regard to the latter, it is still capable of improvement, and even with the most perfect designs it has been so far impossible to

effect the evaporation of more than 5 pounds of water for every pound of coal used. It need hardly be mentioned that in all cases where waste steam or waste heat from other sources is available, this will be used for the purposes of drying.

We will conclude this chapter with an interesting illustration of how it is possible to get over a difficulty which at one time seemed almost insurmountable. It is now possible to dry explosive substances by heat. The manner in which this is effected is by utilising our knowledge that with a sufficient vacuum water will boil and evaporate at a low temperature. The construction which is used consists generally of a closed metal drying chamber heated by steam, and supplied with shelves on which the material to be dried is placed. The chamber is connected with a large explosion chamber fitted with a great number of safety-valves. If at any time an explosion should occur, the gases evolved would be drawn into the explosion chamber, which is always in a state of vacuum, and any surplus pressure would cause the safety-valves to be thrown open. When the drying is complete the steam is turned off, and cold water passed through a system of pipes conveniently arranged in the chamber, by which the whole system is cooled; when the explosive substances are cold they can be removed without danger. It is obvious that all steam and water taps are arranged at a distance from the apparatus, so that they can be regulated without the workmen being compelled to go near the drying chamber whilst it is in actual work.

CHAPTER IV.

THE BLOWPIPE AND THE CRUCIBLE, AND THEIR TECHNICAL EQUIVALENTS.

IN the course of his work in the laboratory the student of chemistry often has occasion to heat substances to high temperatures, and he will learn at an early stage that many different principles are involved in and incidental to that operation. One of its fundamental conditions is, that the temperature of the flame which we apply should be higher than the ultimate temperature to which we want to raise the substance which requires heating; another, that the volume of the substance to be heated should be proportionate to the size of the flame, otherwise, if its volume be too great, loss of heat from radiation and other causes will prevent it from acquiring a sufficiently high temperature. These principles are well known to any student who has worked with the ordinary blowpipe, and has also had an opportunity of studying the subject by the beautiful method of flame reactions introduced by Bunsen, by which the ordinary flame of the Bunsen burner can be made to produce reactions at high temperatures by the use, in the one case, of a carbonised wooden match instead of charcoal, or in the other case, of an extremely thin platinum wire on which a small bead is formed by borax or other means. The student will also have learnt that the character of the flame is not the same all through, and that, if one requires to produce reactions in

which oxidation may take place, the outer and top part of the flame are used. If it is necessary to produce reactions which are of a reducing character, then it will be necessary to use the blue centre of the flame, which, owing to the absence of oxygen, has no oxidising properties.

The same principles will hold good where larger quantities of material are used in the laboratory. For instance, in analytical work in which crucibles are employed, they are heated either with the lid cover on, to prevent access of air, or in a slanting position without the cover, so as to provide a draught of air through the mass.

If we examine the apparatus which is used in works to produce results similar to those obtainable in the laboratory, we find that it is partly constructed on the same principles as those applied in blowpipe work, partly on the same principles as those applied in working with a closed or open crucible. A furnace which is used for operations in imitation of blowpipe work, that is, for work in which the mass to be heated is exposed to the direct action of the fire gases, is represented in Figs. 22 and 23.

It consists of an arched chamber built of bricks and heated from a grate. The substance to be heated is spread on the bed of the furnace chamber; the fire gases pass over it, and are taken out at the end opposite to the fire grate into the chimney. It is a matter of course that a furnace of this kind, when used for operations which require high temperatures, should be lined inside with fire bricks; that is to say, that whilst it is sufficient to build the outside shell of the furnace, which adds to its stability and prevents radiation, with ordinary bricks set in mortar, it is necessary to use fire bricks set in clay, or other heat-resisting material, in those parts which are exposed to the direct action of the flame. It is evident that, according to the nature of the operation which is to take place, it will be necessary to alter the details of construc-

tion in the furnace. Thus, for instance, if we have to oxidise copper scale, which chiefly consists of cuprous oxide, to cupric oxide, the operation involved would be an oxidising operation. It would be an operation in which the presence of oxygen in the

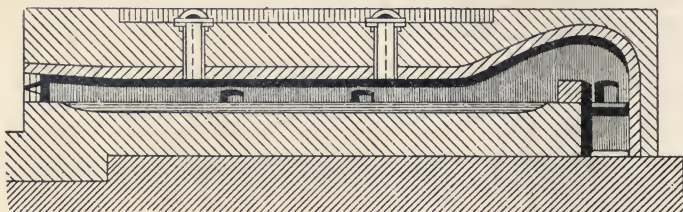


FIG. 22.—Open Roaster (sectional elevation).

flame would be absolutely necessary. The combustion of the fuel would therefore be arranged in such a manner that it will take place in the presence of an excess of air. Such a flame can be produced by having a number of fire bars set

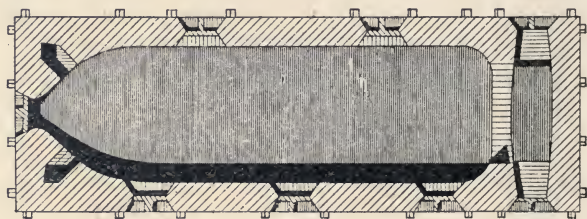


FIG. 23.—Open Roaster (plan).

widely apart, and by charging the fuel in thin layers. But it will be necessary to watch the operation carefully, as if too much air is admitted it would cool the fire gases to such an extent that more fuel would be consumed than would be economical; and where very high temperatures were required, it would prevent us from obtaining them. A furnace of this description is called an open roaster.

Whilst we are dealing with this subject, we may point out that in the case of open roasters it may become necessary to consider the ingredients which are contained in the fire gases; thus, coal which is rich in pyrites would not be suitable in operations in which the sulphurous acid produced would act on the substances operated on. Where such is the case, coke as free from sulphur as possible should be used, or better still a gaseous fuel. In the latter case the furnace will have to be constructed in such a manner that, instead of having a fireplace which is fed with solid fuel, it has a chamber arranged for the combustion of gas.

If, instead of an oxidising flame, a reducing flame is required, a similar furnace may be used, which only differs from the one described above in the arrangement of the fireplace and the management of the combustion of the fuel. An example of a reducing operation—with which, no doubt, the student is familiar, from his study of chemical technology—is that of producing black ash. In the manufacture of soda by the Le Blanc process, salt-cake (which is anhydrous sodium sulphate), coal, and limestone (which is calcium carbonate) are melted together and produce black ash, a compound of complicated composition, which, on lixiviating, yields a solution of crude sodium carbonate. This is distinctly a reducing operation; and in order to produce fire gases suitable for it, the fire bars are placed close together and the fuel is put on the bars in thick layers; in this manner no excess of air is drawn through the bars, and the fire gases, on passing over the mixture of ingredients which produce the black ash, not only heat them to the melting point, but also keep them in a reducing atmosphere and help to further reduce them.

All these furnaces are wasteful in the consumption of fuel, and wherever it is practicable the waste gases from them are used for other operations, as, *e.g.*, for boiling down or drying.

In many of the melting operations which are carried on in

open roasters it is necessary to mix the ingredients during the process, or to rake them up in such a manner as to expose different surfaces to the fire gases. In order to save the cost of hand labour, machines have been constructed which enable us to conduct such mixing operations by mechanical means. Such a furnace is, for instance, the one which goes by the name of 'the revolver,' and is used for the same purpose as the hand furnace described above. It consists of a large iron drum built up in sections, which is lined inside with highly refractory firebricks of a special kind to resist the action not only of the heat but of the alkaline black ash. The apparatus is arranged in such a manner that the drum revolves slowly whilst the furnace gases supplied from the fireplace attached to it are made to pass through the revolver, and on leaving it are used for evaporating and drying purposes. Such an apparatus can only be used where very large quantities have to be dealt with. A cylinder of 9 ft. in diameter and of 16 ft. in length would not be considered a large furnace. To give some idea as to the work which could be done by such a furnace, we give the following abstract from Lunge's standard book on sulphuric acid and alkali:—

"The Widnes Alkali Co., in 1884, had a furnace built by Messrs Cook & Robinson for decomposing 80 or 90 tons of salt-cake in 24 hours. The fireplace has an area of 17 ft. \times 10 ft., and consumes 25 cwts. of coal per hour. The same firm erected in 1887 a black-ash furnace, larger than any known at that date. The cylinder externally is 30 ft. long and 12 ft. 6 ins. diameter, internally 28 ft. 6 ins. long and 11 ft. 4 ins. diameter. The lining consists of 16,000 firebricks and 120 fireclay blocks, ('breakers'), weighing each $1\frac{1}{4}$ cwts. The bricks weigh about four tons per thousand. The fireplace has four doors, the cylinder three manholes. The weight of salt-cake per charge is 8 tons 12 cwts. For each 100 tons of salt-cake there are also charged about 110 tons of lime mud and 55 tons of mixing

coal. This is altogether about 25 tons per charge. In a week of seven days about forty-eight charges are worked through, equal to a decomposition of 400 tons of salt-cake, yielding 240 tons of 60 per cent. caustic soda. The fuel for firing may be put down as 200 tons per week, or 10 cwts. per ton of salt-cake, against 13 cwts. in ordinary revolving black-ash furnaces. The waste heat of the latter furnaces evaporates sufficient liquor from 20° to 50° Tw. to keep three self-fired caustic pots working, which are boiled at a strength of 80° Tw. Were it not for this evaporation, no less than seven self-fired pots would be required to do the work, showing a difference of 80 tons of fuel."

Even this enormous machine is not quite the largest that has been built. Our illustration shows a revolver which was constructed by Messrs R. Daghish & Co., Ltd., for Messrs Kurtz & Co., Ltd., of St Helens, and its dimensions are as follows: diameter 12 ft. 6 ins. and length 30 ft. 6 ins.

Besides the operations which may be carried on in open furnaces, and which are imitations of the work of the blowpipe, there are many operations which have to be carried on in closed vessels, just as crucibles and muffles have to be used in the laboratory. Although it is found very cumbersome to use crucibles on a large scale, they are still in use in many operations, such as for melting up the best brands of steel, copper, and brass. They are made of fireclay or plumbago, or of steel and other material. In most cases the manner in which these crucibles are heated is rather primitive. The furnace, which is provided with a grate at the bottom, represents a cylindrical or square shaft, in the middle of which the crucible is placed on a kind of pedestal or on a setting of bricks, and surrounded with coke, which, on being lit and kept burning through a powerful draught from a closely adjoining chimney, produces sufficient heat to melt substances which require a very high temperature. In this way it is possible to handle fairly large quantities of metals, on account of their

high specific gravity and the comparatively small bulk which a

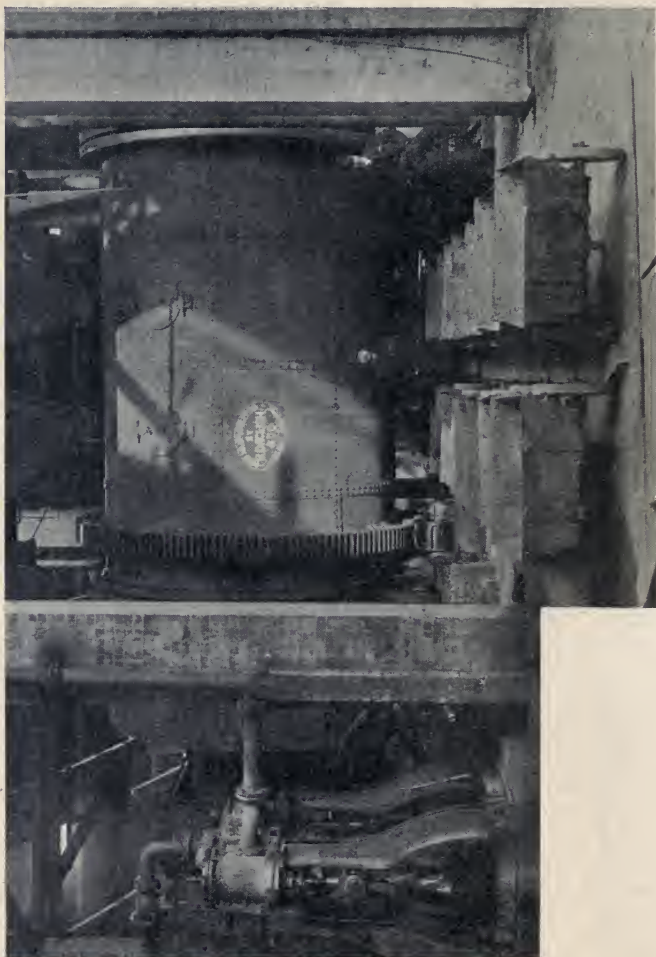


FIG. 24.—Revolving Black-Ash Furnace.

considerable weight of them takes up; but in purely chemical operations the use of crucibles is limited to work on a com-

paratively small scale. When, therefore, it is necessary to heat chemicals to a high temperature in such a manner that they are excluded from contact with the fire gases, a furnace is used which goes by the name of a closed roaster, and the prototype of which is the salt-cake furnace, as used in the manufacture of Leblanc soda.

Figs. 25 and 26 show such a furnace. The closed or blind roaster consists of an arched muffle built of firebricks set in fire-clay, and constructed in such a manner that the fire gases pass underneath the bed of the muffle on their way to the end furthest from the fireplace. They are then taken over the top of the arch back to a convenient point near the fireplace, and finally into the main flue or into the chimney. The bed is generally made of tiles of suitable size, up to 2 ft. square, which rest on walls carried along the length of the furnace, and thus provide channels through which the fire gases pass under the bed. Doors are provided in suitable positions in front of the furnace through which the mass can be charged, raked, and discharged. A pipe is supplied at the top of the muffle through which any gases evolved during the operation are carried into the condenser. These furnaces may be made up to 30 ft. in length; they cannot conveniently be made much more than 5 ft. in depth, as otherwise the process of raking up and mixing would become unmanageable.

Although it is possible to build a muffle with bricks and tiles in such manner as to make it almost perfectly air-tight, it must be borne in mind that when it becomes heated up the bricks and tiles expand and press on the mortar and clay between them, so that small openings are formed. In the course of time the muffle will therefore cease to be absolutely air- or gas-tight. This drawback becomes still more apparent if the furnaces are worked intermittently, or heated in such a manner that the temperature varies at different times, within considerable limits. It has been found by experience that if, for the

reasons stated above, the muffle ceases to be completely gas-tight, the gas evolved in the muffle, *e.g.* hydrochloric acid,

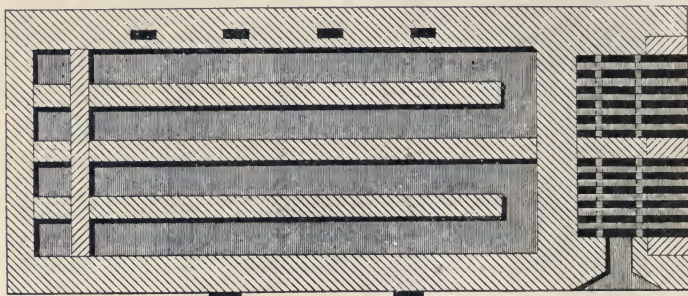


FIG. 25.—Blind Roaster (plan).

is drawn into the flues through which the fire gases pass, the reason for this being that the pressure of the hydrochloric

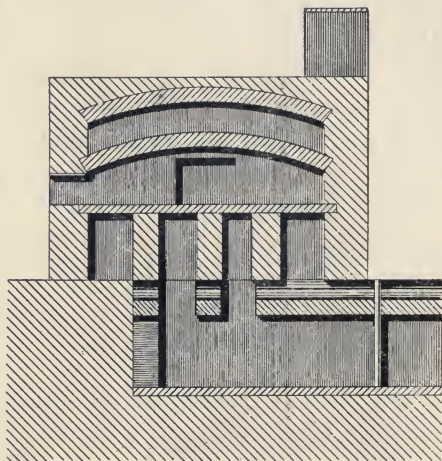


FIG. 26.—Blind Roaster (sectional elevation).

acid gas in the muffle is greater than the pressure of the fire gases in the flues. The fire gases thus become contaminated with hydrochloric acid and pollute the atmosphere. In order



to overcome this difficulty a number of devices have been proposed, all of which are based on the principle of making the pressure in the supply of the fire gases greater than the pressure exerted by the evolution of hydrochloric acid in the muffle. These furnaces are called plus-pressure furnaces, and the principle on which they are designed should be used wherever noxious gases are evolved in the muffle. They vary in the details of construction, but it will be sufficient to describe one in which the fireplace is built in such a manner that the air cannot have access to it except by pipes through which the necessary quantity of air is blown by means of a 'Roots' blower or other blowing engine. The fire gases travel, as usual, under and over the muffle, and, before going into the chimney, are taken through a stack in which are contained a number of pipes arranged in a similar manner to that shown in the 'Green' economiser (p. 59). The air which comes from the blowing engine first passes through these pipes, is heated up by the waste heat of the furnace, and then passes into the fireplace.

Considerable economy in the consumption of fuel is effected by heating the air supply, and the best results in that direction are obtained by the so-called system of regeneration. This consists in arranging flues in such a manner that the air which is used for combustion is heated by storing up the heat of the furnace gases as they pass toward the chimney. In order to produce this effect two chambers are built side by side and filled in a honeycomb fashion with bricks. We will call these chambers A and B, and will now follow an operation in which they are used. The fire gases, after heating the furnace, are passed through chamber A. After some time the enormous quantity of brickwork inside the chamber becomes heated to the temperature of the flue gases. When this point is reached the flue gases are diverted from the chamber A, and the flue gases are made to pass through the chamber B, which in its turn becomes heated up. At the same time a door or valve in

chamber A is opened so that the air passes through this heated chamber A, and from there underneath the furnace in which the coal is being burnt. By thus connecting the two chambers alternately with the atmosphere and with the flue it is possible to heat the air supply to a considerable temperature by the waste flue gases. This principle may be carried still further in cases where gas is used as fuel, and the regenerative chambers may be arranged in such a manner that both the air used for the combustion as well as the gas, *i.e.* the fuel, are heated up before combustion. In this manner great heat can be produced, and great economies in fuel can be effected.

CHAPTER V.

THE STEAM BOILER AND OTHER SOURCES OF POWER.

WE have had occasion, when discussing the question of drying apparatus and elsewhere, to refer to mechanical arrangements which are used in work on a large scale, and which have no parallel in the work as carried on in the laboratory. These mechanical arrangements, which are all designed with the view of saving the cost of labour, may be moved and controlled by different agencies. Thus, where steam is the controlling power, the steam will be produced in a boiler and made to drive a steam engine; where gas is the controlling power, the gas has to be produced in one of the many different ways which are known, and may then be utilised in a gas engine for producing the power required. Where electricity is the moving power, it is generated in a dynamo, and this again acts on a motor. But the three agencies of which we have spoken, that is, steam, gas, and electricity, obtain their power by means of the combustion of coal. It is therefore clear that unless sound principles are applied to the production of power, the application of that power will not be economical. If, for instance, it would take 2 pounds of coal under a boiler to produce a certain mechanical effect, and only 1 pound to produce the same effect by some other means, the cost of work done would be as two to one.

We will briefly give a description of power-producing apparatus, with such remarks as will enable the student to

understand the principles of their construction, economical working, and application.

The steam boiler is used for the evaporation of water under pressure. It consists, in its simplest form, of a cylindrical vessel made of wrought-iron or steel, two-thirds filled with water, and heated by means of coal or other combustible matter. But it is clear that in its simplest form it cannot properly utilise the heat supplied to it, as we have shown before that in order to

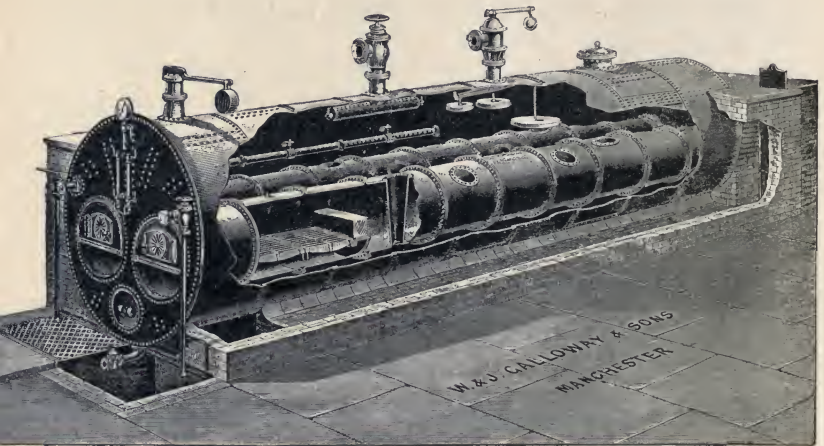


FIG. 27.—The Galloway Steam Boiler and Furnace.

utilise heat to the best advantage it must be taken over the largest possible surface. For that reason tubes are inserted in the boiler in the manner shown in the Galloway boiler, Fig. 27. By doing this one gains as much additional heating surface as is represented by the tubes. The fire bars are placed between these tubes, and the fire gases travel along the tubes and are taken through brick flues which run along each side of and under the bottom of the boiler, and pass out at the back into the chimney. The water evaporated is replaced by fresh water by means of a pump or an injector, and gauge glasses,

which are in front of the boiler, always indicate the level at which the water stands. Pressure gauges indicate the pressure of the steam; and a safety-valve, consisting of a lever arrangement, with a corresponding weight for the pressure up to which one wishes to work, is arranged in such a manner that the valve automatically opens when the pressure exceeds that point and the steam freely escapes. The gases of combustion which pass from the boiler into the chimney still contain heat which could be utilised. For that reason, in every properly designed installation there is an arrangement for heating the feed water by means of the heat which would otherwise pass from the boiler into the chimney, and such an arrangement is known by the name of an economiser.

This consists of a number of tubes, generally 96 for one boiler, encased in brickwork in

such a manner that the gases leaving the boiler have to pass round the pipes. As a considerable amount of soot and flue dust, consisting of ashes which are mechanically carried forward, would settle on these tubes, and thus in time form crusts which would reduce the efficiency of the apparatus, scrapers are made to travel in a vertical

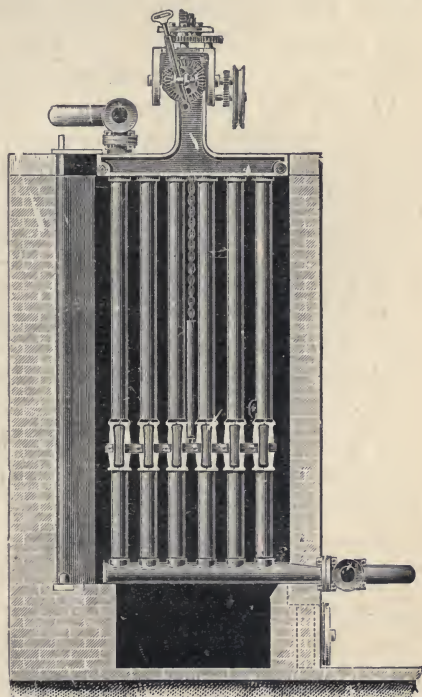


FIG. 28.—The Economiser.

direction on the tubes so as to keep them clean. This is done by means of a little steam engine which works quite automatically, and reverses its motion when the scrapers have reached either the top or the bottom of the pipes. The cold water enters the pipes and circulates through them, and then passes into the boiler at a temperature of 100° C. or more. The economy effected in this way is very considerable, and may amount to 20 per cent. on the fuel or more.

Whilst, years ago, it was considered unusual to work a boiler at a higher pressure than 50 or 60 pounds to the square inch, the tendency now is to work at as high a pressure as possible, as it is far more economical to produce steam of high pressure than steam of low pressure. Boilers are now constructed to work at a pressure of 200 pounds or more per square inch, and with steam at such pressures steam engines have been perfected in such a manner as to reach a degree of economy never before attained. It has been found that the flue gases from boilers, even after heating the feed water, still contained available heat, that is to say, more heat than would be necessary to produce sufficient draught in the chimney. This heat is now used in many cases for converting the saturated steam which comes from the boiler into superheated steam. Apart from the extra economy which is thus rendered available in the motive power of the steam, the great advantage of using superheated steam lies in the fact that it can be conducted through considerable lengths of piping without condensation. This fact should make superheated steam particularly valuable in chemical works, where heating and boiling apparatus is often a great distance from the boiler.

There are many other forms of boiler than that of which we have given an illustration above. They are all based on the principle of exposing as much heating surface as possible to the flue gases by increasing the number of tubes and reducing their diameter.

We need not enter into the description of a steam engine in detail, as it is too well known, and as the principles on which it works, and which determine the details of construction, form part of the course of study in physics. We need only mention that there are, generally speaking, two kinds of steam engines—that in which the steam, after going through the cylinder, passes into the air, and that in which the waste steam is condensed: they are accordingly classed as non-condensing,

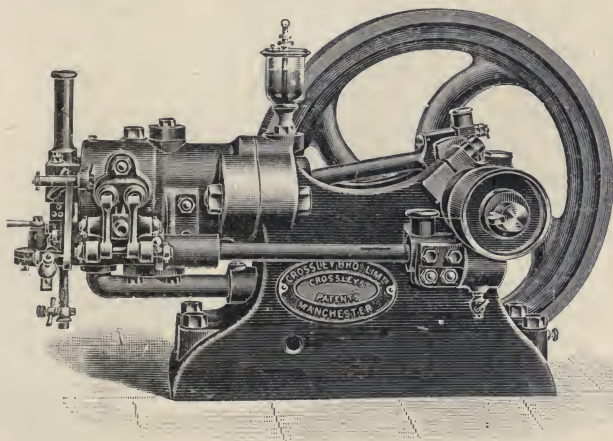


FIG. 29.—Gas Engine (Crossley).

or condensing engines. The same remarks which we have made on the boiler apply to the engine. In this case the aim should be to produce the greatest power from a given quantity of steam. Considerable economy can be effected by using a condensing engine, but where the waste steam can be used for other purposes, as for instance boiling or drying, a non-condensing engine may be found, at a lower cost, quite as economical, and even more so.

Of late years the great improvement which has taken place in the economical production of gaseous fuel obtained from coal has produced an equal advance in the construction of gas

engines, which now can be obtained up to 1000 horse-power and more. The principle upon which gas engines work is

fundamentally different from that upon which the steam engine works. In the steam engine the piston is moved by the pressure of the steam; in the gas engine the gas itself exerts no pressure upon the piston, but the necessary pressure is produced by the explosion which is made to take place through mixing gas with the necessary volume of air and igniting it.

Figs. 29 and 30 show standard designs of a gas engine.

The gas used for these engines may be either ordinary coal gas, a mixture of coal

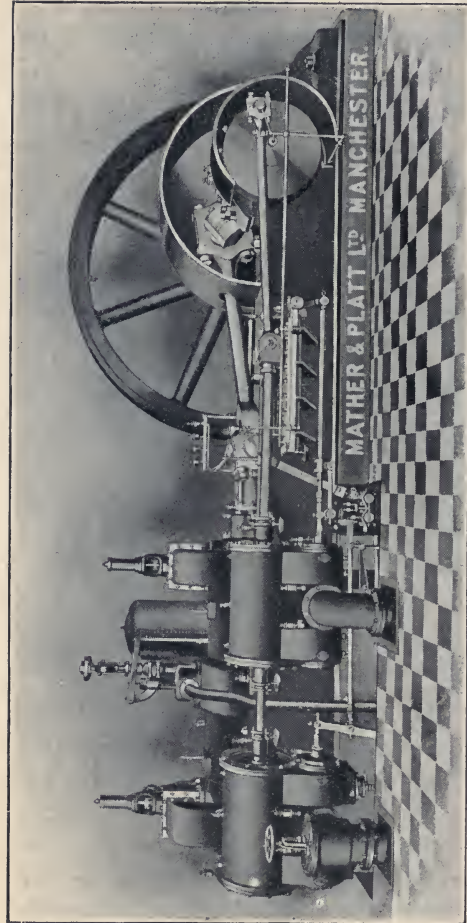


FIG. 30. — Two-cycle Gas Engine (Mather & Platt).

gas and water gas, or altogether water gas—that is, a mixture of hydrogen, carbonic oxide, and nitrogen. As it is

possible to produce gas in suitable localities from poor coal which otherwise could hardly be utilised, and as it is further possible to separate valuable ammonia and tar products which in the ordinary combustion of coal are lost, the use of gas in engines enables us to produce power in a most economical way.

Although not of much importance to chemical works in this

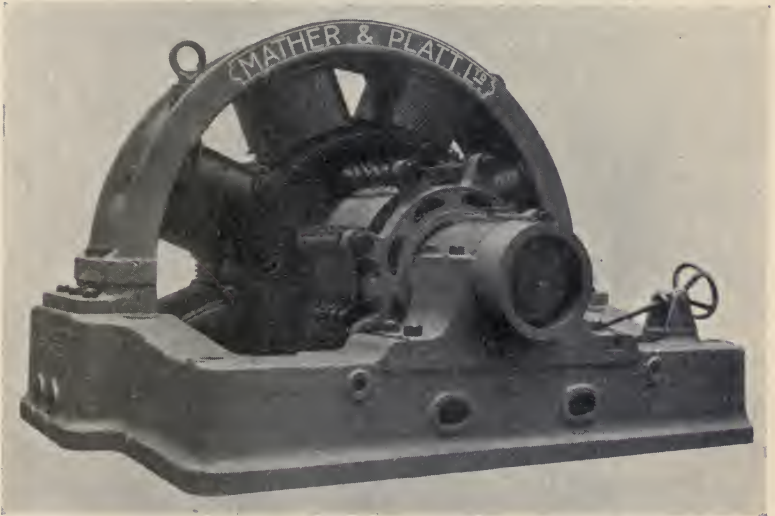


FIG. 31.—Eight-pole Multipolar Dynamo.

country, we may mention that engines are built on the explosion principle, in which petroleum or benzine is used as the ordinary source of fuel. Most of these engines contain an additional arrangement by which the petroleum or benzine is first heated so as to convert it into vapour; the vapour is conducted to the piston, air mixed with it, and explosion brought about by ignition, as in the gas engine.

In the steam engine and in the gas engine we convert the

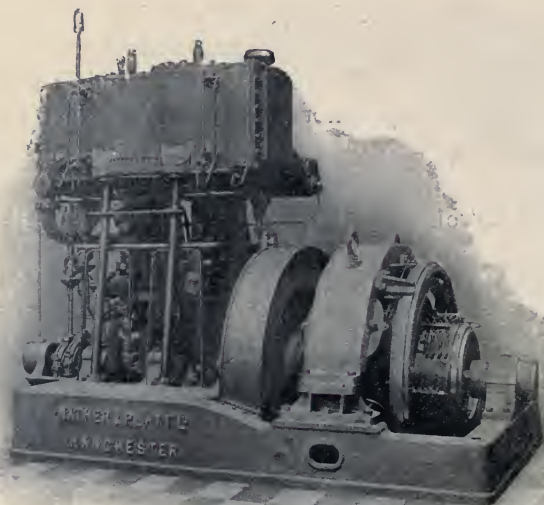


FIG. 32.—Direct-coupled Steam Engine and Generator.

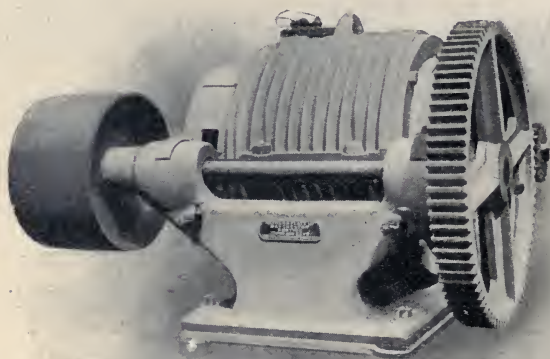


FIG. 33.—Standard type of Motor.

energy of coal into the energy of steam, or into the energy produced by the combustion of a mixture of gas and air, and this directly produces the power of the engine. But it is sometimes found more economical not to take the power direct from the engine as produced there, but first to convert it into electricity by means of a dynamo, and to work a motor from



FIG. 34.—Steel-clad Motor.

the dynamo. It would lead too far to enter into the principles and details of construction of a dynamo and a motor, and we therefore only give illustrations of standard types representing them.

The same may be said about other kinds of motors which are used in special cases. If, for instance, instead of using steam, one were to use compressed air or water under pressure in a

machine constructed similarly to a steam engine, it would be possible to transform the energy of the compressed air or water into power produced by the engine. Such engines are used in special cases, particularly in small installations in towns where water is supplied under hydraulic pressure, or in works where compressed air is used for other purposes, such as for stirring or for lifting liquids.

CHAPTER VI.

GENERAL REMARKS ON THE APPLICATION OF HEAT IN CHEMICAL ENGINEERING.

In the metric system the quantity of heat necessary to be imparted to one gramme of water to raise its temperature through one degree Centigrade is termed a heat unit, or calorie. In technical calculations another heat unit, termed a great calorie (Cal.), is generally used; it is the quantity of heat necessary to be imparted to one kilogramme of water to raise its temperature through 1° C. The British unit of heat, or B.T.U. (British Thermal Unit), is the amount of heat necessary to raise 1 pound of water through 1° Fahrenheit; since 1° F. is equal to $\frac{5}{9}$ of a degree C., and 2.2 lbs. = 1 kilogramme, we have to divide $\frac{5}{9}$ by 2.2 to obtain the ratio between the two units, which makes one B.T.U. = .252 Calorie.

It has been found that, in order to convert 1 kilogramme of water of the temperature of 100° C. into steam at the same temperature and at the ordinary pressure of the atmosphere, 537 Calories are required. As it takes 100 Calories to raise 1 kilogramme of water from 0 to 100° , the total quantity of heat required in order to convert 1 kilogramme of water at 0° C. to steam at 100° C. will be 637 Calories. If this process is carried on in a closed vessel, such as a steam boiler, from which the steam cannot issue freely, and is therefore subjected to a pressure of more than 15 lbs. to the sq. in., which represents the pressure of the atmosphere (or 1.033 kilogramme to the

sq. cm., which is the equivalent of the atmospheric pressure in the metric system), the temperature of the steam produced is higher than 100° C., and the number of Calories required to produce the steam at the increased pressure is naturally greater than 637 Calories. The following table will show the actual results which have been found :—

| Pressure in atmospheres. | Temperature in °C. | Calories per kg. | | | Weight of 1 c. metre Steam in kilogrammes. |
|--------------------------|--------------------|------------------|----------------|-------------|--|
| | | Heat of Water. | Heat of Steam. | Total Heat. | |
| 1·0 | 100 | 100·5 | 536·5 | 637·0 | ·60 |
| 2·0 | 120 | 121·4 | 521·8 | 643·2 | 1·16 |
| 3·0 | 133 | 134·9 | 512·2 | 647·1 | 1·79 |
| 4·0 | 144 | 145·4 | 505·0 | 650·4 | 2·23 |
| 5·0 | 152 | 153·7 | 499·0 | 652·7 | 2·75 |
| 6·0 | 159 | 160·9 | 494·0 | 654·9 | 3·26 |
| 7·0 | 165 | 167·2 | 489·6 | 656·8 | 3·77 |
| 8·0 | 170 | 173·8 | 485·6 | 658·4 | 4·27 |
| 9·0 | 175 | 178·0 | 482·0 | 660·0 | 4·77 |
| 10·0 | 180 | 182·7 | 478·7 | 661·4 | 5·27 |

The steam produced in this manner shows a temperature corresponding with the pressure. Thus, *e.g.*, steam at one atmosphere pressure shows a temperature of 120° C.; at two atmospheres 133° C., and so on. (The pressure is always reckoned 'above' that of the atmosphere, hence one atmosphere pressure as shown on the gauge of a boiler really represents not 15 lbs. but 30 lbs. per sq. inch; but it is always referred to as 'one atmosphere.') If, now, we were to disconnect the steam from the boiler and to heat a certain volume of it to a higher temperature than that which belongs to it in its normal state, we should require more fuel to do so, and we must expect to get that amount of fuel back in its equivalent of work. As a matter of fact, we should find that the steam on being heated in the enclosed space would exert a greater pressure. If, on the

other hand, whilst heating the steam to a higher temperature, we were to allow it to expand in such manner as to remain at the same pressure as in its normal state, we should find that the temperature of the steam would become higher than it was before. Taking, for instance, steam at two atmospheres pressure, we find from the table that its temperature would be 133° C. If, whilst disconnecting it from the water contained in the boiler, and without altering its pressure, we were to heat this steam up to 145° , it would be no longer saturated with water, but become non-saturated, *i.e.* superheated steam. It would be steam that would still have a pressure of two atmospheres; and if it were allowed to pass through a pipe or other conducting channel it could not become saturated steam until its temperature had cooled down to 133° . It therefore follows that superheated steam can be conducted a distance without condensation taking place, and this is one of its most valuable properties.

Another property of superheated steam which in chemical operations should prove valuable, but which up to the present has not been utilised to the extent which it deserves, is that of yielding in proportion to its effectiveness less water on condensation than saturated steam. If, as is often the case in chemical operations, we use live steam for heating up a liquid either to its boiling point or to a point below it, the bulk of the liquid at the end of the operation will increase by the amount of steam which becomes condensed: naturally this amount will be less when we use superheated than when saturated steam is employed.

If we heat a liquid by means of 'live' saturated steam the quantity of heat which the steam will transmit to the liquid will depend upon the initial temperature of the liquid and the pressure of the steam. Thus, for instance, if steam were used of three atmospheres pressure, we find that its total heat amounts to 650.4 Calories. If the liquid which we want to heat is water,

and its initial temperature is 15° C., the heat available from the steam would be $650 - (100 - 15)$, that is, 565 Calories; in other words, 1 pound of steam at three atmospheres pressure would be able to heat up 5.65 pounds of water to the boiling point. In practical work this will not be absolutely correct, as more steam than that calculated will be required. If, instead of passing the steam into the liquid direct, it is used as 'confined' steam, that is, if the liquid is heated up by means of a coil or jacket through which the steam circulates without coming into contact with the liquid, the efficiency will depend upon several other factors besides the pressure of the steam. We have then to take into consideration the property of the material through which the steam is conveyed in relation to its capacity for giving off that heat by transmission. Different materials show considerable differences in their capacity for transmitting heat. It has been found that copper possesses the highest capacity of any material applied in practical work; and putting this down at 100, we find that that of wrought-iron is about 90, that of cast-iron about 60, and that of lead about 50. Experience has shown that it is possible to evaporate 100 litres of water per hour from 1 square metre of heating surface consisting of copper. To obtain the same effect by means of steam coils or jacketed pans made of other materials, it is necessary to increase the heating surface in the inverse ratios given above.

In connection with this subject it is important to know what amount of radiation may take place from the vessels which are used. According to Péclet, the amount of heat (S) expressed in Calories given off by radiation for every square metre per hour is

$$S = 124.72 K \times 1.0077t[1.0077T - 1] \text{ Calories}$$

in which T is the temperature of the apparatus and t the temperature of the surrounding atmosphere. The coefficient K of radiation for different substances may be taken as follows, in this formula:—

| | | | |
|----------|------|-----------|------|
| K = Iron | 3·17 | K = Paper | 3·77 |
| Brick | 3·60 | Sand | 3·62 |
| Wood | 3·60 | Silver | ·13 |
| Copper | ·16 | Wool | 3·68 |
| Brass | ·26 | Zinc | ·24 |
| Glass | 2·91 | Tin | ·22 |

In the production of steam in a steam boiler, in the evaporation of liquids, in the carrying out of melting processes, everything depends upon the economical utilisation of fuel; and although, in practical work, the results obtained are often very different from those which would be expected from theoretical considerations, yet it is necessary to understand the theory of the subject. As the chief material used as fuel in this country is coal, we will confine our remarks to a short consideration of the utilisation of that material.

The value of coal expressed in calories evolved in its combustion can be ascertained either by calculation or by actual determination in a calorimeter. The chief constituents of coal which in combustion evolve heat are carbon and hydrogen. Those which absorb it during combustion are moisture and the inorganic matter which remains in the form of ash. Dulong's formula for calculating the number of calories (V) evolved by the combustion of 1 kg. of coal is—

$$V = 8000 C + 29000 \left[H - \frac{O}{8} \right] + 25000 S - 600H_2O.$$

If, *e.g.*, we had a coal which in 1 kg. contained

| | | | | | |
|-----------------------------|---|---|---|---|-------------|
| C | · | · | · | · | ·756 |
| H | · | · | · | · | ·051 |
| O | · | · | · | · | ·069 |
| S | · | · | · | · | ·026 |
| N | · | · | · | · | ·016 |
| Ash | · | · | · | · | ·046 |
| Moisture (H ₂ O) | · | · | · | · | ·036 |
| | | | | | <hr/> 1·000 |

we should obtain—

$$V = 8000 \times .756 + 29000 \left[.051 - \frac{.069}{8} \right] + 25000 \times .026 - 600 \times .036 = 7905 \text{ Calories,}$$

so that 1 kg. of this coal would yield on combustion 7905

Calories, or 1 lb. of it would yield $\frac{7905}{2.52 \times 2.2} = \frac{7905}{5.544} = 14260$

B.T.U. On an average the value of coal is 7500 Calories, and that of coke about 7000 Calories. From these data it would be expected that 1 lb. of good coal should be capable of producing 12 lbs. of steam. In practical work, except in special cases, it is impossible to obtain more than 7 or 8 lbs. of steam per lb. of coal. The reason for this discrepancy is due to several circumstances. Apart from loss of heat through radiation, it is not possible to regulate the admission of air in such a manner as to use the theoretical amount which would be necessary for the complete combustion, and any excess of air which is admitted into the furnace has to be heated by the fire gases, and therefore absorbs heat without doing work. A second consideration is this, that in order to keep the fire burning it is necessary to produce sufficient draught to take atmospheric air through the system. Where this is done by means of a chimney it will be necessary that the flue gases, after having passed through the system, should still be at about 300° C. in order to produce sufficient draught. Where other means of producing a draught are available (commonly expressed by the term 'forced draught,' which consists of either blowing air through the coal or removing the exit gases by means of an exhauster), it is possible to carry on combustion in such a manner that the flue gases on leaving are below the temperature which would be required if the draught were produced by a chimney; but in that case it must not be forgotten that in order to obtain forced draught power or steam is required, and as this has to be produced by its equivalent in

coal, the saving which is effected by utilising the fuel gases to greater advantage is partially lost.

The question of utilising coal to the best advantage in practical work has been most carefully elaborated in the case of steam-boiler installations. The points which have been particularly studied are the ratio between the total area and the space between the bars for the admission of air, the total area of heating surface, etc. The results obtained are most important, not only because they are a guidance in the construction of other evaporating plant, but also because they enable one to apply these results in some measure, however crude, to installations in which fuel is used for other purposes than evaporation, for which, except in special isolated cases, there are at present no data known for the guidance of the chemical engineer. We therefore give a few of the results which are accepted in the setting of steam boilers.

A single-flued or 'Cornish' boiler, fitted with Galloway cross tubes, 30 feet long by 7 feet diameter, will evaporate 350 gallons of water per hour for a total heating surface of 730 square feet. A two-flued or 'Lancashire' boiler, with Galloway tubes, will evaporate 550 gallons of water per hour for a heating surface of 922 square feet.

A similar 'Galloway' boiler will evaporate 650 gallons of water per hour for a heating surface of 970 square feet.

In determining the size of a fire grate it is generally assumed that 1 lb. of coal will evaporate from 5 to 7 lbs. of water, and 1 lb. of coke from $4\frac{1}{2}$ to 6 lbs.; on these assumptions the total grate area should be for every 100 lbs. of fuel burnt per hour, in the case of coal, from 7 to 8 square feet, and in the case of coke, from 8 to 9 square feet. The open spaces between the bars should be about $\frac{1}{4}$ to $\frac{1}{3}$ of the total grate area. The total length of the fire grate should not exceed 7 feet. The sectional area of the flues should be equal to the area represented by the open spaces between the bars.

The theoretical temperature produced by the combustion of coal or coke can be calculated from well-known thermo-chemical data; but it does not agree with the results found in practice.

The chimney required for combustion should have a section from one-fourth to one-sixth of the sum of the grate areas; its height should be from 25 to 50 times its diameter.

CHAPTER VII.

THE FUNNEL AND ITS TECHNICAL EQUIVALENTS.

MANY operations in the laboratory—in fact, nearly all operations connected with quantitative gravimetric analysis—depend upon the production of insoluble or sparingly soluble precipitates, which by various means are separated from the liquid in which they are suspended. If the precipitate is suspended in a large amount of liquid, and if it settles well, part of the liquid may be poured from it. The same would apply on a large scale, only that in the case where in the laboratory it would be possible to pour the liquid off, on a large scale taps could be arranged in cisterns at convenient distances, which, on being opened, would let off the clear liquid and leave the precipitate undisturbed at the bottom. When the precipitate is easily disturbed, it is usual in laboratory work to use a syphon made of glass tubing for drawing off the clear liquid. On a large scale glass syphons are only used in special cases. The syphons used are generally made of lead or copper tubing, according to the nature of the liquid, and may be constructed to work automatically by making the short end of the syphon dipping into the liquid of a flexible material and connecting it to a float, which is automatically lowered as the level of the liquid descends. In most cases in the laboratory it will be found more convenient to effect the separation of the precipitate from the liquid by filtering the mass through filter paper placed in a funnel. Where comparatively small quantities have to be dealt with on a large

scale, the filter paper may be replaced by bags made of cotton, woollen, or linen cloth, the coarseness or fineness of which will depend upon the nature of the precipitate. The choice of suitable filter cloth is of great importance, and comparative tests should be made in the laboratory before deciding which kind of cloth should be used in the works.

In order to accelerate filtration, the laboratory chemist often filters under diminished pressure by fixing the funnel into a flask which is connected with a Bunsen pump, thus drawing the filtrate into the flask. This may be done on a large scale in an apparatus which is shown in Fig. 35.

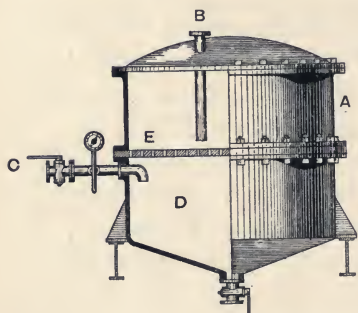


FIG. 35.—Apparatus for Filtering under diminished pressure.

The liquid enters the apparatus A at B, C being connected with a vacuum pump; the space D will become exhausted, and the liquid will be drawn through the filter cloth which is placed on the false bottom E, leaving the residue on it.

It will occur to the student that this apparatus might be used in a different way. Suppose, instead of drawing the air through by creating a partial vacuum, we were to pump air into the top of the apparatus, we could then force the liquid at increased pressure through the filter cloth instead of drawing it through by means of a vacuum. This is an operation which is not performed in the laboratory, because it would not only be difficult to construct suitable apparatus, but because it would not offer any particular advantage over filtering into a vacuum. On a large scale, however, it is different. Working in a vacuum means working in a closed system, and thus adding to the expense of the installation. Moreover, each time the apparatus

had to be emptied the vacuum would be broken, and a loss in labour and fuel incurred. It is therefore cheaper to work under pressure than to work in a vacuum, and for this reason filtering under pressure has become one of the most important accessories to chemical work. The apparatus which is used for this purpose is called a filter press, and consists, broadly speaking, of a set of chambers, separated by filter cloth. The mixture of liquid and precipitate is passed, by means of a pump, compressed air, or by natural gravitation, into the press.

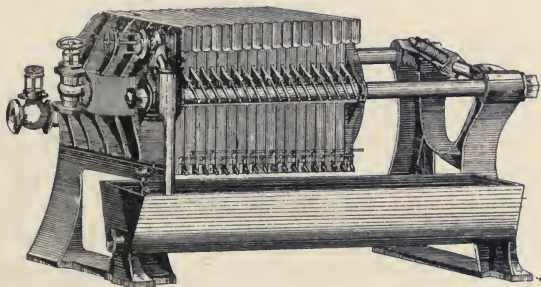


FIG. 36.—Chamber Filter Press.

There are two kinds of filter presses—chamber presses and frame presses. In the chamber presses the mixture of liquid and solid matter is introduced through a channel which runs through the centre of the press. The filter cloth hangs from the top of the chamber so as to cover each side of it, and has an opening cut in its centre so that it can be screwed tight into the channel of the chamber. On screwing the press together, it is evident that the two filter cloths will touch each other, and the chances of obtaining a water-tight system are therefore increased. The sides of the chambers project in such manner that the cake of separated solid matter collects in the space formed by the projections, and on opening the press the pressed mass falls out automatically. In frame presses the cake is formed in frames which are separated by filter cloth,

in which there are openings at the side, through which the liquid mixture is introduced. On opening the press, the cake remains in the frames, which can be lifted out and emptied. Fig. 36 represents a chamber filter press.

Whatever the construction of the press may be, it is provided with solid end pieces, one of which is stationary and the other movable by means of a screw or lever or other mechanical arrangement. The most usual materials of which presses are made are iron and wood, but for special purposes they may be lined in those parts which are exposed to the liquid with lead, ebonite, or any other resisting material. As stated before, they may be fed either by natural gravitation or by means of pumps or compressed air, and arrangements are generally provided for washing the cakes free from the original liquor. As the presses may be worked at almost any pressure, it is evident that care must be taken in ascertaining at what pressure the substance which one may require to filter works best. Thus, with very slimy substances great pressure would only have the effect of depositing a thin film on the filter cloth; it would become stopped up, and further filtration would cease.

The manufacture of filter presses has become a speciality with several well-known firms of engineers, who construct them in many varieties, to suit special purposes. They may be obtained capable of dealing with substances which either have, during filtration, to be kept at a raised temperature so as not to crystallise out, or which may have to be kept at a low temperature so as not to melt. These purposes are generally effected by channels being provided in the chambers through which steam, hot or cold water may be passed.

Besides being used for filtering purposes, a funnel is often used in the laboratory for draining crystals or similar substances free from part of their moisture or mother-liquor. Sometimes the student in the laboratory will effect this purpose more quickly by putting the crystals into a little bag attached

to a string and swinging the bag round for some time. In doing this he practically does what a centrifugal machine does on a large scale. It is well known that when a body is compelled to move in a curved line, say a circle, it has a tendency to relinquish the curved line and proceed at a tangent, that is, to get away from the centre of curvature. The natural consequence is that it presses against the sides of the body in which it is made to move, and is thereby prevented from going into space. This tendency, known as centrifugal force, is proportionate to the square of the velocity.

A centrifugal machine, or a hydro-extractor, as it is often termed, based on this principle, and represented in Fig. 37, consists of a cage A, which is made to revolve at great velocity inside a solid frame B, supplied with an aperture C through which any liquid may drain. The cage is made of sheet copper or iron, perforated with holes or with slits. A centrifugal machine may be over-driven or under-driven, that is, the arrange-

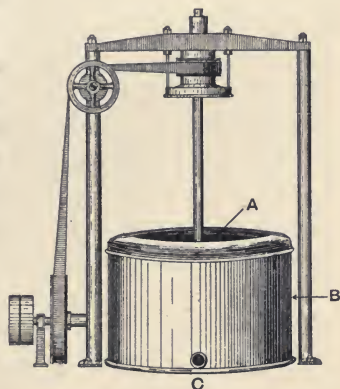


FIG. 37.—Centrifugal Hydro-Extractor.

ment by which it is coupled up to the engine may be placed either below or above the cage. If crystals containing moisture are placed in the cage and the machine is set in motion, the crystals are thrown against the sides of the cage and the water forced through the openings, so as to leave the crystals comparatively dry. When the mass which is to be dried is of a very fine texture, so that it would go through the openings in the cage, it is necessary to place a filter bag in the cage on which the crystals or other materials are deposited. In that case it is particularly necessary to bear in mind that with double

velocity the pressure against the sides becomes four times, with triple, nine times, and so on, what it had been before, so that it is quite possible that with a centrifugal machine revolving at a great speed one might get worse results than with a machine revolving at a lower speed, as then the centrifugal force becomes too great, and the filter cloth or the interstices of the cage may become stopped up. The fact that the centrifugal power increases proportionately to the square of velocity adds to the danger of the machine. Care must be taken that the mass in the cage is evenly distributed. Hydro-extractors are made which are provided with an arrangement by which any unevenness of distribution is automatically counterbalanced.

It follows, of course, that the centrifugal machine can also be used for filtering or drying precipitates, but in most cases it will be found that a filter press is more suitable for that purpose, as in this case it is easier to wash the precipitate with a minimum quantity of water or liquid than in a centrifugal machine. In the case of precipitates it is always necessary to use a filter cloth in the centrifugal machine, and it is then particularly necessary to see that the velocity at which it works is suited to the material, and is not so great that it stops up the pores of the filter.

It is often found necessary in the laboratory to filter substances through sand, asbestos, glass, or similar material, which in that case is placed at the bottom of the funnel. On a large scale similar arrangements are frequently used, particularly for clearing water or trade effluents, and in sewage works. In such installations, generally, large cisterns are built in the ground with brick, concrete, or similar material. These may contain false bottoms, or may be simply provided at the bottom with channels for letting off the clear filtered liquor. They often also have arrangements for distributing the original liquor evenly over the top of the tank. These cisterns are partially or wholly filled with sand, coke, coal, broken bricks, or similar material.

The processes of filtering are of great importance, and require considerable practical experience. They belong unfortunately to those parts of chemical engineering in which theory can be of but little use to the student, except in those points which we have indicated. They present, however, an interesting example of processes which, though impracticable in the laboratory, can be carried out successfully on a large scale.

CHAPTER VIII.

THE MORTAR AND ITS TECHNICAL EQUIVALENTS.

IN order to produce chemical reactions it is necessary that the substances should be brought into as intimate contact as possible. Liquid substances may be made to react without preliminary mechanical treatment, but where we have to deal with solids it is well known that the finer they are powdered and the more intimately they are mixed the easier it will be to obtain the reaction desired. In the laboratory we may use a hammer in order to break up large pieces of mineral matter, then we may put the smaller pieces thus obtained into an iron or porcelain mortar and powder them finer, or we may pass them into an agate mortar and grind them there to the finest powder which we can obtain. It will be noticed that in working on a small scale we are restricted to the force which our arms or wrists can exert, aided to some extent by any leverage which we might obtain, as in the case of using a longer or shorter handle with the hammer. But in working on a large scale, obtaining our power from an engine, the force which we can exert is almost unlimited, so that in manufacturing work we can produce effects in crushing and grinding by means which we cannot apply in the laboratory. It naturally follows that in the construction of the apparatus we need not adhere to the means which are at our disposal in the laboratory, but may adopt constructions in which we can make use of the greater force which is at our command.

Thus, in breaking up large stones into smaller fragments we may make use of the forces which are obtained by a cutting or crushing motion. Fig. 38 represents a stonebreaker in which the jaw A is made to move backwards and forwards in a horizontal direction against a fixed plate or wedge, so that any large pieces of ore which are placed between are crushed into smaller pieces. The width between the two crushing parts

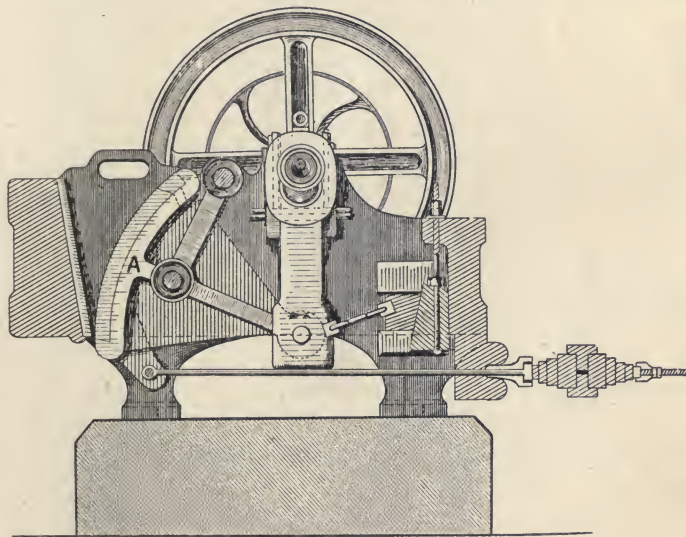


FIG. 38.—Stonebreaker.

may be regulated so as to produce larger or smaller fragments. The same effect may be produced by passing the large pieces of ore through grooved crushing rollers. Stone-breaking machines are made in different sizes, according to the hardness of material and the quantity which they have to deal with, and the power required varies accordingly,—a few cwts. to ten tons per hour, and from half a horse-power to twelve horse-power and more.

The pieces which we have obtained in the crusher may vary in size, and it is practicable to obtain them as small as nuts. The next step would be to reduce these nuts to powder, and this may be done in many different ways. Where a hard ore has to be further reduced in size, an apparatus may be used which resembles a mortar in its appearance and action. If we wish to imitate the pounding action of a mortar on a large scale we could construct a mortar itself in cast-steel; we could further have a heavy pestle of the same material, to which we could fix a rod with a short piece at the top projecting at a right angle. If we now had a shaft carrying a curved piece of steel revolving near the pestle in such a manner that the curved piece caught the projection of the pestle at each revolution, it would lift the pestle up, and the latter falling by its own gravity would crush the ore. An arrangement of a number of pestles working side by side is largely used in the preparation of ores, and is represented in Fig. 39.

In like manner, as explained in the stonebreakers, the ore may also be further reduced in fineness by passing it through steel or iron rollers, which may be either grooved or smooth; or soft materials, such as coke and similar substances, may be crushed by being made to pass between two cogwheels fixed on two shafts which revolve in the same or in opposite directions. Where plain or grooved rollers are used, there may be a number of them arranged vertically in such a manner that the material is first reduced to a certain fineness, then passed through into a second set of rollers below the first set, where it is still further reduced, and so on, so that one may commence with coarse material at the top, and draw from the bottom in one and the same machine a product of almost any fineness which may be required.

Where it is necessary to obtain hard ores in the finest state of division, that object is often attained by levigation. The substance is finely ground in the dry state, mixed with a large

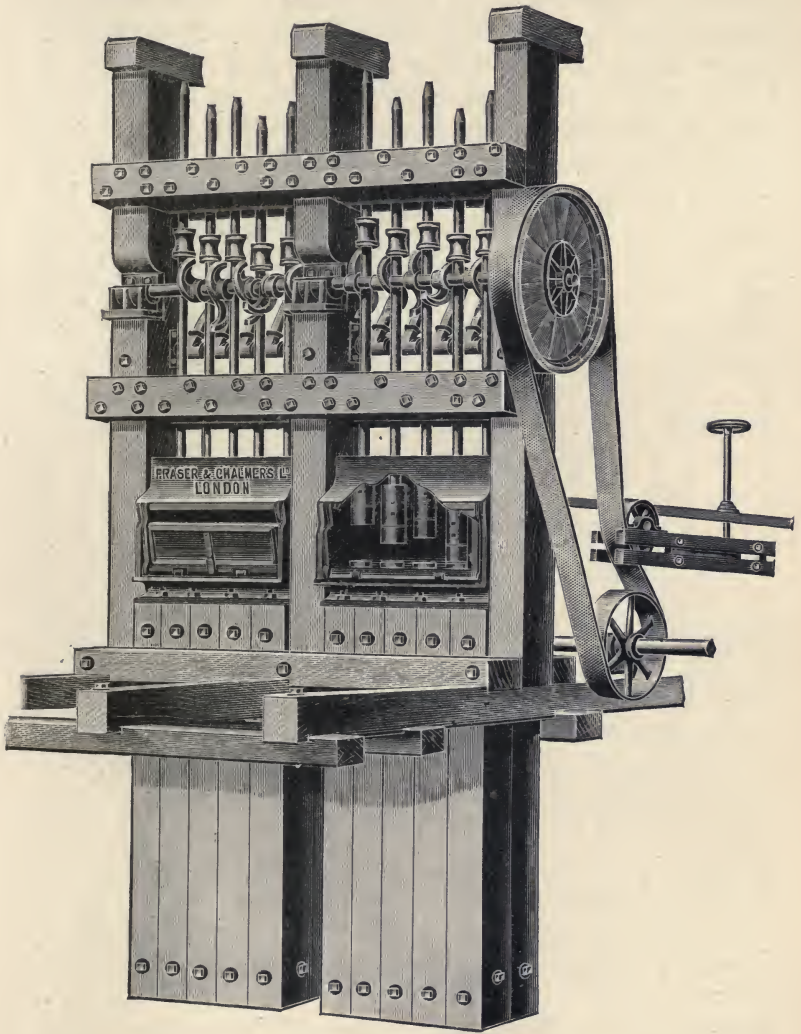


FIG. 39.—Ore-crushing Machine (Stamp Mill).

quantity of water, and run into a series of tanks in such a manner that it first enters one tank and is left there for a certain period, then taken into a second tank, and so on. It follows that the coarsest material will settle out in the first tank, somewhat finer in the second tank, and that in the last tank the very finest material will be obtained. Instead of first grinding the material in the dry state and then mixing it with water, it may from the start be mixed with water in the grinding mill. The apparatus used for this purpose resembles in its appearance and principle a mortar mill, such as can be seen wherever building operations on a large scale take place. As is well known, the mortar mill consists of a plate on which heavy rollers, generally two, revolve. If, instead of a shallow plate, a deep trough is arranged, the bottom of which may be made of chilled steel, and the sides of which may be built of bricks, and if the rollers are also made of steel, we have a machine which in principle represents a wet grinding mill. Mills which are built on the principle of mortar mills are generally termed edge-roller mills, and they may be used for dry grinding as well, in which case the trough we have described is replaced by a shallow pan, generally made of cast-iron or steel. It is, however, often inadmissible to grind substances in iron, as they become more or less contaminated with that impurity. Edge-roller mills are therefore sometimes made in granite, both as regards the bed and the runners; and all parts which are liable to be touched by the material which has to be ground are arranged in such a manner that no iron or other objectionable material enters into their construction.

Owing to the great variety which we find in the hardness of different substances and in other properties, such as their tendency to cake together, designs of mills are exceedingly numerous. To go back again to the ordinary mortar, we can imagine that the mortar, instead of having a solid bottom, had that part cut out conically, and in its place had fitted into it a

grooved cone. If the bottom of the hollow part of the mortar from which the cone was cut contained a number of teeth, or were also grooved, it would follow that if the bottom cone were made to revolve, anything falling between the ridges of the bottom cone and the grooves of the hollow part of the mortar

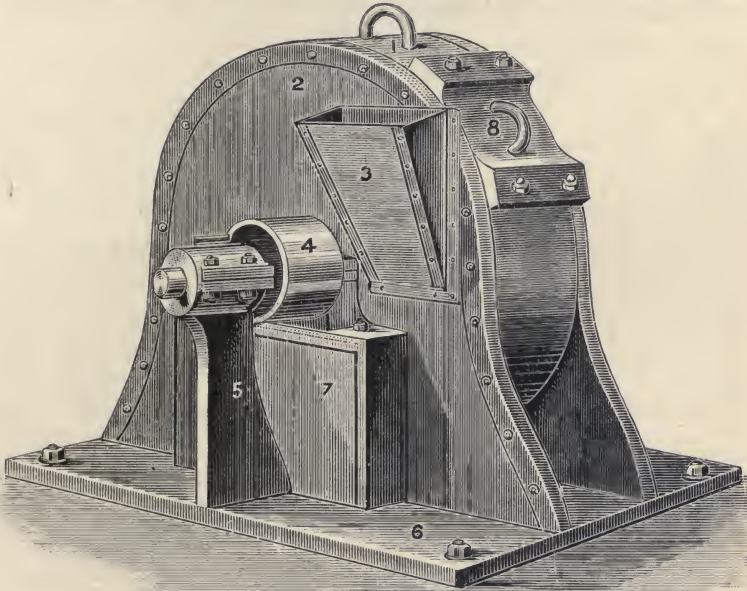


FIG. 40.—Disintegrator.

would become crushed, and on this principle a number of machines are constructed which are useful for grinding soft materials, such as soda-ash and similar chemicals. Very useful machines for grinding are those which are known by the name of disintegrators, as it is possible by their help to grind materials of very varied hardness. Fig. 40 represents one of these machines.

The disintegrator consists of a number of steel bars, which are fitted into two or three concentric circles or drums round the driving shaft, and joined to two cages by upright wrought-iron discs and rings. The cages are fixed on horizontal shafts, and fit into one another in such a way that the drum of one cage can turn in the circular space between the two drums of the other cage. Pulleys on the shafts on which these are fixed are arranged in such a manner that the two cages rotate in opposite directions. The cages are enclosed in a casing of sheet iron (which can be easily removed), with which is connected a hopper for feeding the machine. The material to be ground is fed into the innermost drum, and is thrown outward by centrifugal force through the spaces between the bars, which are revolving in opposite directions. The material is thus subjected to a great number of blows, and is ground to a considerable degree of fineness. As the disintegrators revolve at great speed, a thousand revolutions per minute and more, and as they work on the centrifugal principle, any obstruction which may occur in these machines will produce serious consequences; they therefore require careful attention.

Another construction which is frequently used for grinding materials of moderate hardness is one in which the grinding is effected by the weights of iron rollers. The mill consists of a cylindrical vessel (Fig. 41), commonly called a mill barrel, in which are placed a number of solid cast-iron rollers. There is a manhole at the top or sides of the barrel, with an arrangement by which it can be easily opened and closed, through which the material to be ground is charged, and ultimately discharged. These mills are either driven from a pulley fixed on the centre shaft or from gearing working into a spur wheel fixed round the outside centre of the barrel. Instead of using rollers for grinding, a number of cannon balls may be used for the same purpose. Both this mill and the one next to be described may be used for grinding materials both in the dry

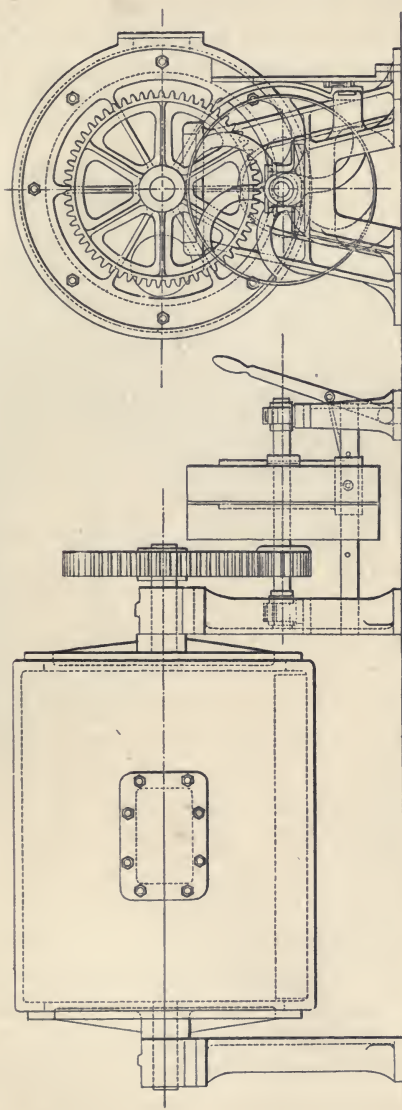


FIG. 41.—Mill for Grinding by aid of Rollers.

and in the wet state, and it is possible to obtain a very finely ground mass by their means. Instead of a cylindrical barrel, a spherical vessel is frequently used, which rotates at an angle to the plane. The grinding in this mill is effected with the aid of cannon balls.

Where an extreme degree of fineness is required, and it is not practicable to use iron or steel machinery, the well-known mills which have been used for many years for grinding corn are still applied. In these mills the material is ground between two circular stone slabs into which grooves are cut, and which rotate against each other.

We have only enumerated a few of the many designs in the market. In choosing a mill for a special purpose, it is essential to consider the particular requirements for which it is wanted. Thus, if we can set aside a mill for a special purpose, so as to always grind the same material in it, it is not very essential that one should be able to take the mill quickly to pieces for cleaning purposes. If, however, a mill is required to grind alternately several kinds of materials, so that it has to be carefully cleaned out between changes, one will have to lay particular stress on choosing one of such construction as will allow the cleaning to be done in the shortest time. In all cases it is necessary to make sure that any broken parts can be easily replaced, and it will be even necessary to consider local conditions, as in some constructions of mills, such as the stamps, the noise produced is such that they would be considered a nuisance in densely populated parts.

Although every maker of grinding machinery will undertake to work samples through his machines, and recommend such machines amongst those which he makes which would meet the requirements of the case best, it is not always possible, particularly in new installations, to provide sufficient material for the purpose. To get a thorough knowledge of the machines used in chemical technology, it is necessary that one should see

them at work, and every opportunity should be taken of obtaining such practical demonstration.

The material, after leaving the grinding mills, is not of uniform fineness. It is therefore often necessary to separate the finest part from the grit, and for that purpose sieves, made either in

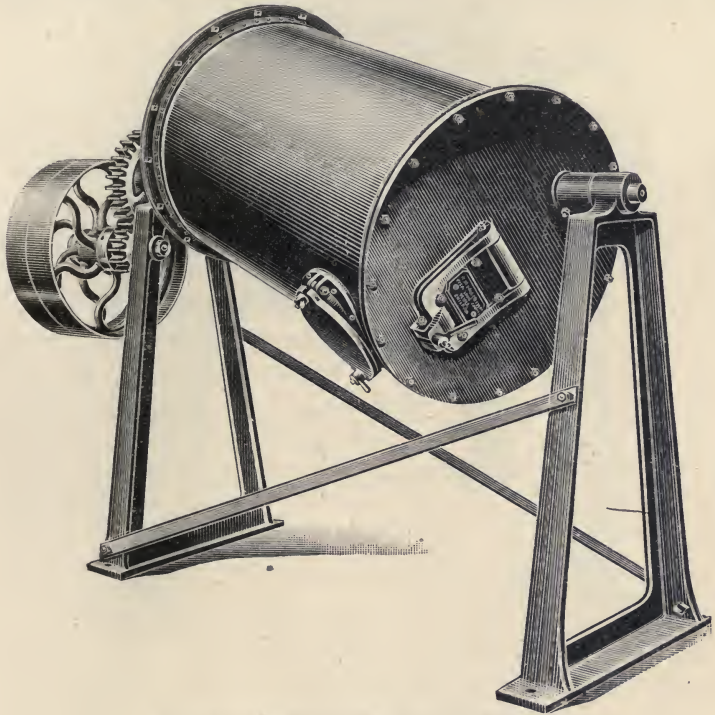


FIG. 42.—Machine for Mixing dry Materials.

metal wire or in silk mesh, are used. This mesh, in the case of metal, is classified according to the number of openings in the linear inch, and is accordingly given as 20, 40, 60, 80, or 90 mesh. Everyone is familiar with the ordinary sieve, which consists of a shallow drum, into which a sheet of copper, brass, or silk mesh is fitted; it may be used where not very large quantities

have to be dealt with, and a number of such sieves may be placed on a table and suitably fastened to it whilst the table is made to revolve at a fair speed, in such a manner that it occasionally receives a knock which throws it violently up. Where large quantities have to be sieved, an oblong sieve may

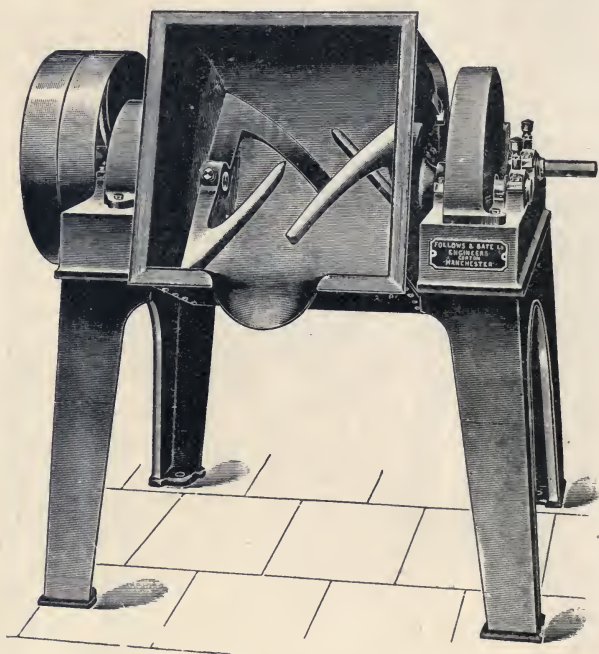


FIG. 43.—Machine for incorporating Liquids and finely-ground Solids.

be used, arranged in such a manner that it has a quick, horizontal, oscillating movement, and occasionally receives a knock throwing it up in a vertical direction. As the material moves along in the sieve, the finest part will fall through into a box underneath, and the coarser part can be made to travel into another receptacle, from which it is taken back to the mill to be ground finer. Another construction is one in which the

mesh is placed outside a frame, and forms either a circular or an octagonal long tube, which is made to revolve by means of a centre shaft.

Besides being used for grinding materials, the mortar is frequently used as in the laboratory for mixing ground substances together, or for incorporating finely ground solids with liquids. The same operations have frequently to be carried out on a large scale, and a convenient arrangement for mixing dry materials is that shown in Fig. 42, which consists of an iron drum, fixed obliquely on a horizontal axle. Through the rotation of the drum the various materials inside are thrown against one another, and in a short time become thoroughly mixed. When it is desirable to incorporate liquids and finely ground solids, many of the mills which we have discussed could be used, particularly edge-runner and roller mills. In many cases special apparatus designed for the purpose will, however, be found more suitable. One of these is shown in Fig. 43, and consists of a mixing trough, in which rotate blades of special construction. A machine of this description may be obtained in different sizes, and capable of dealing with small or large quantities.

CHAPTER IX.

MEASURING INSTRUMENTS AND THEIR TECHNICAL EQUIVALENTS.

AMONGST the most important operations carried on in the laboratory are those relating to measurements. They are of manifold kinds, and are applied for the determination of the weight of solids, the volume of liquids and gases, the temperature, the pressure in relation to that of the ordinary atmosphere, etc. As the quantities to be dealt with, and the circumstances under which operations are carried on, are different in works, it is evident that although the principles upon which apparatus is constructed for use in large installations are substantially identical with those used in the construction of laboratory apparatus, yet the details and dimensions will not be the same.

Taking as an instance the balances which are used in the laboratory, we find that they depend upon the principle of an oscillating beam, in which the position of the centre of gravity determines the sensitiveness of the instrument; and in practical work ordinary beam scales are frequently used in sizes which render it possible to determine weights up to 1 ton and more. Fitted with knife-edge centres and bearings, they can be made extremely sensitive, and are therefore particularly useful in the handling of expensive goods. A more convenient system is represented by a platform weighing-machine, which may be made either on the principle of the above-mentioned scales or on the

principle of decimal or centesimal leverage. Such a machine is shown in Fig. 44, where a platform by a system of levers is connected with the indicating apparatus which carries the weights. The levers are adjusted in such a manner that the actual weight placed on the platform requires only one-tenth or one-hundredth of that weight to be balanced. The indicating arrange-

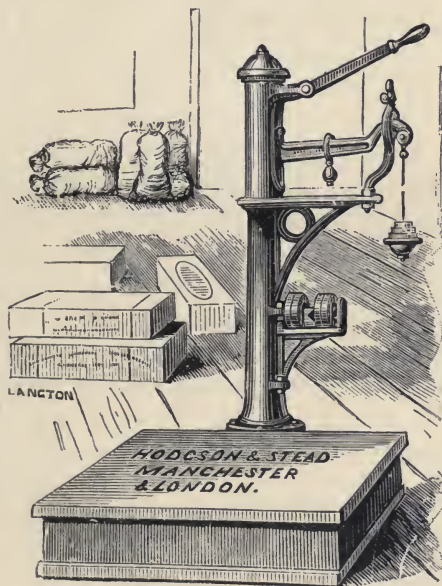


FIG. 44.—Platform Weighing-Machine.

ment consists of a steelyard with division-marks representing pounds and fractions of pounds, and having at its extreme point an arrangement for carrying weights representing cwts. and fractions of cwts. The pounds and fractions of a pound are, as with a rider on a chemical balance, recorded by a running weight which moves on the divisions on the steelyard. These weighing-machines can be made to carry weights up to 8, 10, or more

tons. Some weighing-machines are constructed in such a manner that they require no weights, but indicate the result on a dial; others may be made to weigh definite quantities of powdery substances automatically by a system of shutters acted on by levers.

The measurement of liquids, where the same quantities are often used, is generally performed in vessels of convenient (preferably rectangular) shape. The contents of these may be found either by calculation, or by filling them with water to the required level and ascertaining the volume by calculation from the weight obtained. As one cubic foot of water weighs 62.5 pounds (equal to 6.25 gallons), it is easy to calculate from the weight in pounds how many cubic feet or how many gallons a vessel will hold. In like manner, when it is desirable to ascertain the volume of a liquid other than water, this can be easily ascertained by weighing the liquid and dividing the weight thus obtained by 6.25 times the specific gravity, when the result will give the capacity in gallons.

In the laboratory the determination of the specific gravity of a liquid as performed in a pycnometer is somewhat tedious, but in a works, the areometer, which is used for the purpose, enables one to obtain the result almost instantly. This consists of a bulbous body and a thin stem. The former is filled with shot or mercury, and its total weight adjusted in such manner that when it is placed in a liquid it will sink deeper or be raised higher according to the specific gravity of the liquid. The stem is divided in such a manner that the scale marked on it indicates the specific gravity of a liquid at the point to which the stem sinks into it, either by giving the figures for the specific gravity direct, or on a scale which can be easily converted into it. In this country the areometer generally used is that constructed by Twaddell; each degree corresponds to an addition of .005 to the specific gravity of water; so that if, for instance, the instrument indicates 6° Twaddell, it means that the specific

gravity is $1 + (6 \times \cdot 005)$, that is, 1.03. If the instrument indicates 53° Twaddell, it means that the specific gravity is $1 + (53 \times \cdot 005)$, that is, 1.265. On the Continent there are several other aerometers used, and the table which is given below will enable the student to convert statements expressed by these arbitrary scales approximately into specific gravities, or, with a slight calculation, specific gravities into these scales.

If d be the specific gravity of a liquid as compared with water = 1, and n the variable showing the degree on the respective scale, then we have for the different scales—

For liquids heavier than water:

| | |
|----------------------|-------------------------------------|
| Baumé | $d = \frac{145.9}{145.9 - n}$ |
| Cartier | $d = \frac{136.8}{126.1 - n}$ |
| Beck | $d = \frac{170}{170 - n}$ |
| Brix | $d = \frac{400}{400 - n}$ |
| Balling | $d = \frac{200}{200 - n}$ |
| Gay-Lussac | $d = \frac{100}{100 - n}$ |
| Twaddell | $d = \frac{\frac{n}{2} + 100}{100}$ |

For liquids lighter than water:

| | |
|-------------------|-------------------------------|
| Baumé | $d = \frac{145.9}{135.9 + n}$ |
| Cartier | $d = \frac{136.8}{126.1 + n}$ |

| | |
|----------------------|-------------------------|
| Beck | $d = \frac{170}{170+n}$ |
| Brix | $d = \frac{400}{400+n}$ |
| Balling | $d = \frac{200}{200+n}$ |
| Gay-Lussac | $d = \frac{100}{100+n}$ |

Before leaving the subject of weights and measures as far as solids and liquids are concerned, it may be useful to point out that there are certain coincidences which enable one to convert English weights and measures into the metrical system without tedious calculations, and sufficiently near for ordinary work. Thus, for instance, as an English ton contains 2240 lbs., and as 1 kilogramme is equal to 2.2 lbs., for purposes of quick calculation it may be taken that 1000 kilogrammes are nearly equal to 1 ton, or that 50 kilogrammes are equal to 1 cwt. As 1 cubic foot of water weighs 997.14 ozs., which is very nearly 1000 ozs., and as 1 litre weighs 1000 grammes, it follows that results expressed in grammes per litre also represent the same result expressed as ozs. per cubic foot. Thus, for instance, if an analysis were to give us 55.5 grammes per litre of salt, we could say straight away that that represented 55.5 ozs., which is 3.47 lbs. of salt, per cubic foot. Again, as one gallon weighs 10 lbs., the grammes per litre divided by 100 are equal to lbs. per gallon. Also, as 1 gallon weighs 70,000 grains, any results which are found as grammes per litre multiplied by 70 will give the result in grains per gallon.

Where it is necessary to measure a quantity of gas in motion, an apparatus of a similar kind to that used for the measurement of coal gas by means of ordinary gas meters is used. Where this is not practicable, the speed with which the gases travel is determined. Suppose we wanted to determine the amount of

sulphurous acid passing into the atmosphere from a chimney, we could easily get at the amount of sulphurous acid per cubic foot by aspirating that amount or a multiple of that quantity through a standard iodine solution. By ascertaining from drawings or by measuring the sectional area of the chimney at the point at which we took the sample, we could ascertain the number of cubic feet of gas which passed through the chimney in a certain time if we knew the speed at which the gases travel. The apparatus which is used for determining the speed is called an anemometer, and is based upon the movement of a column of ether in a tube when under the influence of a current of gas.

The measurement of temperatures in the laboratory is nearly always performed by means of an ordinary mercury thermometer, and, where this is feasible, the same means are used on a large scale, as for accuracy, and the ease with which the latter can be verified, the mercury thermometer is the best. But it must be borne in mind that the ordinary thermometer is only reliable within points which are neither too near the freezing nor the boiling point of mercury. For temperatures higher than 320° or 330° Centigrade it is now possible to use specially constructed mercury thermometers, which, being filled up with nitrogen or carbon dioxide gas under pressure, and made of refractory glass, will indicate temperatures up to 550° C. A serious objection to glass thermometers is that they are liable to be broken. That objection can to some extent be got over by encasing them in suitable metal cases, leaving that part of the scale uncovered by metal on which the reading is observed. In order to meet different requirements, thermometers are constructed of all sizes and shapes up to 3 feet and more in length, bent at right angles or in other ways, and constructed in such a manner that the scale is only uncovered for that range of degrees which it is desired to observe. For temperatures above 550° C. instruments are used which are termed pyrometers, the construction of

which is based on different principles. One class of construction depends upon the fact that metals expand with a rise of temperature, and the increase in length in the metal, which may be in the shape of a bar or a spiral, is transferred by a lever arrangement to a scale and indicated by a pointer. Pyrometers have also been constructed which depend upon the principle of the expansion of air, the heat being indicated on a dial in a similar manner. It may be stated here, as a rule which applies to all measuring instruments for heat, that it is necessary to check them from time to time, and this applies not only to pyrometers, but also to thermometers, which, as is well known, change in the course of time.

One of the simplest and, if properly conducted, one of the most reliable ways of determining high temperatures is by means of the calorimeter. The calorimeter is based on the fact that if a substance of known specific heat, and of known weight, heated to a certain point, is dropped into a known quantity of water of known temperature, it will cause that quantity of water to rise in temperature by a definite amount. If, therefore, the weight of the substance used and the specific heat of it be known, and a definite quantity of water be taken for the purpose of the experiment, it will be possible from the rise of temperature in the quantity of water taken to determine the heat to which the original substance was raised. The apparatus consists of a metal box, generally made of sheet copper, which is placed in a wooden box, the space between the two being filled with a bad conductor, such as wool or similar substances. The copper box is covered with a lid which is provided with two holes, one to allow a thermometer graduated in tenths of degrees to pass through, the other to enable one to drop in the heated mass of metal which is used for ascertaining the temperature. A stirrer is fixed in such manner that the water in the calorimeter can be mixed to equalise the temperature. The metal cylinder may be made of wrought-iron,



copper, nickel, or platinum. In order to carry out the test, the apparatus is two-thirds filled with an accurately measured quantity of water, the metal cylinder is placed in a metal spoon fixed on a sufficiently long rod and passed into the flue or furnace, the temperature of which has to be determined. It is left there for a sufficient time, twenty minutes or half an hour, and then quickly removed and dropped into the calorimeter. The temperature of the water in the calorimeter is taken immediately before the metal cylinder is dropped into it and shortly after. If the original temperature of the water be t^0 and the maximum temperature after inserting the heated cylinder be t^1 ; if the weight of the metal cylinder be p and the specific heat of the metal of which it is made be c , the weight of the water added to the water weight of the copper vessel and stirrer p^1 , then the temperature T of the hot cylinder is

$$T = t^1 + \frac{p^1(t^1 - t^0)}{pc}$$

The water weight means the actual weight of the copper vessel multiplied by the specific heat of copper. It must not be forgotten that the specific heat of metals varies with the temperature, and this fact should be taken into consideration.

A very convenient form of measuring temperatures is now at our disposal in the form of electrical thermometers. These are of twofold construction; they may be either resistance or contact thermometers. In the resistance thermometers, use is made of the fact that the resistance of a metal to the passage of a current depends upon the temperature, so that if, for instance, a platinum wire is exposed to the heat of a furnace and a weak current is passed through it, that current will affect the needle of a galvanometer according to the temperature of the wire. The contact thermometer, on the other hand, depends upon the fact that if two pieces of different metals, as, for instance, an iridium and a platinum wire, are placed in contact,

an electric current is produced which varies with the temperature to which the contact place is exposed; and this current can also be measured by means of a galvanometer, which may be adjusted to a scale in such a manner that the degrees Centigrade or Fahrenheit are shown on a scale direct. These instruments are extremely useful, particularly as they can be used in places and in apparatus in which it would be difficult to introduce other kinds of thermometers; but it is important here, as in every other case, to check the instruments from time to time.

Another kind of thermometer much used now is the Thalpotassimeter. This instrument works on the principle that liquids exposed to different temperatures in a closed space will, according to the temperature, produce a pressure which can be read off on a convenient scale. The liquids used for the purpose vary according to the temperatures which are required to be measured. For low temperatures, such as required in a vacuum apparatus, etc., they may be ether or alcohol; for higher temperatures, mercury or other liquids. A peculiar system of determining temperatures is often used in furnaces in the manufacture of pottery and similar ware, and consists of little cones made of glazing material having different degrees of fusibility. The approximate melting point of these cones is known, and by placing a number of them in the furnace it can be easily ascertained which of them is first affected by the heat. The actual temperature at which the furnace is working will lie between the fusing point of this and that of the cone having the next higher fusing point which is not affected.

For quick determinations, which may be left to the workman, it is sometimes convenient to make use of the known temperatures at which certain metals or compounds melt. Thus, for instance, potassium nitrate melts at 329° C., and bismuth at 264° C. If we introduce these two in a little spoon fixed on a long handle into the furnace to be tested for heat,

and if we find that the bismuth melts and that the potassium nitrate does not, then we may take it that the real temperature is between the two melting points.

The instruments designed for ascertaining in the laboratory the composition of mixtures of gases constitute one of the triumphs of scientific accuracy. In work on a large scale, where absolute precision is not required, and where approximate results are satisfactory, so long as they can be obtained with the least expenditure of time, the apparatus which is used for a similar purpose is naturally constructed on different lines to that used in the laboratory.

The main difference in the construction of the apparatus consists in the substitution of water and similar liquids for mercury, not only because mercury is an expensive material, but also because its high specific weight renders work with large quantities extremely cumbersome. To carry about an apparatus filled with mercury, of sufficient size to allow of measurements being made on such large quantities that slight differences in the volume would still show, would be impracticable; yet it is often necessary to perform tests on the spot, without first transferring the gas samples to the laboratory. Although it is over thirty years since technical gas analysis was introduced into chemical works, its importance, not only to chemical works but to other branches, is hardly yet sufficiently recognised, and for that reason we may dwell on this point a little longer. One of the first uses to which gas analysis was put in chemical works was that in which the amount of oxygen was determined in the gases leading from sulphur or pyrites burners. It is well known that for the manufacture of sulphuric acid, sulphur or pyrites is burnt in kilns by means of air. If too much air is added, the gases become too dilute, and the chambers in which the sulphuric acid forms do not work to the best advantage. If the quantity of air admitted is too small, there are losses in the quantity of nitre required. It is therefore necessary, in

order to properly regulate the admission of air to the kilns, to ascertain whether too much or too little air is introduced, and this knowledge is gained by drawing samples at intervals from the gases leaving the burners or kilns, and determining the quantity of oxygen which is left in them. This may be done by means of a simple apparatus which is known as a Bunte burette, in which the gases, after the sulphurous acid has been removed, are passed into a eudiometer and shaken up with an alkaline solution of pyrogallic acid. The free oxygen present is thus absorbed, and determined in quantity by difference from the volume of the remaining nitrogen. Apart, however, from the use of gas analysis in specifically chemical operations, there are other processes in which it is important to determine the composition of gaseous constituents which are formed, and the most important are those which relate to the combustion of coal and other kinds of fuel.

We have in previous chapters frequently had occasion to point out that the commercial success of many operations depends upon the economical utilisation of heat. If we leave out of consideration the power of wind and water, which is at present, and particularly in this country, not much utilised, we find that the results of chemical reactions and of physical processes, as conducted in chemical works, are only due to the conversion of the energy stored up in coal into other kinds of energy. It is therefore of the greatest importance that we should obtain the utmost yield from the latent energy of fuel. In many cases an examination of the products of combustion will enable us to approach that point more closely, and for that reason we should be in a position to analyse the products of combustion quickly and with sufficient accuracy.

The well-known apparatus which is used for the determination of gases of combustion is called an 'Orsat,' and enables one in a very short time to determine the amount of carbon dioxide, carbon monoxide, and oxygen, and, by difference, also

nitrogen, in the products of combustion. Apparatus has also been constructed to show automatically at any time the amount of carbon dioxide which is present in flue gases. One consists of two delicately balanced glass spheres, of which one is surrounded by air and the other by the flue gas which is to be tested, the difference in weight, as indicated by the beam on which these spheres are balanced, showing the difference in the specific gravity between the air and the gas to be tested, from which the percentage of carbon dioxide can be calculated. Another kind of apparatus is constructed, on purely mechanical principles, in such a manner that the machine itself performs the function of the determination of carbon dioxide by absorption in caustic potash, and records the results automatically.

CHAPTER X.

MATERIALS USED IN CHEMICAL ENGINEERING, AND THEIR MODE OF APPLICATION.

APART from a sound knowledge of physics and chemistry, the successful designing of apparatus used on a large scale depends upon a knowledge of the details of construction, and this again requires a knowledge of the details of such other trades as enter into chemical engineering. It is impossible to design a plant, or even to understand the construction of a plant properly, without being to some extent acquainted with the principles of iron-founding, the coupling of pipes, bricksetting, carpentering, joinering, etc. It must be understood that it would be impossible to have such a knowledge of all these branches as would enable one to do the practical work; but with a general knowledge of the principles which underlie the work in different trades, and by carefully watching work in progress, a great deal of useful knowledge can be obtained. Another important point gained will be this, that in constructing new designs we shall understand whether the whole and its details can be readily executed, and if so, which will be the most economical way.

As this is a subject of great importance, we will consider a few of the principal trades which enter into the construction of chemical plant in this chapter.

It may be safely stated, that although everyone has had ample opportunity of watching bricksetters at their work, few

will have exercised their powers of observation sufficiently to know exactly how the work should be and is done. The main object in building with bricks is to arrange the different courses in themselves and amongst each other in such manner as to produce a homogeneously interlaced mass. There are many possible ways of attaining that object, but we shall only mention a few of the most important.

The average standard brick is supposed to be 9 ins. long, $4\frac{1}{2}$ ins. wide, and 3 ins. in thickness. It is usual in building to express the thickness of walls not in inches, but in the number of bricks. Thus a wall $4\frac{1}{2}$ ins. thick would be termed half brick; one 9 ins., one brick; one 14 ins., one and a half bricks thick. Strictly speaking, bricks are not made exactly to the above sizes, but about $\frac{1}{4}$ in. less in each direction, so that when the interstices between them are filled with the binding material, their dimensions are represented by the above integers without fractions. The width of the binding material between the bricks should be about $\frac{3}{8}$ in. A standard brick weighs approximately 7 lbs., and a thousand of them, termed a load, from 61 to 63 cwts. In measuring brickwork it is usual to reduce it to a thickness of 14 ins. and express the quantities in 'rods.' One rod of brickwork = 272 superficial feet $1\frac{1}{2}$ bricks thick. It is made up of 235 feet of bricks and 71 of mortar, and requires 4300 standard bricks. It is generally stated that a bricklayer and his labourer can set about 800 bricks in a day's work; but in work requiring careful handling, such as furnace-building or boiler-setting, the quantity achieved per day will be much less.

The chief aim in bricksetting is that of obtaining a good bond; and the principal point which has to be considered on that score consists in arranging the courses in such a manner that the bricks in one course cover the joints between the bricks in the course below. The two chief methods used are the English and the Flemish bond. The former gives the best results, and

is preferable to the latter where strength and durability are required. Fig. 45 shows the difference between the two sufficiently clearly without further explanation; figs. 46 and 47 demonstrate the means adopted for obtaining a good bond in building corners.

In work which is not exposed to great heat, ordinary bricks

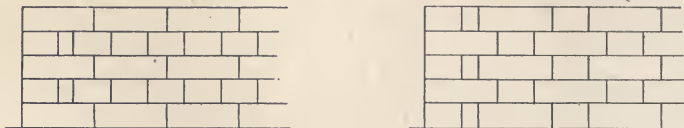


FIG. 45.—English and Flemish Bond.

made of impure coloured clay, more or less mixed with sand, are used, and ordinary mortar is used for binding the bricks together. The latter is made by mixing slaked burnt lime with sand. One cubic yard of lime takes from 4 to 6 cubic yards of sand, and yields 4 to 6 cubic yards of mortar. But if

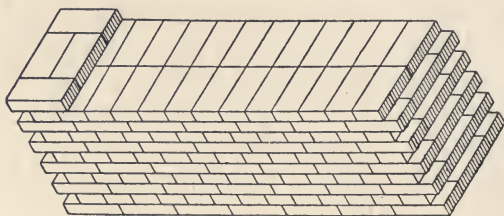


FIG. 46.—Bond.

the finished brickwork is exposed to damp, or if it is required to hold or store water, it is necessary to use cement, of which the Portland brand is considered to be most suitable. Generally speaking, cements are silicates of lime and alumina which have been strongly ignited, and are placed on the market in the form of fine powder. It must be borne in mind that whereas ordinary mortar shrinks on setting, cement expands.

But it is not usual to use cement by itself except in special cases; it is generally used mixed either with sand or with mortar.

In works in general, bricks set in cement or in cement mortar are usually applied for foundations for buildings, for water-tanks, and for foundations for engines. In the latter application, it is sometimes overlooked that under the continuous action of oil, cement becomes disintegrated; it is therefore advisable, apart from the fact that every apparatus, and

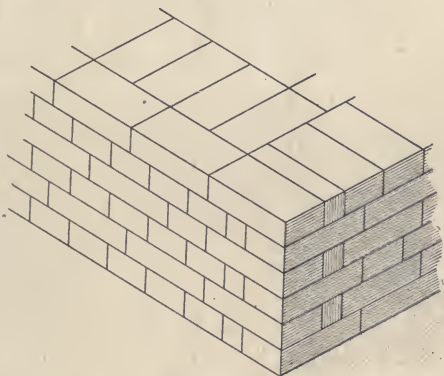


FIG. 47.—Bond.

particularly engines, should be kept clean, to make such arrangements for oiling purposes as to prevent the oil from oozing into the ground.

In chemical works cement is found to be particularly useful, as it resists the action of alkalis, acids, and many chemicals to a remarkable degree. It has, moreover, the useful property of being able to stand a considerable degree of heat, safely up to 200° C., and even higher, and to be equally unaffected by operations which require a temperature below freezing point.

Where brickwork is exposed to great heat it is necessary to use special bricks, called firebricks; they are made of a purer

clay than the ordinary building bricks, and are set in ground clay. They are made in standard sizes, similar to ordinary bricks, and may be obtained in almost any shape to suit different constructions. As they are about five times as expensive as ordinary bricks, they are sparingly used, and only where it is absolutely necessary. In drawing a plan of a furnace or similar structure, it is therefore necessary to specially indicate where either kind of bricks should be placed. This is generally done by colouring those parts which are to be built in firebrick and clay yellow.

Besides firebricks, tiles made of similar refractory material are frequently used in furnaces and similar constructive work. They are particularly useful for covering spans of more than 6 inches, such as occur in flues and small fireplaces. Thus we have seen in Chapter IV. that the bed of a 'blind' roaster is made of tiles, the reason for this being that we are thus enabled to make the flues wider. If we were to use ordinary or fire bricks for the purpose, we could not place the side walls forming the flue more than 5 or 6 inches apart, otherwise the 9-inch brick would not rest on them securely. By using tiles we can therefore span distances which are too large to be covered by brick, and too small to be covered by arches, or where, for other reasons, it would be inconvenient to use an arch.

In parts which are exposed to great heat, spans of more than 15 inches should be covered by arches. These are built up in the form of a segment of a circle, which should have sufficient 'spring' to be stable. Although in former times it was usual for the bricksetter to cut his ordinary bricks into suitable shape for the arch, it is better to order specially shaped bricks for that kind of work. It may be laid down as a general rule, that in designing a furnace or other brick apparatus every detail should be worked out in such a manner that no cutting of bricks by the bricksetter is required. Bricks may be obtained from the makers of almost any size and shape, and in such intermediate sizes as will represent a brick cut into half

or into a quarter of its original size. In all work exposed to heat it is particularly necessary to set the bricks and tiles in such a manner as to allow for the expansion which will take place, otherwise the structure will soon crack in many places and become leaky and unsafe.

On starting a new furnace it is necessary to heat it slowly and gradually, and according to its size and the temperature which is to be maintained. It may take from three days to a month to bring it up to working heat. In like manner, when a furnace has to be stopped, it has to be cooled down very gradually; this is done by letting the fires down slowly, and then closing the dampers so as to prevent cold air from passing through.

Apart from its use in the construction of buildings and roofs, into which we need not enter more particularly, timber is employed in the construction of tanks, casks, and barrels, and is manipulated by the carpenter, joiner, or cooper. The different pine woods are mostly used for chemical purposes, though other kinds of timber will be found sufficiently strong and durable for many purposes. Most kinds of timber will stand the action of liquids as long as they are not too strongly acid, but alkaline solutions will act injuriously on them. Certain solutions, without being either acid or alkaline, have a peculiar disintegrating influence on woods, and will in time ooze through the pores and leak away; some calcium and magnesium salts show particularly this objectionable property. Wooden structures, such as tanks or barrels, which have been used for the storage of liquids, should not be allowed to stand dry for any length of time. If not in use they should be filled to their full capacity with water, otherwise they will cease to be liquid- or water-tight. In constructing them it is necessary to see that no material is used which would act or be acted upon by the liquid which the tanks or barrels are to hold. It would, *e.g.*, be out of the question to use iron nails in the construction of a tank

intended to hold a solution of pure aluminium sulphate. Many tanks are built up of staves in a manner similar to that in which barrels are made. They are slightly wider at the bottom than at the top, so that the hoops which are used for pressing the staves together can be easily tightened by being moved towards a part of greater circumference. It is often required to know approximately the contents of a barrel. A simple formula for calculating it is

$$V = \frac{1}{12}\pi h(2D^2 + d^2)$$

in which D is the diameter at the widest point, d the diameter of the lid or bottom, and h the height of the barrel.

Wherever there is any doubt as to what kind of timber would be most suitable for the construction of tanks, it is necessary to immerse in the laboratory samples of different kinds of woods in the liquid which the tanks are destined to hold, and under the same conditions with regard to heat as will prevail in actual work.

The most important of all materials which enter into the construction of chemical apparatus is iron. It is usual to distinguish three kinds which are used in the arts and manufactures, viz., cast-iron, wrought-iron, and steel. But in order to obtain the best technical effects from them it is necessary to make further distinctions, and to consider their properties more in detail, particularly when they have to be used for special purposes. Ordinary grey cast-iron, as it comes from the blast furnace, contains from $2\frac{1}{2}$ to $4\frac{1}{2}$ per cent. of carbon, mostly in the form of graphite, and also silicon; in white cast-iron the carbon is chemically combined with the iron. It may contain manganese in varying quantities, from 1 to over 20 per cent. In steel, the quantity of carbon is more than $\frac{1}{4}$ per cent.; in wrought-iron, less.

It is impossible to give an adequate description of the process of iron-founding. The different stages of it, the making of the

patterns, the manner of moulding, and other details, must be seen to be clearly understood. At the same time, it is of the greatest importance that the student should be acquainted with the details of this kind of work, and that he should take an opportunity of watching the different processes in a foundry. The explanation of this and similar processes might be greatly advanced if cinematographs were used as an aid to the lectures. Within the walls of the college or technical school it would be possible to demonstrate to the student in a most instructive manner the work of the bricksetter, the pattern-maker, the moulder, the iron-founder, the turner, and many other craftsmen; and any points which were not clear to him could be easily demonstrated by reproducing the picture on the screen, and stopping it at such intervals as might be required for explanations.

A little instance will show the importance of being acquainted with the details of different trades. I found that castings which I used for work with corrosive substances became corroded and gave way in odd places in a manner which I could not account for. It occurred to me that this might be due to the fact that the studs which are used for supporting the core of a mould were made of wrought-iron, and remained in the finished casting. The casting therefore consisted in those parts in which the studs were left of wrought-iron, and not of cast-iron. It is well known that different chemicals have a different action on cast-iron as compared with wrought-iron; in many cases wrought-iron is more easily attacked than cast-iron. Apart from this, it is well known that wherever two metals are joined, probably owing to an electric current which is set up, the corrosive action is increased. I have therefore lately made it a point in all specifications for chemical work to insist upon cast-iron studs being used, with results which confirm the correctness of my views.

Going further into such details as can be explained in writing, it must be noted that the patterns which are made for

castings must be larger than the actual size shown in the drawing. Roughly speaking, it may be taken that on cooling down, the molten metal shrinks to the extent of $\frac{1}{8}$ to $\frac{1}{10}$ of an inch for every lineal foot, and an allowance for this is always made in preparing the patterns and laying out the moulds into which the iron is cast.

If we, further, consider the manner in which iron is prepared for casting, we will find that it is melted with the addition of such substances as will produce a slag. The slag will rise to the top in the cupola, but some of it will still be left in the molten iron, or formed during the time of transferring the molten mass to the place in which it has to be cast into form, and will rise to the top of the finished casting. It is therefore necessary to arrange the mould in such a manner that the weakest part of the apparatus is at the top. If, for instance, we require a pipe which is to be heated at one end, it would be necessary to cast this pipe in a vertical position, and in such a manner that the part which is to be exposed to heat would be at the bottom of the mould. By casting it a little longer than required and cutting the superfluous end-piece off, we should obtain a pipe which would be perfectly sound all through, and particularly strong at the bottom part.

By mixing different grades of metal in the cupola, different makers produce cast-iron vessels which resist the action of special chemicals particularly well. The manipulation of cast-iron in the cupola to produce castings which have specific resisting properties in relation to different chemicals is a matter which has not yet received the attention it deserves. That the properties of cast-iron are largely influenced by admixtures with other elements is well established; and it is possible that when our knowledge has become more complete, we shall be able to use iron vessels in operations for which at present they are not suitable. It may be generally said that cast-iron will withstand the action of alkalies when they are in solution and

when melted; that it is hardly attacked by strong acids, but easily by weak acids; that many neutral salts can be safely manipulated in it, whereas others cannot. The probability is that dissociation is the fundamental cause why neutral salts act on iron. Thus, for instance, ammonium chloride, which is a typical representative of the action of dissociation, acts strongly on iron on boiling down. Under ordinary circumstances and in a dry atmosphere iron does not change, but in moist air or in contact with water it soon becomes oxidised and rusts. Wrought-iron exhibits this property in a more pronounced manner than cast-iron. It is well known that by coating iron vessels with a thin layer of a material which will prevent access of air, such as paint or varnish, it can be preserved indefinitely. Where iron vessels have to be bedded-in, one must be careful to choose the substance in which they are to be imbedded in such a manner that it may not act on the iron. It has been found that iron which has been bedded in lime or plaster of Paris rusts very rapidly, whereas if bedded in cement or in tarry matters, such as asphalt, it remains unaltered. These are only a few of the details which have to be considered in chemical engineering in the use and application of iron. They will show that in that branch of knowledge no detail can be too small to receive due consideration.

As regards wrought-iron, the principal point which has to be considered when it is used in conjunction with cast-iron, as frequently occurs in constructive work, is that its coefficient of expansion is greater than that of cast-iron. Wherever a doubt exists whether cast-iron, wrought-iron, or steel should be used for a special purpose, it is always advisable to try in the laboratory the action which the substance which has to be manipulated exerts on these materials, and to do so as nearly as possible under the same conditions as will prevail in the works.

Next in importance to cast-iron, as far as its application

in chemical industries is concerned, comes lead. Its most valuable property is that of not being attacked by hot or cold sulphuric acid as long as the strength of the latter is under 140° Twaddell. As this acid enters into a great many operations, it is natural that the vessels in which such operations are performed should either be made of, or coated with, lead. It is now possible to obtain cast-iron vessels of almost any size coated with lead, which has been fixed on the iron by a special process of casting or plating. Apparatus of the most varied description is made on this principle, and lead-coated or lead-lined boiling and evaporating pots, autoclaves, hydro-extractors, perforated plates, tubes and pipes are in the market.

As regards the use of sheet lead, we have in the first chapter explained that it is usual to distinguish the different thicknesses in terms of weight per square foot. The annexed table gives the standard weights in pounds, and the corresponding thickness in decimals of an inch:—

| | | | | |
|--------------------|---|--------------------|--|--|
| 3 lbs. per sq. ft. | = | ·051 in. thickness | | |
| 4 " " | = | ·068 " " | | |
| 5 " " | = | ·085 " " | | |
| 6 " " | = | ·102 " " | | |
| 7 " " | = | ·119 " " | | |
| 8 " " | = | ·136 " " | | |

—from which the weight of sheets of greater thickness can be easily calculated by simple proportion.

Lead pipes are made in standard lengths of 15, 12, and 10 feet: their thickness varies between $\frac{1}{10}$ and $\frac{1}{4}$ of an inch, and their weight can be approximately calculated by the formula $15\cdot517t(D+t)$ lbs. per foot, where D is the internal diameter and t the thickness in inches.

We have pointed out before that in constructing chemical apparatus from lead sheets (and the same applies to lead pipes) the edges are joined together by means of a strip of lead which

is melted on to the edges. The heat required for the purpose is obtained from a small portable apparatus in which hydrogen is evolved from zinc and dilute sulphuric acid. By means of a long india-rubber pipe the gas is conducted into a burner which is arranged on the same principle as the burner which is used in the laboratory for glassblowing, and the necessary air is supplied from a hand blower, which is generally manipulated by the plumber's apprentice. The zinc and acid used for the evolution of hydrogen should be free from arsenic, so as to avoid the formation of the highly poisonous arseniuretted hydrogen.

It is a peculiar property of lead that whilst it expands in the usual way under the influence of heat, it does not contract in the same ratio on cooling; allowance for this must therefore be made where necessary, so as to avoid bulging. The chemical properties which determine its use should be familiar to the student. It stands the action of dry or moist air; it is little affected by chlorine, but is acted upon by hydrochloric acid; ammonium sulphate is almost without action on it, whereas the chloride, especially on heating, dissolves it readily. Organic acids and many inorganic salts in solution, such as chlorides, nitrates, nitrites, etc., attack lead and bring it into solution. It is also necessary to remember that if lead is in contact with other metals, as, *e.g.*, iron, copper, or the like, galvanic action may be set up and reactions produced which may be injurious to the leaden vessels. Leaden vessels must, moreover, never be bedded in cement, as direct contact with the latter makes them brittle.

The use of copper is restricted on account of its being easily attacked by many acids, and by ammonia. But as it is a good conductor of heat, and as its great tensile strength allows of its being used in thin sheets for the construction of chemical apparatus and of tubes, it is still largely used in chemical engineering. Generally speaking, it is used more in organic

than in inorganic chemical industries, most extensively in brewing, in distilling apparatus for alcohol and other organic inert volatile compounds, in sugar-refining, etc. Where two or more sheets have to be joined together, this may be done either by riveting or by brazing, and for the latter purpose different solders are used, which, according to their higher or lower melting point, are termed 'hard' or 'soft' solder.

Of other metals, gold and silver are only used for special apparatus in isolated cases; platinum, for concentrating sulphuric acid; zinc for vessels for storing, and for scoops and similar vessels used in handling dry goods; and tin, almost exclusively in the form of tubes. Nickel and aluminium are also now largely used in the construction of apparatus for chemical works, and will no doubt be used more frequently in the future as the prices for these goods become further reduced.

Of equal importance to the metals are the different alloys which are obtained by fusing together certain metals in certain proportions. In this manner substances of metallic appearance are obtained which in many cases exhibit properties different to either of their constituents. The best known amongst them is brass, which in its usual form contains about 70 per cent. of copper and 30 per cent. of zinc. By increasing the quantity of copper to 80 per cent. or even more, the colour of the resulting alloy passes from yellow to reddish, and it becomes softer and more tenacious. Some makers add a little tin to the mixture; if the quantity of the latter is increased, whilst the amount of the zinc is reduced, the alloy is classed amongst the bronzes; these are harder and resist acid better than brass; by the addition of phosphorus these properties are still further emphasised.

Aluminium forms alloys of valuable properties, that with copper being known as aluminium bronze; with magnesium, as magnalium; the former resists the action of many salts in solution, such as alkali chlorides, ammonia compounds, caustic, etc.; the latter has great tensile strength and can be soldered.

Of the lead alloys, the one with antimony is best known; it is harder than lead, but retains its acid-resisting properties, and is largely used for taps.

Metal sheets, tubes, and wires, with the exception of lead, are generally specified by gauges. These are ascertained by means of a steel plate with incisions of different widths, against which the arbitrary numbers of the respective gauges are marked. By ascertaining into which of these incisions the wire or plate will fit, and noting the number marked against that point, the gauge can be accurately ascertained. In the English standard gauge, 0,000,000 represents a thickness of half an inch, No. 1 three tenths of an inch, and so on down to No. 50 with the corresponding thickness of one thousandth of an inch. Unfortunately this is not the only gauge in use, and this should be borne in mind to avoid mistakes. As it may be useful to the student in future work, and is an item which might be troublesome to find, we insert here particulars of the German gauge. There are 25 numbers, and the thickness is expressed in millimetres:—

| No. | mm. | No. | mm. | No. | mm. | No. | mm. | No. | mm. |
|-----|------|-----|------|-----|------|-----|-------|-----|-------|
| 1 | 5.50 | 6 | 3.75 | 11 | 2.50 | 16 | 1.375 | 21 | 0.750 |
| 2 | 5.00 | 7 | 3.50 | 12 | 2.25 | 17 | 1.250 | 22 | 0.625 |
| 3 | 4.50 | 8 | 3.25 | 13 | 2.00 | 18 | 1.125 | 23 | 0.562 |
| 4 | 4.25 | 9 | 3.00 | 14 | 1.75 | 19 | 1.000 | 24 | 0.500 |
| 5 | 4.00 | 10 | 2.75 | 15 | 1.50 | 20 | 0.875 | 25 | 0.438 |

Notwithstanding the wide range of useful properties which the metals and their alloys possess, there are special occasions in which they cannot be used in contact with certain chemicals, and in such cases it is necessary to employ glass, porcelain, earthenware, rubber, or ebonite. Thus large glass vessels are used in the concentration of sulphuric acid; glass pipes have been and are used for conducting hydrochloric acid gas from

the furnace to the condensers; whilst earthenware pipes are used for the same purpose in conveying nitric acid gas in the manufacture of the liquid acid. The larger the apparatus made of these materials is, the more costly it becomes, not only on account of its original price, but also on account of the greater difficulty in its handling, and the greater risk and liability of its becoming damaged.

Earthenware goods are glazed, and their durability and resistance to the action of chemicals depend largely on the quality of the glaze. Badly glazed vessels absorb the liquids which are stirred or heated in them, and soon become useless. It is hardly necessary to mention that earthenware apparatus should never be placed suddenly on hard, unyielding supports; they should not be exposed to sudden wide changes of temperature, nor to violent shocks. When heated in a water, sand, or oil bath, the level of the liquid which they contain should be kept above the level of the bath, so that the expansion of the earthenware may be more gradual.

A highly important material for the construction of chemical apparatus is enamelled iron, as it combines the good qualities of earthenware with the durability of iron. A good enamel, besides being able to resist the action of the chemical which is to come in contact with it, should have the same coefficient of expansion as the iron on which it is coated. Unless this is the case, it will soon crack and the corrosive liquid will find its way to the iron, with the result that the enamel will peel off.

The problem of always applying the most suitable material in the construction of chemical apparatus is one of the greatest importance to the chemical engineer and manufacturer. Closely connected with it in the building up of installations is the art of connecting the different parts of apparatus in such a manner as to produce a machine which as a whole shall be water or gas tight. According to the materials used, different ways may be adopted to attain this purpose, and we will in the

following consider a few of those which are most commonly employed.

Suppose we have to construct an apparatus in which a gas has to be evolved and conducted to another apparatus a considerable distance away. The materials of which the pipes would have to be made would depend upon the properties of the gas, and might be any of the metals, alloys, or other substances discussed above. But the manner of joining the pipes would not only depend upon the chemical properties of the gas, but also on the material of the pipes and the pressure of the gas.

It is evident that wherever it is feasible we should use cast- or wrought-iron pipes as being the cheapest and most durable material. The former are mostly joined together by flanges, which contain a number of corresponding holes through which the screw bolts are passed. A ring made of compressible material and constituting the packing is inserted between the flanges, and by tightening the bolts a perfectly secure joint is obtained. This should never be done by first tightening one screw as far as it will go, and then another, and so on; but we first give one screw a few turns, then bring the opposite screw to the same tightness; then proceed in the same way with the other screws, and repeat the process until the flanges are uniformly pressed together. In the case of iron pipes not exposed to the action of corrosive gases or liquids, the choice of packing chiefly depends upon the temperature which it may have to stand. For ordinary temperatures, rings made of woven or compressed yarn or of india-rubber may be used; for higher temperatures, asbestos rings, or solid or hollow metal rings. But as flange joints are the safest and most convenient means of joining surfaces together, it frequently happens that they are used in cases where highly corrosive substances have to be conveyed, and with pipes made of lead, copper, or earthenware. In such cases it is clear that the material of which the flange is made is not of such importance

as the material of which the packing consists, for the latter is directly exposed to the corrosive action, whereas the flange is protected from it. Suitable packing can be made with the following materials: india-rubber, asbestos covered with white or red lead, graphite, or mixtures of graphite and oil, asphalt, lead (sheet or pipe), copper (sheet or pipe), millboard, etc.

Wrought-iron pipes may also be joined together by means of flanges, but the most usual way is to join them by means of screw couplings. We have on previous occasions mentioned other forms of joints and the different cements which are used for the purpose. In these matters a knowledge of chemistry and physics, combined with common-sense, will enable the student to avoid mistakes which are frequently made by those who only follow to the letter prescriptions found in books. Taking, for instance, the case of connecting pipes, it will always be necessary to consider the conditions under which the pipes are worked. Thus, if there is a great length of piping liable to get hot, it follows that provision must be made to allow for expansion; and it is clear that this could be done in several ways, such as by joining a few of the pipes in stuffing-box fashion, or using elastic metal tubing as packing between flanges, or occasional lengths of flexible metal tubing instead of rigid pipe, etc. It is also clear that, where necessary, loss of heat should be prevented by covering the pipes with some non-conducting material.

CHAPTER XI.

TECHNICAL RESEARCH AND THE DESIGNING OF PLANT.

THE purpose of the preceding chapters has been to introduce the student to a subject which, as a separate course of study, is unfortunately neglected at our universities and technical schools.

The first object of the study of chemical engineering should be to enable the student to more easily grasp the details of such technical processes as are taught in books and lectures.

The present system of teaching chemical technology is such as to render its study unnecessarily difficult. Too many types of machinery and plant are placed before the student at once, just as they occur in connection with certain industries which are brought to his notice. Take, for instance, the Leblanc soda industry, a favourite course of lectures in chemical technology; nearly every mechanical process is here represented which occurs in practical work, including apparatus for grinding, stonebreaking, evaporating, crystallising, filtering, melting, etc. etc. Whilst the student has to wade through this bewildering mass of what is to him new matter, he is likely to miss the essential principles which underlie both the chemical and engineering problems of the manufacture. To teach technical chemistry on these lines is tantamount to teaching such chapters in physics as statics or dynamics to students who have no knowledge of mathematics, trusting that they may obtain the

necessary knowledge of mathematical problems involved by reading them up at the time they occur. It is universally recognised that a course of mathematics should precede that of physics; it should also be recognised that chemical engineering occupies a similar relation to technical chemistry, and should precede the courses of chemical technology. The result of study on these lines will be, that the student will be able to assimilate the principles of technical work and apply them successfully to problems which may present themselves in branches of chemistry which have not been specially taught him. If our technical chemists of this and the next generation are to hold their own, it will be necessary that the universities and colleges should recognise this; but particularly, also, that it is not their province to turn out specialists in one or other of the countless fields of chemical technology, but men equipped with a sound general knowledge, and who have been trained to use their knowledge. To achieve this, the course of study should be thoroughly systematic.

The second object of a knowledge of chemical engineering should be to enable the student to design plant required for the carrying out of new processes which he has worked out himself. As the subject of technical research work is an unknown quantity at our universities and colleges, it is no wonder that the designing of plant has received no attention. The two should go hand in hand, for without adequate plant the best chemical process cannot succeed.

The ideal course of technical study would be one in which the student could devote the first two years entirely to theory, to lectures on higher mathematics, physics, and theoretical chemistry, and to work in the laboratory on analytical methods and preparations. After that he should pass to the technical side of the institution, which should be equipped with workshops containing all the standard apparatus used in chemical work, and on such a scale that work with several cwt. of material

could be carried on in them. There should be laboratories and drawing-offices, and the student should attend lectures on chemical engineering, chemical technology, and such other subjects as will be of practical use, as, *e.g.*, mechanical drawing, patent law, calculations of cost, etc., supplemented by practical demonstrations in the workshop and visits to works. In the fourth year he should be put on to some simple technical research, and after working it out in the laboratory, should be made to work his process in the workshop on a large scale. The designing of plant for this or other special purposes would conclude his course.

Although the subject of technical research does not, strictly speaking, come within the province of this book, it is so closely connected with chemical engineering that a brief outline of its scope may be found useful, and I will therefore attempt in the following pages to demonstrate on simple examples the principles which govern it, the lines on which it may be carried out, and the manner in which the knowledge gained by chemical work will influence the application of chemical engineering in the construction of plant.

The primary object which the technical chemist has before him is to produce on a manufacturing scale an article cheaper or better than has been done before, to utilise waste products to advantage, and to avoid or abate such effluents, whether gaseous, liquid, or solid, as may create a nuisance. He must therefore accustom himself to deal with large quantities, or, as it has been aptly expressed, to think in tons. To this should be added, that he must think, not only in equivalents, but in pounds, shillings, and pence, and to realise that he should be careful to attach the proper meaning to the term 'equivalent' when used in technical language.

To the laboratory student, *e.g.*, barium carbonate is BaCO_3 , sulphuric acid is H_2SO_4 , hydrochloric acid is HCl , and their equivalents are respectively 197, 98, and $2 \times 36.5 = 73$. In

order to neutralise 197 lbs. of barium carbonate it will therefore require the number of pounds of sulphuric acid or hydrochloric acid expressed by their equivalents. But in technical work we do not deal with pure substances, and therefore the equivalents have to be modified in the ratio of the impurities contained in the materials used. Thus, if we should have to operate on a native barium carbonate, and found that it contained only 95 per cent. of actual barium carbonate, if our sulphuric acid contained only 80 per cent. of actual sulphuric acid H_2SO_4 , and if our hydrochloric acid contained only 30 per cent. of actual HCl, then the proportions of materials which would be equivalent to each other would be as

$$\frac{197}{.95} : \frac{98}{.80} : \frac{73}{.30} = 207.4 : 122.5 : 243.3.$$

And if the prices for these articles were £5 per ton of crude barium carbonate 95 per cent., 30s. per ton of sulphuric acid 80 per cent., and 25s. per ton of hydrochloric acid 30 per cent., we should have to divide these prices by the same factors which we have used for their equivalents, and should then obtain the prices of the actual effective matter contained in them. We should then find that we have to pay £5, 5s. 6d. per ton for actual $BaCO_3$, 37s. 6d. per ton for actual H_2SO_4 , and 83s. 4d. per ton for actual HCl. This point will become clearer if we compare the prices of the same article in different degrees of purity or concentration. On page 142 we find the price for pure sulphuric monohydrate is £5, 10s.; that of ordinary 168° Tw. = 98 per cent. H_2SO_4 is £3, 5s., and that of 150° Tw. = 80 per cent. is £1, 12s. 6d. per ton. We should thus have to pay per ton of H_2SO_4 as follows:—in the monohydrate £5, 10s.; for acid of 168° Tw. $\frac{3.25}{.98} = £3, 6s. 4d.$, and for 150° Tw. $\frac{1.625}{.80} = £2, 0s. 7d.$; so that by neglecting to choose the cheapest acid we might pay from £1, 5s. 8d. to £3, 9s. 5d. too much per ton of H_2SO_4 if

it were immaterial for our purposes at what degree of purity or concentration we used our acid.

These considerations are important when the question arises as to which of several qualities of the same material at our disposal will be relatively the cheapest. But the lowest-priced goods are not always the cheapest; there may be impurities in the cheaper quality which in subsequent operations it might be found more costly to remove than if one had started from a purer though more expensive article. Ordinary hydrochloric acid, for instance, contains a considerable amount of iron and sulphuric acid, and in working it up these impurities may be more expensive to remove than if one had used pure hydrochloric acid at more than double the cost from the outset. As a practical instance we may mention the manufacture of aniline hydrochloride; here it is necessary to use a pure hydrochloric acid, as the crude article would yield an unsaleable product. Another instance is that of nitrate of soda in connection with the manufacture of nitric acid. For many purposes it is necessary to obtain a nitric acid as free as possible from chlorine compounds, and in these cases such parcels of nitrate are picked out as contain the least amount of sodium chloride, even though the price may be higher than that of a lower grade nitrate.

We may now proceed to the further question as to what it would cost to produce 1 ton of barium sulphate and of barium chloride from the materials we have mentioned above. Having regard only to the quantities of the chemicals which we use and their prices, without reference to what we might call mechanical expenses, that is, labour, plant, etc., we know that theoretically it takes 197 tons of carbonate of baryta to produce 233 tons of barium sulphate, but we have also found that with the barium carbonate at our disposal it will take 207.4 tons to produce 233 tons of sulphate of baryta of 100 per cent.

If the price of carbonate of baryta 95 per cent. is taken at

£5 per ton, it would cost 5×207.4 , that is, £1037 to produce 233 tons of barium sulphate, that is, £4.45 per ton. In the same way we find that it would take, not 98 tons of sulphuric acid, but 122.5 tons of our acid of 80 per cent. to produce 233 tons of barium sulphate, so that the cost of sulphuric acid per ton of barium sulphate produced, taking the sulphuric acid at £1, 12s. 6d. per ton, would be $122.5 \times 1.625 \div 233$, *i.e.* £.854 per ton of sulphate of baryta produced. If we now add up the cost of barium carbonate and sulphuric acid, that is, £4.45 + £.854, we get £5.304 as the cost of chemicals, of the quality and prices indicated above, necessary to produce 1 ton of barium sulphate. This calculation can be simplified, as it is not necessary to calculate the cost of each item separately, and in its simplified form it would stand as follows:—

| | |
|--|-------|
| Barium carbonate 95 per cent. = 207.4 tons | |
| @ £5 | £1037 |
| Sulphuric acid 80 per cent. = 122.5 tons | |
| @ £1.625 | 199 |
| | £1236 |

i.e. $1236.0 \div 233 = £5.304$ is the cost for chemicals per ton of barium sulphate. The calculation of cost for barium chloride with two equivalents of water of crystallisation, and having the formula $BaCl_2 + 2H_2O = 244$, will be easily understood from the following calculation:—

| | |
|--|----------|
| Barium carbonate 95 per cent. = 207.4 | |
| tons @ £5 | £1037.0 |
| Hydrochloric acid 30 per cent. = 243.3 | |
| tons @ £1, 10s. | 364.95 |
| | £1401.95 |

i.e. $\frac{1401.95}{244} = £5.745$ is the cost for chemicals per ton of crystallised barium chloride.

If the points to be considered in technical research were only those which have been given above, the matter would be extremely simple; but there are other factors which have not been touched upon so far, and which play a most important part in technical research. For it is not only necessary to consider the quantity of the impurities which the materials we are using contain, but it is even more essential that we should know exactly the nature of these impurities, and how far they will influence the quality and cost of the final product.

In order to show this, and in general to explain the course of a technical investigation, we will follow an extremely simple case of technical research through the laboratory experiments to its application on a large scale. The case we have taken is a purely hypothetical one, and the figures are arbitrarily chosen, so that the student may for himself obtain correct data by repeating the experiments on these lines.

We will assume that we have a source of cheap barium carbonate guaranteed to contain 95 per cent. of BaCO_3 delivered to us finely ground at £2, 10s. per ton. We will further assume that we can buy sufficient quantities of muriatic acid at £1, 10s. per ton delivered at the works, and that we are up to the present buying barium chloride at the rate of £6, 10s. per ton delivered at our works, of which we use 10 tons per week in another branch of our works. What will it cost to produce that quantity, and will it be cheaper to continue buying barium chloride or to make the article ourselves?

In taking up a problem involving technical research, a thorough knowledge of the general properties of the substances used and produced, and in particular a knowledge of the composition of these substances, is required. The former may be obtained from books, the latter can only become known by analysis. Further data will be necessary, which can only be ascertained by experiment, and it is these data which constitute the actual technical research. It is hardly necessary to state

that they vary in each case, and the example which we are giving is only intended to show the general principles which should guide us in the right direction, as applied to this particular example.

We will suppose that we have acquired such a knowledge of the properties of barium carbonate, hydrochloric acid, and barium chloride, by previous experience and by a careful study of the literature, as would justify us to proceed further in the matter. The first step in our research will then be to ascertain the exact qualities of the substances at our disposal. We should commence by analysing a fair average sample of our barium carbonate, and we might find that it contained—

| | |
|-----------------------------|----------------|
| BaCO ₃ | 95·0 per cent. |
| CaCO ₃ | 5·0 „ |
| | 100·0 „ |

On analysing our hydrochloric acid we will assume that we find it stands 30° Tw. = 1·15 sp. gr. and contains per litre—

| | |
|---|-------------|
| HCl | 290·0 grms. |
| H ₂ SO ₄ | 5·0 „ |
| Fe ₂ Cl ₆ | 1·0 „ |
| | 296·0 „ |

For every ton of our carbonate of baryta we shall require the following quantities of HCl:—

| | | |
|--|-----------------------------|-----------------|
| To saturate ·95 ton of BaCO ₃ | $\frac{·95 \times 73}{197}$ | = ·352 ton HCl. |
| To saturate ·05 ton of CaCO ₃ | $\frac{·05 \times 73}{100}$ | = ·00365 „ „ |
| Total . . . | ·35565 | „ „ |

Our hydrochloric acid contains sulphuric acid which will neutralise a certain quantity of barium and calcium carbonate :

as a matter of fact, whichever of the two constituents it may attack first, it will ultimately yield barium sulphate. The equivalent of 5 grms. of H_2SO_4 is $\frac{5 \times 73}{98} = 3.72$ grms. HCl, so that, calculated on its neutralising properties, our hydrochloric acid contains $290 + 3.72 = 293.72$ parts HCl in every 1150 parts by weight. It will therefore require

$$\frac{1150 \times .35565}{293.72} = 1.392 \text{ tons hydrochloric acid to neutralise one}$$

ton of our barium carbonate. We will now examine the result after neutralisation. Of the 1.392 tons of hydrochloric acid we find that $\frac{5 \times 100}{1150} = .435$ per cent. is there as H_2SO_4 , *i.e.*

$$.0061 \text{ ton } \text{H}_2\text{SO}_4 : \text{ this is equivalent to } \frac{197 \times .0061}{98} = .0122 \text{ ton}$$

BaCO_3 . We therefore have the following data. For every ton of barium carbonate used we have available for conversion into barium chloride $.95 - .0122 \text{ ton} = .9378 \text{ ton } \text{BaCO}_3$, which will require 1.392 tons of our hydrochloric acid, and should yield the theoretical quantity of $\frac{244 \times .9378}{197} = 1.162$ tons of $\text{BaCl}_2 + 2\text{H}_2\text{O}$.

We may now make a preliminary calculation as to the cost of chemicals in the process:—

| | | | |
|--|---|---|--------|
| 1 ton barium carbonate at £2, 10s. | . | . | £2.500 |
| 1.392 tons hydrochloric acid at £1, 10s. | . | . | 2.088 |
| | | | £4.588 |

$$\text{i.e. } £4.588 \div 1.162 = £3, 19\text{s. per ton } \text{BaCl}_2 + 2\text{H}_2\text{O}.$$

Besides barium chloride we obtain barium sulphate as an insoluble precipitate and calcium chloride in solution. We have now ascertained that, assuming that we had to pay £6, 10s. per ton for barium chloride, there would be a margin of £2, 11s.

per ton between the cost of chemicals and further expenses if we made it ourselves, and we might consider it worth our while to pursue the matter further.

In that case we should begin a series of experiments made on the actual products, and produce barium chloride from our raw materials in the laboratory. We should remember, first of all, that barium chloride is but slightly soluble in hydrochloric acid, and that we should, therefore, at no time have a large excess of acid present; further, that there is a hydrate of hydrochloric acid which contains 20·18 per cent. of HCl, and distils over as such at 110° C.; so that if we wish to avoid loss of HCl, we should always have less than 20 per cent. of it present and keep the temperature below 110° C.; and, lastly, that a saturated solution of barium chloride holds about 40 per cent. of the salt in solution, and that it will therefore be useless to try to obtain a stronger solution. But it might also occur to us whether it might not be possible to utilise the property of hydrochloric acid to throw down barium chloride from its aqueous solution, and whether we might not at some time find it advantageous to make our own hydrochloric acid and use it in the form of gas, for the double purpose of precipitating the barium chloride and leaving a solution containing sufficient HCl to serve for a further neutralising operation. This is a matter on which we cannot enter more fully here, but we mention it incidentally to show that it is not out of the question that reactions which sometimes appear to stand in the way of successful work may be turned to advantageous use, and should always receive due thought by being considered from every point of view.

We might now proceed to make a few experiments somewhat on the following lines:—

Experiment 1.—We should weigh into a basin 100 grammes of barium carbonate, and gradually add to it as much water as will ultimately produce, with the addition of hydrochloric acid,

a saturated solution of barium chloride. 100 grammes of barium carbonate will produce 116.2 grammes of $\text{BaCl}_2 + 2\text{H}_2\text{O}$; and as we know from text-books that 100 parts of water at 100°C . will dissolve 72 parts of $\text{BaCl}_2 + 2\text{H}_2\text{O}$, it follows that 116 grammes of $\text{BaCl}_2 + 2\text{H}_2\text{O}$ will require for solution 162 grammes of water. We have found that 100 grammes of our barium carbonate will require 139 grammes of our hydrochloric acid, which contains actual HCl 35.6 grammes and $139 - 35.6 = 103.4$ grammes of water. Of this water there will be required $\frac{36 \times 116.2}{244} = 17.1$ grammes to provide for the water

of crystallisation, so that we have left available water for dissolving the barium chloride $103.4 - 17.1 = 86.3$ grammes. As we require altogether 162 c.c. H_2O for our purpose, we must mix our barium carbonate with $162 - 86.3 = 75.7$ grammes of water before adding the hydrochloric acid.

We therefore add to the 100 grammes of our barium carbonate about 80 c.c. of water and heat up to about 100°C . We then add gradually 139 grammes, or by measure 120 c.c., of our hydrochloric acid, and carry on this operation until no more CO_2 is evolved, noting the time it takes to do so and how far the froth rises at its maximum. The point which we now have to determine is how to deal with the iron, which, being contained in the hydrochloric acid, might contaminate our finished product. We have two courses open to us. We may either use an excess of acid, and thus keep the iron in solution; in that case it would gradually accumulate in subsequent operations, and ultimately adhere in objectionable quantities to the crystals of barium chloride. The other course, and the preferable one, would be to try to eliminate it altogether. This might be done in many ways, by adding ammonia, or caustic soda, or ferrocyanide of potassium or sodium, but the use of either of these substances would introduce further foreign matters. We might, however, remember that barium carbonate precipitates ferric hydrate

from its soluble compounds, and we shall probably find that if we add an excess of barium carbonate, we may neglect this small excess of barium carbonate in our calculations, as it would yield its equivalent as barium chloride, which is of greater commercial value.

We have now obtained a nearly saturated hot solution of barium chloride, which we filter through a hot funnel, leaving the filtrate to crystallise. We finally collect, drain, and weigh the crystals of barium chloride, measure the mother-liquor, and determine its specific gravity.

Experiment 2.—In order to explain another point of interest, we will assume that the mother-liquor from the first experiment measures 160 c.c. This mother-liquor will contain a certain amount of calcium chloride, say 8.5 grammes, besides a considerable amount of barium chloride. By boiling it down, we should arrive at a point at which the maximum quantity of the latter would crystallise out. But in order to save fuel when applying our experiments to work on a large scale, we might use half the mother-liquor, *i.e.* 80 c.c., instead of water, to mix with the next lot of barium carbonate, and add the hydrochloric acid to that mixture. After filtering and crystallising we should again obtain 160 c.c. of mother-liquor, which would now contain $8.5 + 4.25 = 12.75$ grammes CaCl_2 . It can be easily seen that however long we continue this proceeding our mother-liquor could never contain more than twice the original quantity of $\text{CaCl}_2 = 17$ grammes in the 160 c.c., for here we have a geometrical progression $8.5\left(1 + \frac{1}{2} + \frac{1}{2^2} + \dots + \frac{1}{2^\infty}\right)$ which adds up to 2×8.5 . If we therefore ascertained by a separate experiment that the presence of that quantity of calcium chloride had no detrimental effect on the quality of the barium chloride produced, we could save half the cost of evaporation by using half the mother-liquor as described above in the mixing operation in the place of water.

Making a series of experiments on these lines, we shall arrive at such data as will give us a fair idea as to what will be the actual yield in practice of barium chloride. We will assume that we find it 95 per cent. of the yield which we calculated. In order not to complicate matters, we will also assume that we do not take into consideration the final mother-liquors, which still contain some barium chloride and considerable quantities of calcium chloride. We may now consider what plant we shall require on a large scale in order to carry out the different operations.

For a production of 10 tons per week we must produce 2 tons of barium chloride per day; 1.162 tons of barium chloride is equal to 1 ton of our carbonate of baryta, or, taking off 5 per cent. for loss in working, 1.104 tons barium chloride will be obtained for every ton of barium carbonate, and for every 1.392 tons of hydrochloric acid used. We require, therefore, for every 2 tons of barium chloride—

| | | | | | |
|-------------------|---|---|---|---|------------|
| Barium carbonate | . | . | . | . | 1.812 tons |
| Hydrochloric acid | . | . | . | . | 2.521 „ |

The 2.521 tons of hydrochloric acid equal 5649 lbs. at 1.15 sp. gr. = 491.2 gallons. We found in Experiment 1 that we had to add 75.7 grammes water extra for every gramme of barium carbonate; this, calculated on 1.812 tons or 4059 lbs., comes to 3073 lbs. = 307 gallons of water. The final bulk of our liquor will therefore come to nearly 800 gallons; and, allowing for frothing, we should require a vessel to hold at least 1200 gallons if we wanted to mix each day's work in one batch. We have calculated these quantities so as to show how to perform these calculations; the safest and most reliable way will, however, be to take the actual quantities as obtained in Experiment 1, and calculate them on the basis of 2 tons barium chloride per day. We will assume that the two sets of figures agree, and we shall next have to settle the question as to the means by which we

are going to heat up the mixture of hydrochloric acid and barium carbonate, and of what material we shall have to make the vessel in which this is done.

Without taking into consideration the initial temperature and specific heat of the solid and liquid matter, radiation and other points, we should require about $\frac{8000 \times 100}{2.2} = 368,200$

Calories in order to heat 800 gallons of water to 100° C. Taking the heating power of good coal at about 7000 Calories, we should only want 52.6 kgs. = 115 lbs. of coal for this purpose. Although the operation might only take six hours, a labourer would have to attend to the fires long before the work could be started properly, as the flues would cool down considerably in the interval between two operations. It will probably save labour and be more advantageous in other respects if in this instance we use steam instead of an open fire, especially if there should be waste steam from an engine or from other sources at our disposal.

Having decided on the use of steam, the next question to be decided will be whether to use live or confined steam? Here, again, we have to consider that, on account of the frothing caused by the evolution of CO₂, we must take our time over the mixing operation. We shall therefore have considerable loss of heat due to radiation, so that we shall require far more steam for heating than the theoretical calculation will show, and therefore have a corresponding excess of condensed steam, *i.e.* in the last instance of mother-liquor, to deal with. We may therefore be justified in assuming that confined steam will probably be the most economical way of applying heat in the mixing operation.

Although, by taking care that we always have an excess of barium carbonate present, we might use an iron coil for conveying heat to the mixing operation, yet the slightest shortage would cause the iron to be attacked by the acid. We should

run far less risk if we made the coil of lead, and an experiment should now be made to ascertain whether it would be safe to use lead in the construction of this apparatus, by conducting an operation in the laboratory similar to the one described in Experiment 1, but having several pieces of lead at the bottom of the basin whilst neutralising. The acid should be run to the top of the mixture, so as to be nearly neutralised when it reaches the bottom of the dish. We will assume that the experiment turned out satisfactorily, and that we decided, subject to further experiments to be considered later on, to adopt the use of a lead coil for heating.

We have, roughly speaking, about 400 gallons of liquor to commence with, which, in the course of an operation lasting about six hours, will be increased to 800 gallons. We shall require the preliminary heating up of 400 gallons of liquid, to be performed as quickly as possible, say in an hour; therefore the dimensions of the lead coil will be calculated on that basis, taking also into account the heat required for the heating up of the 4059 lbs. of barium carbonate. To obtain the latter item we shall have to determine the specific heat of BaCO_3 , and will assume it to be .2, in which case it would require as much heat as 80 gallons of water. We have then 480 gallons = 2177 litres, which we assume have to be heated up from 0° to 100° C., and which will require 217,700 Calories. It is known that 1 square metre of copper tubing will transmit from 1000 to 1500 Calories per hour for every degree rise in temperature. Taking the average at 1200 Calories, we should require for a rise of 100° say about 1.8 square metres of copper pipe. For lead pipe, in such conditions as we have here, the effect would only be about one-third, so that we should want 5.4 sq. m. Assuming the diameter of our pipe to be 6 centimetres, its length would be 29 metres; or, in other words, for a lead coil of $2\frac{1}{2}$ inches diameter, we should require piping amounting to 95 feet in length.

The size of the mixing vessel must be such as to allow for frothing; if 7 feet in height, 3 feet of this should be allowed for frothing and the space taken up by the coil, so that we have to calculate what cylindrical vessel 4 feet high will hold 800 gallons, or 128.3 cub. ft. If we place these figures in the formula for the volume of a cylinder we have $d = \sqrt{\frac{128.3}{\pi}} = 6.4$

feet. We shall therefore have for the dimensions of the mixing vessel 6 ft. 5 ins. in diameter and 7 ft. in height, and with these dimensions the 95 ft. of lead pipe would give us nearly five windings in the coil. This vessel might be made of lead, wood, or enamelled iron, or might be built in brick. The objection to lead would be, that it might be attacked at the top, where the strong acid could come in contact with it; the objection to wood, that the calcium chloride in the liquors might ooze through it; and to enamelled iron, that the enamel might chip off. The ultimate choice would lie between wood and brick, and the question which to choose could only be satisfactorily determined by an experiment on a small works scale. It is at this stage that the student will miss the workshop, in which he could make such an experiment.

We will assume that we had made these experiments in the workshop; that we had found that bricks set in good Portland cement would withstand the action of our liquids, and that we decided to build a tank 6 ft. 5 ins. in diameter and 7 ft. high. We have from the outset assumed that the tank must be circular, because we had in our minds that we should have to provide it with an agitator. We should now draw a complete plan of the apparatus for mixing, including wooden agitator, how it is fixed, how geared, showing the steam coil with steam trap, the running-off tap, the supply of hydrochloric acid, and means of carrying off the poisonous vapours of CO_2 ,—in fact, everything that would be necessary to conduct the operations safely, economically, and efficiently.

We shall have, in like manner, to consider the construction of each apparatus that will be used in the further stages of manufacture. But it would exceed the purpose and limit of this book to go further into the details of the many points which have to be taken into account, and in which the student should be guided and checked by a master who combines the necessary knowledge with practical experience. It must suffice to indicate that the plant for each operation has to be drawn to scale, including filtering apparatus, boiling-down plant, storage vessels for mother-liquors, crystallising vessels, etc. In each case the material of which the vessel or apparatus has to be made will have to be carefully chosen, and its suitability, where necessary, must be ascertained by experiment in the laboratory. When all the details have been worked out, a general plan of the manner in which the apparatus is to be arranged is to be drawn on lines which involve the least amount of cost in shifting the solids and liquids, making use, wherever possible, of natural gravitation. The connections with the boiler, with shafting, etc., will have to be drawn in; and where a certain piece of ground is given in which the work is to be performed, the plant has to be adapted to its size and shape. If a building has to be erected for the housing of a plant, it must be designed so as to suit the ground and the plant. Finally, an estimate of the cost of plant must be made, and specifications of work and materials required written out.

We have taken pains to find one of the simplest instances of technical research as an example, and yet it will be seen that there is a very large amount of thought and work involved in carrying it through. In order to simplify our explanations, we have not even taken into consideration that use might be made of the carbonic acid evolved, and that the final mother-liquor and the barium sulphate formed must be dealt with. Even as far as we have gone we have not completed our work, for only after getting all our data together are we able to calculate

approximately what it will actually cost to produce 10 tons of barium chloride per week.

We will assume that the plant required will cost £1000, and that it will depreciate to the extent of 10 per cent. per annum ; in that case we have to distribute £100, over 500 tons of barium chloride = 4s. per ton. In like manner we should deal with the other items, and might obtain a weekly estimate somewhat as follows:—

| | | | |
|--|-----|----|-----|
| Depreciation on plant 10 per cent. | £2 | 0 | 0 |
| Labour, three men at 25s. | 3 | 15 | 0 |
| Coal (total, including steam) | 2 | 0 | 0 |
| Water | 0 | 3 | 0 |
| Gas | 0 | 2 | 0 |
| Office expenses (apportioned) | 1 | 0 | 0 |
| Laboratory | 0 | 10 | 0 |
| Sundries | 0 | 10 | 0 |
| | £10 | | 0 0 |

So that we should have to add to the cost of chemicals, £1 per ton, the total cost being thus brought to $\frac{£3, 19s.}{.95} + £1 = £5, 3s. 2d.$ per ton of barium chloride. Other charges of purely financial and commercial items should be added to this, but it would lead too far to discuss them here.

Many simple examples of technical research could be found which, treated in a similar manner, would be instructive. Other never-failing sources of themes are supplied by the patent literature, and many interesting investigations could be submitted to students if they were taught to carry out the process as described in the patent specifications ; and a student who, under a competent master, had carried on technical research of this kind for twelve months, or even less, should, after leaving college, gain as much experience in one year's work in a factory as it would otherwise take him five years or more to acquire.

CONCLUSION.

To keep within the limits of an elementary book, it has been necessary to touch only lightly on many important subjects and to omit others, a knowledge of which would be useful to advanced students. Apart from intentional omissions (such as, for instance, the subject of electro-chemical technics, of which only a few special branches are sufficiently known, and in which it would be too early to generalise), there will, no doubt, be noticed omissions, due to this being a first attempt at representing the subject in a somewhat novel form. The author will be grateful for suggestions as to how this book may be improved.

The measurements have, as far as practicable, been given in the metric system, which all students of chemistry should be familiar with. Where it was necessary to state the ultimate results in English measurements, we have purposely made the preliminary calculations in the metric system, and converted the final results into English measurements.

The calculations incidental to the text have been made by means of Fuller's ingenious slide rule, which, being equal to an ordinary slide rule of 41 ft. 8 ins. in length, gives accurate results with a great saving of time. In some cases Boucher's calculating circle with a dial of 5 inches diameter has been used, which is even more convenient than, though not as accurate as, Fuller's instrument. In the author's opinion, every student should at an early stage be accustomed to work with these instruments; if he can only save half an hour a day by using them, he will, apart from being able to utilise the time thus saved, be induced to make calculations which, on account of their tediousness, he would not otherwise perform.

Tables of prices of chemicals and of a few materials have been added, but it will be clearly understood that the figures given must not be taken as absolute. The values of chemicals

and other commodities are liable to frequent fluctuations; still, with the reservations expressed here, it will be better that the student should have some idea of prices than none at all.

CURRENT PRICES OF CHEMICALS AND MATERIALS.

| | £ | s. | d. |
|---|--------------------------|----|------------------|
| Acid, Acetic, 25 per cent. per cwt. | 0 | 6 | 9 |
| „ „ 40 per cent. „ „ | 0 | 9 | 3 |
| „ „ glacial „ „ | 1 | 11 | 6 |
| „ Arsenic, S.G. 2·000 „ „ | 1 | 0 | 0 |
| „ Benzoic, ex gum „ lb. | 0 | 2 | 9 |
| „ Boracic „ cwt. | 22/ to 24/ | | |
| „ Butyric, pure concentrated 50 per cent. „ lb. | 0 | 1 | 4 |
| „ „ 80 per cent. „ „ | 0 | 1 | 10 |
| „ „ absolute „ „ | 0 | 3 | 0 |
| „ Carbohc, crude 60° „ „ | 0 | 1 | 10 |
| „ „ crystallised 40° „ „ | 0 | 0 | 6 $\frac{1}{4}$ |
| „ „ liquid 95/97 per cent. „ gall. | 0 | 0 | 9 |
| „ Formic, 40 per cent. „ cwt. | 1 | 7 | 6 |
| „ „ 65 per cent. „ „ | 2 | 0 | 0 |
| „ „ 90 per cent. „ „ | 2 | 10 | 0 |
| „ Gallic, pure crystals „ lb. | 0 | 1 | 11 |
| „ Hydrofluoric „ „ | 0 | 0 | 3 $\frac{3}{4}$ |
| „ Muriatic (Tower Salts), 30° Tw. per bot. (1 cwt.) | 1/6 to 1/9 | | |
| „ „ (Cylinder), 30° Tw. „ | 0 | 3 | 0 |
| „ Nitric, 80° Tw. per lb. | 0 | 0 | 1 $\frac{1}{2}$ |
| „ Nitrous „ „ | 0 | 0 | 1 $\frac{1}{2}$ |
| „ Oxalic „ „ | 0 | 0 | 2 $\frac{1}{2}$ |
| „ Picric „ „ | 0 | 0 | 11 $\frac{1}{2}$ |
| „ Phosphoric, 1·750 „ „ | 0 | 0 | 9 $\frac{3}{4}$ |
| „ Salicylic, powder „ „ | /10 $\frac{1}{2}$ to 1/2 | | |
| „ „ crystals „ „ | 1/0 $\frac{1}{2}$ to 1/4 | | |
| „ Sulphuric (fuming 50 per cent.) . . . „ ton | 15 | 10 | 0 |
| „ „ (monohydrate) „ „ | 5 | 10 | 0 |
| „ „ (Pyrites, 168° Tw.) „ „ | 3 | 5 | 0 |
| „ „ („ 150° Tw.) „ „ | 1 | 12 | 6 |
| „ „ (free from arsenic, 145° Tw.) „ „ | 1 | 15 | 0 |
| „ Sulphurous (solution) S.G. 1·025 . . . „ „ | 3 | 0 | 0 |

| | | £ | s. | d. |
|--|-----------|-----|----|-----------------|
| Acid, Tannic, commercial I. | per cwt. | 4 | 17 | 6 |
| " " " II. | " " | 6 | 6 | 0 |
| " " pure | " lb. | 0 | 1 | 4 |
| " Tartaric | " " | 0 | 1 | 0 |
| " Valerianic, trihydrated | " " | 0 | 4 | 3 |
| " " monohydrated | " " | 0 | 4 | 9 |
| Aldehyde, 75 per cent. | " " | 0 | 1 | 3 $\frac{1}{2}$ |
| Alizarine, 20 per cent. | " " | 0 | 0 | 7 $\frac{1}{2}$ |
| Alum, loose lump | " ton | 5 | 2 | 6 |
| Alumina Sulphate (pure) | " " | 3 | 17 | 6 |
| " Hydrate, | " cwt. | 0 | 14 | 0 |
| Alumino-ferric cake | " ton | 2 | 5 | 0 |
| Aluminium (ingot metal, 98/99 $\frac{3}{4}$ per cent.) | " " | 148 | 0 | 0 |
| Ammonia, Anhydrous | " lb. | 0 | 1 | 5 |
| " 880 = 28° B | " " | 0 | 0 | 2 $\frac{3}{4}$ |
| " = 24° B | " " | 0 | 0 | 1 $\frac{1}{2}$ |
| " Carbonate | " " | 0 | 0 | 3 $\frac{3}{4}$ |
| " Fluoride | " " | 0 | 1 | 1 |
| " Muriate | " ton | 22 | 10 | 0 |
| " " (sal-ammoniac) 1st | " cwt. | 1 | 19 | 0 |
| " " " 2nd | " " | 1 | 17 | 0 |
| " Nitrate | " ton | 34 | 0 | 0 |
| " Oxalate | " lb. | 0 | 0 | 5 |
| " Phosphate | " " | 0 | 0 | 4 $\frac{1}{4}$ |
| " Sulphate (grey), London | " ton | 11 | 7 | 6 |
| " " " Hull | " " | 11 | 5 | 0 |
| " Vanadate | " lb. | 1 | 1 | 6 |
| Amyl Acetate, pure | " " | 4 | 14 | 6 |
| Aniline Oil, (pure) | " " | 0 | 0 | 4 $\frac{1}{2}$ |
| " Salt | " " | 0 | 0 | 4 $\frac{1}{4}$ |
| Anthracene, 30 per cent. per unit | " " | 0 | 0 | 2 |
| Antimony Metal | " ton | 31 | 0 | 0 |
| " Bifluoride, 66 per cent. Oxide Antimony | " lb. | 0 | 0 | 7 |
| " Oxide, white | " cwt. | 1 | 14 | 0 |
| Antimony (Tartar Emetic). | " lb. | 0 | 0 | 7 $\frac{1}{2}$ |
| " Sulphide | " " | 0 | 0 | 10 |
| Arsenic, red | " cwt. | 1 | 15 | 0 |
| " white powdered | " ton | 15 | 10 | 0 |
| Barium, Chloride calcined | " cwt. | 0 | 6 | 3 |
| " " crystals | " " | 0 | 6 | 3 |
| " Carbonate (native), 92/94 per cent. | " ton | 5 | 0 | 0 |
| " Hydrate | " cwt. | 10/ | to | 11/ |

| | | £ | s. | d. |
|--|----------|-----|---------|-----------------|
| Barium, Nitrate | per cwt. | 0 | 17 | 6 |
| „ Peroxide, 80/85 per cent. | „ „ | 2 | 0 | 0 |
| „ Sulphate (native levigated) | „ ton | 40/ | to 60/ | |
| „ Sulphide | „ cwt. | 0 | 5 | 0 |
| Benzol, 90's | „ gall. | 0 | 0 | 11 |
| „ 50/90 | „ „ | 0 | 0 | 10 |
| Bisulphide of Carbon | „ ton | 17 | 10 | 0 |
| Birch Oil | „ lb. | 0 | 0 | 2 $\frac{3}{4}$ |
| Bleaching Powder, 35 per cent. | „ ton | 6 | 7 | 6 |
| „ Líquor, 7 per cent. | „ „ | 3 | 10 | 0 |
| Borax | „ cwt. | 0 | 13 | 0 |
| Butyl, Acetate | „ lb. | 0 | 2 | 6 |
| „ Benzoate | „ „ | 0 | 7 | 0 |
| „ Butyrate | „ „ | 0 | 6 | 6 |
| „ Valerianate | „ „ | 0 | 6 | 0 |
| Calcium Chloride | „ ton | 2 | 17 | 6 |
| „ Oxide from marble | „ cwt. | 0 | 10 | 0 |
| „ Sulphite | „ „ | 1 | 0 | 0 |
| Chalk, precipitated | „ „ | 0 | 9 | 0 |
| China Clay (at Runcorn), in bulk | „ ton | 20/ | to 27/6 | |
| Chloral, Chloroform | „ lb. | 0 | 2 | 6 |
| „ Hydrate, tablets | „ „ | 0 | 1 | 7 |
| „ „ crystals | „ „ | 0 | 1 | 10 |
| Chromium Acetate (crystal) | „ „ | 0 | 0 | 6 $\frac{1}{4}$ |
| Copper | „ ton | 48 | 10 | 0 |
| „ Oxide (copper scales) | „ „ | 50 | 0 | 0 |
| „ Sulphate | „ „ | 18 | 15 | 0 |
| Creosote (ordinary), naked | „ gall. | 0 | 0 | 1 $\frac{1}{2}$ |
| „ (filtered for Lucigen light) | „ „ | 0 | 0 | 2 $\frac{1}{4}$ |
| „ from beechwood tar | „ lb. | 0 | 2 | 4 |
| Formaldehyde, 40 per cent. | „ cwt. | 2 | 12 | 6 |
| Glucose Chips | „ „ | 0 | 13 | 0 |
| Glycerine (crude), 80 per cent. | „ ton | 28 | 0 | 0 |
| „ (distilled, S.G. 1260) | „ „ | 60 | 0 | 0 |
| Grease Oils, 18° Tw. | „ „ | 3 | 0 | 0 |
| Iodine | „ oz. | 0 | 0 | 6 |
| Iron Chloride | „ cwt. | 0 | 19 | 0 |
| „ Sulphate (Copperas) | „ ton | 1 | 15 | 0 |
| „ Sulphide | „ „ | 3 | 10 | 0 |
| Lead (sheet) | „ „ | 12 | 15 | 0 |
| „ Acetate (white, <i>ex ship</i>) | „ „ | 24 | 10 | 0 |
| „ „ (brown, „) | „ „ | 16 | 0 | 0 |

| | | £ | s. | d. |
|--|----------|-----|--------|----|
| Lead, Borate | per cwt. | 3 | 13 | 0 |
| „ Carbonate (white lead), pure | „ ton | 19 | 10 | 0 |
| „ Linoleate | „ cwt. | 2 | 3 | 0 |
| „ Litharge Flake (<i>ex ship</i>) | „ ton | 14 | 0 | 0 |
| „ Nitrate | „ „ | 22 | 0 | 0 |
| „ Peroxide | „ „ | 2 | 5 | 0 |
| „ Resinate | „ „ | 19/ | to 30/ | |
| „ White | „ „ | 0 | 16 | 0 |
| Lime Acetate (brown, <i>ex ship</i>) | „ „ | 5 | 5 | 0 |
| „ „ (grey „) | „ „ | 7 | 2 | 6 |
| Magenta | „ lb. | 0 | 2 | 6 |
| Magnesium (ribbon and wire) | „ oz. | 0 | 1 | 6 |
| „ Chloride | „ ton | 3 | 5 | 0 |
| „ Carbonate | „ cwt. | 1 | 17 | 6 |
| „ Calcined Magnesia | „ ton | 15 | 10 | 0 |
| Magnesium Sulphate (Epsom Salts) | „ „ | 3 | 2 | 6 |
| Manganese Ore, 70 per cent. | „ „ | 3 | 10 | 0 |
| „ Borate | „ cwt. | 2 | 0 | 0 |
| „ Oxide, black | „ „ | 0 | 6 | 6 |
| „ Peroxide, pure artific. | „ lb. | 0 | 2 | 6 |
| „ Resinate, fused | „ cwt. | 0 | 19 | 0 |
| „ „ precipitated | „ „ | 1 | 10 | 0 |
| „ Sulphate, 95 per cent. | „ ton | 18 | 0 | 0 |
| „ „ technical powder | „ cwt. | 0 | 16 | 6 |
| Methyl Benzoate | „ „ | 0 | 3 | 9 |
| „ Butyrate | „ „ | 0 | 4 | 0 |
| „ Salicylate | „ „ | 0 | 3 | 0 |
| „ Valerianate | „ „ | 0 | 6 | 6 |
| Methylated Spirit, 61° O.P. | „ gall. | 0 | 2 | 1 |
| Naphtha (crude), from coal tar, 30 per cent. at 120° C. | „ „ | 0 | 0 | 4 |
| „ solvent, from coal tar, 90 per cent. at 160° | „ „ | 0 | 1 | 0 |
| „ (wood), solvent | „ „ | 0 | 2 | 4 |
| „ „ miscible, 60° O.P. | „ „ | 0 | 3 | 6 |
| Nickel Sulphate | „ cwt. | 2 | 8 | 0 |
| „ „ and Ammonia | „ „ | 2 | 2 | 0 |
| Oil, Cotton-seed | „ ton | 24 | 5 | 0 |
| „ Linseed | „ „ | 31 | 0 | 0 |
| „ Stearine | „ „ | 28 | 0 | 0 |
| Paraldehyde | „ lb. | 0 | 4 | 0 |
| Pepsin, Porci, R.P. | „ „ | 0 | 18 | 0 |

| | | £ | s. | d. |
|--|---------|-----|----|--------------------------------|
| Phosphorus (red) | per lb. | 0 | 2 | 0 |
| „ (yellow) | „ „ | 0 | 1 | 3 |
| Pitch | „ ton | 1 | 16 | 0 |
| Potassium Bicarbonate | „ cwt. | 1 | 5 | 0 |
| „ Bichromate | „ lb. | 0 | 0 | 3 |
| „ Bisulphite, 50/55 per cent. | „ cwt. | 2 | 0 | 0 |
| „ Carbonate, 90 per cent. (<i>ex ship</i>) | „ ton | 15 | 15 | 0 |
| „ Chlorate | „ lb. | 0 | 0 | 3 |
| „ Cyanide, 98 per cent. | „ „ | 0 | 0 | 8½ |
| „ Fluoride, neutral | „ „ | 0 | 1 | 0 |
| „ „ bi | „ „ | 0 | 1 | 1 |
| „ Hydrate (caustic potash), 90 p. cent. | „ ton | 25 | 0 | 0 |
| „ „ „ 75/80 p. cent. | „ „ | 21 | 0 | 0 |
| „ Potash Hydrate, liquid, 50 p. cent. | „ „ | 13 | 5 | 0 |
| „ Muriate, 80 per cent. (<i>ex ship</i>) | „ „ | 8 | 10 | 0 |
| „ Nitrate (refined) | „ „ | 20 | 10 | 0 |
| „ Oxalate, neutral | „ lb. | 0 | 0 | 3¾ |
| „ Permanganate (small crystals) | „ cwt. | 2 | 0 | 0 |
| „ „ „ (large crystals) | „ „ | 1 | 15 | 0 |
| „ „ „ (large crystals) | „ „ | 2 | 0 | 0 |
| „ Prussiate (yellow) | „ lb. | 0 | 0 | 5¼ |
| „ Sulphate, 90 per cent. (<i>ex ship</i>) | „ ton | 9 | 10 | 0 |
| „ „ (Kainit) | „ „ | 2 | 10 | 0 |
| Pumice Powder | „ cwt. | 0 | 5 | 0 |
| Silver (metal) | „ oz. | 0 | 2 | 1 ⁹ / ₁₆ |
| Sodium (metal) | „ lb. | 0 | 2 | 0 |
| „ Acetate (<i>ex ship</i>) | „ ton | 13 | 0 | 0 |
| „ Arseniate, 45 per cent. | „ „ | 11 | 0 | 0 |
| „ Benzoate | „ lb. | 0 | 2 | 2 |
| „ Bicarbonate (cwt. kegs) | „ ton | 6 | 12 | 6 |
| „ Bichromate | „ lb. | 0 | 0 | 2¼ |
| „ Bisulphite, powder | „ cwt. | 0 | 15 | 0 |
| „ „ crystals | „ „ | 1 | 5 | 0 |
| „ Borate, free from silver | „ lb. | 2/ | to | 2/6 |
| „ „ (borax) crystals | „ ton | 13 | 0 | 0 |
| „ Carb. (alkali), 58 per cent. (bags) | „ „ | 4 | 12 | 6 |
| „ „ (caustic soda-ash), 48 p. cent. | „ „ | 5 | 5 | 0 |
| „ „ (refined „), „ „ | „ „ | 5 | 15 | 0 |
| „ „ (soda crystals) | „ „ | 3 | 0 | 0 |
| „ Chlorate | „ lb. | 0 | 0 | 3⅛ |
| „ Fluoride | „ „ | 5d. | to | 6d. |
| „ Bifluoride, | „ „ | 0 | 0 | 7 |

| | | £ | s. | d. |
|--|---------|-----|----|-------------------------------|
| Sodium Hydrate (60 per cent. caustic soda) | per ton | 8 | 15 | 0 |
| „ „ (70 per cent. caustic soda) | „ „ | 9 | 15 | 0 |
| „ „ (74 per cent. caustic soda) | „ „ | 10 | 5 | 0 |
| „ „ (76 per cent. caustic soda) | „ „ | 10 | 10 | 0 |
| „ „ (77 to 78 per cent. powdered) | „ „ | 13 | 5 | 0 |
| „ „ (99 p. cent. hydrate) | „ „ | 5 | 0 | 0 |
| „ „ (pure liquor, 90° Tw.) | „ „ | 7 | 10 | 0 |
| „ Hyposulphite | „ „ | 17 | 10 | 0 |
| „ Manganate, 25 per cent. | „ „ | 0 | 9 | 9 |
| „ Nitrate (95 p. cent. <i>ex ship</i> , Liverpool) | „ cwt. | 26 | 15 | 0 |
| „ Nitrite, 98 per cent. | „ ton | 9 | 12 | 6 |
| „ Phosphate | „ „ | 0 | 0 | 4 ¹ / ₈ |
| „ Prussiate (ferrocyanide) | „ lb. | 0 | 1 | 2 |
| „ Salicylate, powder | „ „ | 0 | 1 | 4 |
| „ „ crystals | „ „ | 4 | 15 | 0 |
| „ Silicate (glass) | „ ton | 3 | 15 | 0 |
| „ „ (liquid, 100° Tw.) | „ „ | 3 | 15 | 0 |
| „ Stannate, 40 per cent. | „ cwt. | 1 | 6 | 0 |
| „ Sulphate (salt-cake) | „ ton | 1 | 7 | 6 |
| „ „ (Glauber's salts) | „ „ | 7 | 5 | 0 |
| „ Sulphide (crystals) | „ „ | 5 | 10 | 0 |
| „ Sulphite | „ „ | 9 | 10 | 0 |
| Strontium Hydrate, 100 per cent. | „ „ | 0 | 0 | 6 |
| Sulphocyanide Ammonium, 95 per cent. | „ lb. | 0 | 0 | 4 |
| „ „ Barium, 95 per cent. | „ „ | 0 | 0 | 7 ¹ / ₂ |
| „ „ Potassium | „ „ | 5 | 0 | 0 |
| Sulphur, Brimstone, best quality | „ ton | 6 | 10 | 0 |
| „ „ Flowers | „ „ | 6 | 0 | 0 |
| „ „ (Roll Brimstone) | „ „ | 2 | 5 | 0 |
| Superphosphate of Lime (26 per cent.) | „ „ | 33 | 0 | 0 |
| Tallow | „ „ | 0 | 0 | 7 ¹ / ₄ |
| Tin Crystals | „ lb. | 110 | 10 | 0 |
| „ „ English, ingots | „ ton | 0 | 2 | 1 ¹ / ₂ |
| Vermilion | „ lb. | 16 | 15 | 0 |
| Zinc (Spelter) | „ ton | 6 | 0 | 0 |
| „ „ Chloride (solution, 100° Tw.) | „ „ | 6 | 0 | 0 |
| „ „ Sulphate, crystals | „ „ | 6 | 0 | 0 |

¹ Free on board.

Materials used in Construction.

| | | | | |
|---|---|---------|-----------|--------------|
| Cast-Iron, crude, pig, fluctuating | . | per ton | from | £2 10 0 |
| „ „ ordinary large castings | . | „ „ | „ | £5 to £7 |
| „ „ small castings and complicated patterns | . | „ „ | „ | £7 to £20 |
| „ „ enamelled | . | „ „ | „ | £20 to £30 |
| Copper, crude, varies | . | „ „ | „ | £40 to £80 |
| „ to the market price add for plates | . | „ „ | about | £15 0 0 |
| „ „ „ „ tubes | . | „ „ | „ | £30 0 0 |
| Lead, crude | . | „ „ | from | £11 0 0 |
| „ sheet | . | „ „ | „ | £14 to £16 |
| Tin, fluctuates much | . | „ „ | „ | £110 to £150 |
| Lime | . | „ „ | about | 12/ to 16/ |
| Cement | . | „ „ | „ | £2 0 0 |
| Bricks | . | „ | 1000 | 20/ to 25/ |
| Firebricks | . | „ „ | „ | £4 0 0 |
| Coal | . | „ | ton about | 10/ to 15/ |
| Coke | . | „ „ | „ | £0 12 0 |



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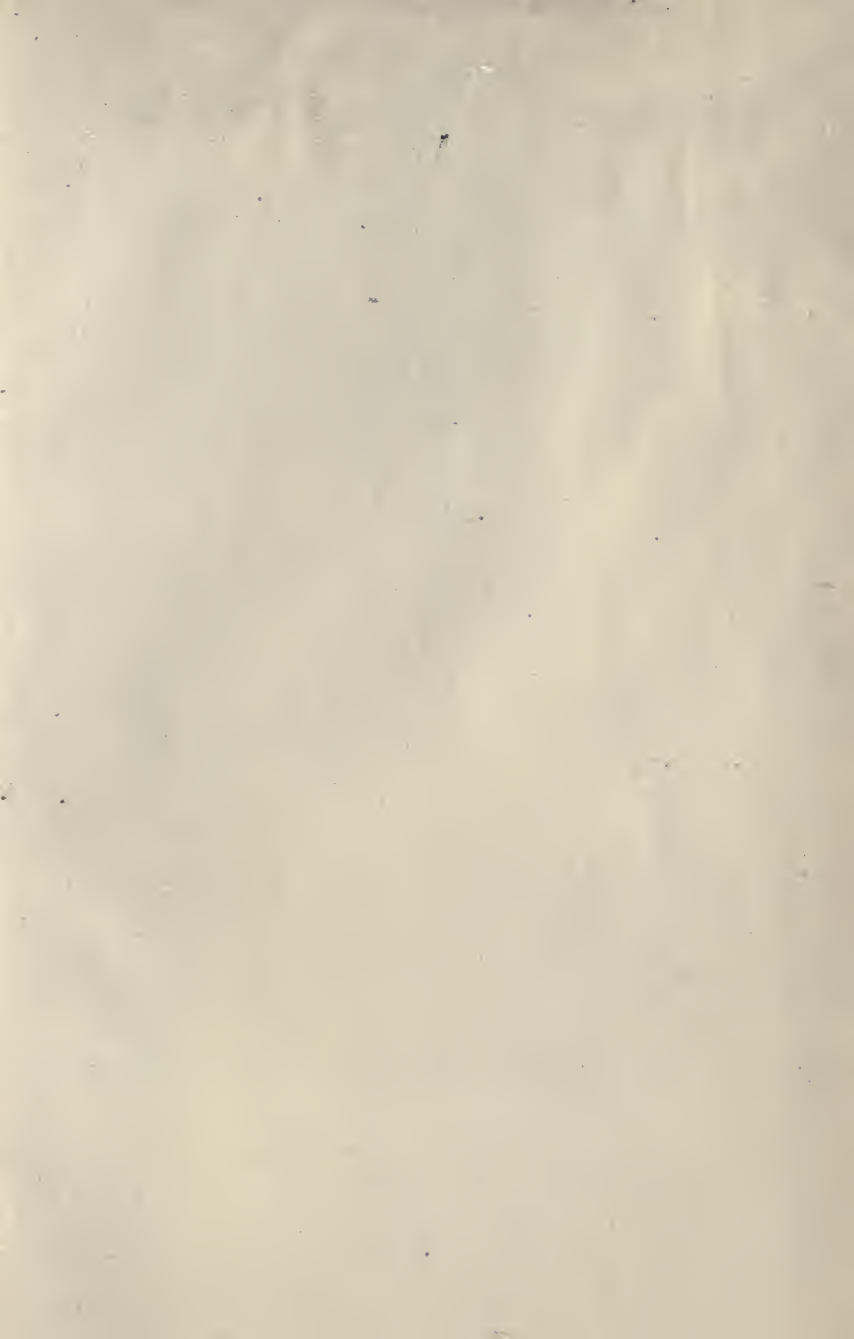
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