CHAPTER II.

BASIC PROCESS.

Introduction.—For many years before its solution by Sidney Gilchrist Thomas, the question of dephosphorising iron in a Bessemer converter had attracted the attention of leading metallurgists both in England and on the Continent. So far back as 1860, when the Bessemer process was first being introduced on the Continent, Tunner, of Leoben, suggested the use of burnt Magnesite as a lining for converters, although at that time his suggestion had no connection with the dephosphorising problem. Wedding and others also proposed lining the converter with Oxide of Iron or with Bauxite, and Lencauchez recommended the manufacture of bricks from burnt lime with some fritting material. Mr. Snelus, in 1872, took out a patent for the manufacture of basic linings from a mixture of lime and magnesia, with a small quantity of clay and Oxide of Iron as a binding material, and Grüner, in his metallurgy published in 1875, suggested calcined Dolomite, with clay, as a binding material. Mr. Snelus and various other investigators were undoubtedly working in the right direction, but from various reasons had failed to make a basic lining a *practical* success.

The Thomas-Gilchrist Experiments.—It was at this stage that Mr. Sidney Thomas brought his great abilities and indomitable energy to bear upon the problem which he ultimately solved so successfully and completely. Having first most carefully studied the question in all its bearings from a theoretical standpoint, he came to the conclusion that the non-removal of Phosphorus during the ordinary Bessemer blow was due entirely to the silicious nature of the slag formed, and that the essential condition for dephosphorising was the formation and maintenance of a basic slag. This, then, was the problem he set himself to solve. It was clear that it was impossible to maintain a basic slag in a vessel lined with silicious material, and therefore the first thing necessary was to obtain either a neutral or a basic lining, in which basic materials could be kept in a fused condition without fluxing it away. After many attempts, under the greatest possible difficulties, this was successfully accomplished by using burnt lime, or burnt Dolomite, mixed with some binding material like Silicate of Soda, argillaceous clay, &c., and with the assistance of his cousin, Mr. Percy Gilchrist, numerous charges of pig-iron, weighing only 8 lbs. each, were dephosphorised in a small toy converter. Step by step, as experiments became possible on a larger scale, the lining was improved, the advantages of additions of lime during the blow, and the necessity for an after blow to remove the Phosphorus, were discovered, and the basic process, as we know it to-day, became an accomplished fact.

The first patent is dated November, 1877, and was for the manufacture of bricks from pulverised lime, with Silicate of Soda as a binding material, other materials also being claimed for the same purpose. The bricks were to be moulded, dried, and afterwards kilned at a high temperature, and the next step was the substitution of aluminous clay for the Silicate of Soda as a binding material. These bricks were made as follows:—Magnesian Limestone, free from Silica, was burnt, finely ground, mixed with 3 to 4 per cent. of good fat fireclay, kneaded with a little water, made into bricks, and burnt at a high temperature; the distortion, however, was so great that they could not be used, and regrinding and remoulding had to be resorted to. The shrinkage of the bricks, varying from 25 per cent. to 50 per cent. of their volume, was a very serious drawback, and many attempts were made to get over this by using pure Magnesia, but the cost greatly militated against its use. Finally these difficulties were overcome by first burning Magnesian Limestone at a very high temperature, to shrink it completely, and then using anhydrous tar or some Hydrocarbon as a binding material, and heating the bricks thus made in closed moulds at a comparatively low temperature sufficient to just coke the tar.

During the early experiments, the inventors were extremely fortunate in interesting Mr. E. P. Martin in their work, and he not only gave them great facilities for carrying out their experiments on a larger scale, but assisted them alike financially and by his business and technical experience. Later on, Mr. Windsor Richards, who was then manager of Messrs. Bolckow, Vaughan & Co., arranged with Mr. Sidney Thomas to try the process on a large scale. It was at these great works at Middlesbrough that the commercial value of the process was proved, and that Thomas and Gilchrist were fortunate enough to obtain the assistance of Mr. J. E. Stead, who rendered them great service in helping to surmount the numerous difficulties that arose before its success was finally assured.

Both Mr. Edward Riley and Mr. Snelus held certain patents bearing on basic bricks and linings, and as it was felt that these gentlemen had certain claims, all parties agreed to submit these to arbitration, with the result that both Mr. Snelus and Mr. Riley became interested in the English patents, the foreign being entirely retained by Messrs. Thomas and Gilchrist.

Basic Bessemer Plant.—The plant employed in the basic Bessemer process differs very little from that used in acid or ordinary Bessemer, such differences as exist being only in matters of detail. The converter is exactly the same, the concentric form already described on p. 6 being often employed, as it enables a larger quantity of metal to be blown in a given sized vessel, and also enables the slag and the metal to be poured off at opposite sides, if desired.

The Lining of the Converter.—The essential difference between the two processes consists in the material used for the refractory lining of the converter, the silicious material used in the ordinary Bessemer process being replaced by a lining of shrunk Dolomite, known as basic material, rammed with anhydrous tar. This lining, together with lime additions made during the blow, allows of the formation of a Phosphate of Lime which is not decomposed by metallic iron at the high temperature of the converter, and thus practically the whole of the Phosphorus present in the iron is removed in combination with the lime in the slag.

Preparation of the Basic Material.—Shrunk Dolomite or basic material is prepared as follows:—A pure Magnesian Limestone, containing not more than 2 per cent. of Silica, should be selected, and the following analyses may be taken as fairly typical of the raw and burnt stone (see tables on next page).

This raw stone is broken into pieces which will pass through a 3-inch ring, and burnt at a very high temperature, preferably in a cupola, lined within a few feet of the charging hole with basic material. Very good material has been made in kilns specially constructed for the purpose, but in practice a basic-lined cupola has been found to give the best results.

The usual method of lining the cupola is to ram it with ground basic material mixed with tar, a collapsible core similar to that used for ramming a converter being used. The cupola having been thoroughly dried, is well charged with coke and blown up, and then alternate layers of coke and broken Dolomite are charged in the usual way, until the cupola is full to within a foot or so of the charging door. At the bottom is a raking-out door. Every two hours such material as has passed below the twyers is raked out. For the first few hours the stone will be very imperfectly burnt, and the greater part will have to be returned to the cupola, but in a short time the furnace will get into working order, and the charging and withdrawing will go on continuously. There is always a certain percentage of the stone which is imperfectly burnt, but this is easily detected by its appearance, and is picked out by hand and returned to the furnace. The temperature of the cupola has to be regulated carefully, as it is quite possible, by using too much coke and too high a pressure of blast, to frit the shrunk stone into a solid mass, when its withdrawal without stopping the cupola entirely is a matter of the greatest difficulty, if not an impossibility.

Dolomites or Magnesian Limestones.

				From Whitehaven Quarry, Porthywaen, Llynclys.			
Silica,	1·72	1·10	1·26	0·9	0·30	0·30	1·10
Oxide of Iron and Alumina,	2·30	1·64	1·80	1·30	1·20	1·19	1·14
Lime,	33·52	34·20	35·00	31 0	33·3	32·9	31·42
Magnesia,	20·05	19·60	19·40	20·6	18·75	19·02	20·00
Carbonic Acid,	42·20	43·30	42·40	46·34	46·60	46·50	46·2

Calcined Dolomite.

			From Whitehaven Quarry.
Silica,	1·66	2·50	1·40
Oxide of Iron and Alumina,	4·80	3·99	3·15
Lime,	56·50	57·32	57·30
Magnesia,	35·83	34·95	37·38
Loss on ignition,	1·06	1·00	0·60

The best results are probably obtained with a blast pressure of 1 lb. at the blower and a consumption of 570 to 670 lbs. of coke per ton of raw stone charged. In most English works it is not usual now to shrink the Dolomite on the works, but it is found to be cheaper to buy the shrunk stone from firms who make a special business of preparing it. It must be carefully stored and protected from moisture, and a large stock should never be kept on hand, as under the best possible conditions it soon absorbs moisture, and rapidly deteriorates. The sooner, therefore, it can be used after shrinking the better. The shrunk material is ground, generally in a good pug mill with edge runners, until the largest lumps are not bigger than large peas, and the remainder is much finer; it is then well mixed with the required amount of well-boiled hot tar, often in the same mill. It

is important to have the tar well boiled to expel moisture; it should be used fairly hot so that it is quite fluid, and just sufficient should be added to enable the material, when rammed and pressed, to bind well together.

Brick Linings.—In the early days of basic practice it was usual to make bricks by ramming the material with red-hot iron rammers into wrought-iron moulds of different shapes and sizes to suit the sweep of the converter. The bricks were usually about 12 by 9 by 6 inches thick, and were baked at a very low heat in the moulds, and allowed to cool in the stove. When cold, the bricks were removed from the moulds by knocking out the cotter pins (shown in fig. 69), and subsequently built up in the converter.

These hand-rammed bricks are not much used now, the usual practice being to mould the bricks in hydraulic presses, placing them in position in the converter as they come from the press *without any baking*. In this case it is customary, and gives good results, to build up the first three or four courses at the bottom of the converter with hard-baked bricks, and the other part with green bricks. As each course of bricks is laid, a backing of 3 or 4 inches of basic material is rammed hard between the bricks and the shell of the converter, the bricks being laid close together without any jointing material. Bricks green from the press are said to give equally good, if not better, results than baked ones, as when the vessel is gradually warmed up all the joints unite better and form a continuous lining. In the first machines designed a pressure of about 3,000 lbs. per square inch was employed, but Mr. Joseph Colley has found that a pressure of about 500 lbs. per square inch gives equally good results.

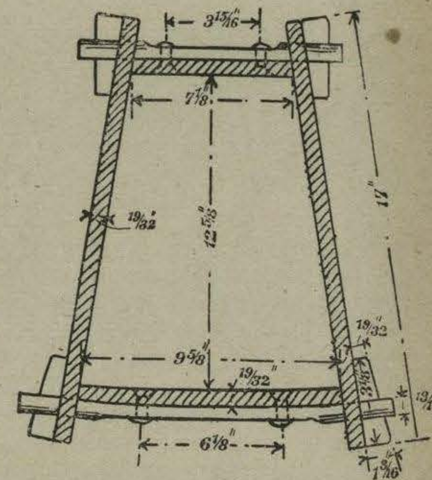


Fig. 69.—Iron Mould for Hand-rammed Basic Brick.

Ramming the Linings.—Another method of lining, and one which, perhaps, when labour, costs, and other matters are taken into consideration, gives the best results, is to ram mixed basic material with hot iron rammers between a plug or taper core and the shell of the vessel, exactly in the same way as described for ramming an acid vessel with ganister (fig. 12, p. 8). The converter for this purpose is usually inverted, lifted out of its trunnions on to a special carriage by means of the hydraulic ram underneath, and taken to the basic repairing shop, where the re-lining can be more conveniently done than when it is in its usual position. This removal of the converter for re-lining is simply a matter of convenience, and in many cases the converter is never removed from the Bessemer shop.

Although shrunk Dolomite is now almost universally employed, very good bricks were made in the early days of basic practice from shrunk lime, both at Witkowitz and Kladno. The following is an analysis of Witkowitz limestone, the Kladno stone being similar, but free from Magnesia; when burnt it contains from 5 to 6 per cent. Silica:—

WITKOWITZ LIMESTONE.*

Lime, ...	47·46 per cent.
Magnesia, ...	2·93 „
Ferrous Oxide (FeO), ...	3·41 „
Manganese Protoxide (MnO), ...	0·29 „
Carbonic Acid, ...	42·85 „
Silica, ...	2·48 „
Alumina, ...	0·53 „

The Bottom Section and Plug.—The bottom section of the converter in basic Bessemer practice is very similar to that used in the ordinary acid process, the essential difference being that basic material is used instead of ganister for the refractory material. The plug or centre portion containing the twyer holes also differs, as instead of having baked fireclay twyers containing the blast-holes fixed in the plug, these passages for the air blast are made by ramming the basic material round a number of wrought-iron taper pins or rods, and afterwards withdrawing these, and so leaving a series of holes. A cast-iron plate (fig. 71) containing the required number of holes is used, and through each hole a wrought-iron rod or pin, about 4 inches longer than the depth of the plug, is passed, having a boss on the end of each pin to prevent its passing quite through the plate. A wrought-iron casing (fig. 70) about 2 feet 6 inches deep, according to the thickness of the plug required, is now cottered round the cast-iron plate, and the whole casing is rammed up with the tar-mixed basic material, special care being taken to ram the material hard round each rod or pin. A rammer, with a hole in the head for the pin to pass through, is used for this purpose.

When the casing is rammed full, the entire plug is suspended from a crane, and the pins knocked out by sharply striking their projecting ends. As they are all made with a fair taper there is no difficulty about this. The bottom-plate in the plan and elevation, with the twyer pins ready in position and the wrought-iron casing ready for cottering on, is shown in fig. 71. E and F are rammers for ramming the basic material. The plug, with the casing still on, is now taken on a trolley to a special oven, where it is very carefully heated, the temperature being gradually raised. One form of oven is a long furnace with two or more sets of parallel rails, so that two or more plugs can be introduced side by side. The fireplace is practically in the centre, so that this is the hottest part of the furnace, and each end of the furnace is comparatively cool. The trolleys on which the plugs rest are put just inside at first, and gradually pushed forward until they reach the hottest part, where they are kept until completely baked, and are then gradually pushed towards the other, and comparatively cool end, from which they are withdrawn. It is very important not to withdraw them too hot, as during cooling in the atmosphere, especially in damp weather, moisture is rapidly absorbed.

At the North-Eastern Steel Works these plugs are made by a special hydraulic press, all hand-ramming being dispensed with, and they are said to stand better and last a greater number of blows.

Instead of using iron rods to make the holes, fireclay twyers, rammed round with basic material, may be used as in the acid Bessemer practice, and these give very fair results, less metal being ejected from the converter than with the ordinary pin-hole plug.

The thickness of the plugs varies from 16 inches to 20 inches, and the number and size of the holes are different at almost every works as the following table shows :—

* Wedding, *Basic Process*, p. 47.

The North-Eastern Steel Co., . .	101 holes, 5/8 inch diameter.
Hickmans, Ltd., ...	60 holes, 11/16 to 13/16 inch diameter.
* Witkowitz, ...	35 holes from 1/2 to 11/16 inch diameter.
* Rotheerde, ...	64 „ „ 9/16 inch diameter.
* Kladno, ...	84 „ „ 3/8 inch diameter.

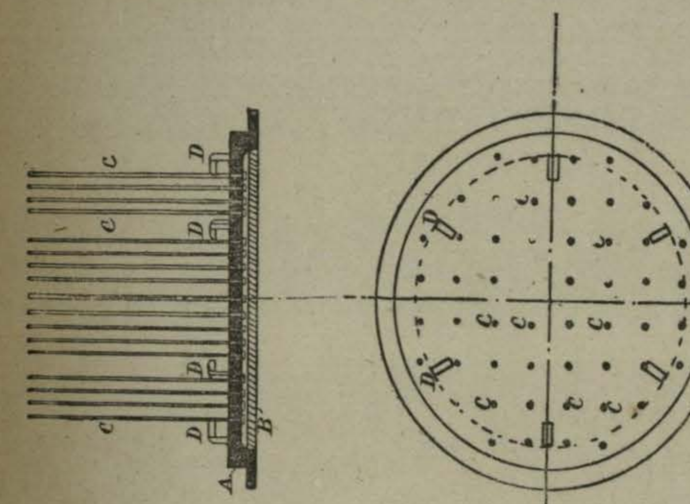
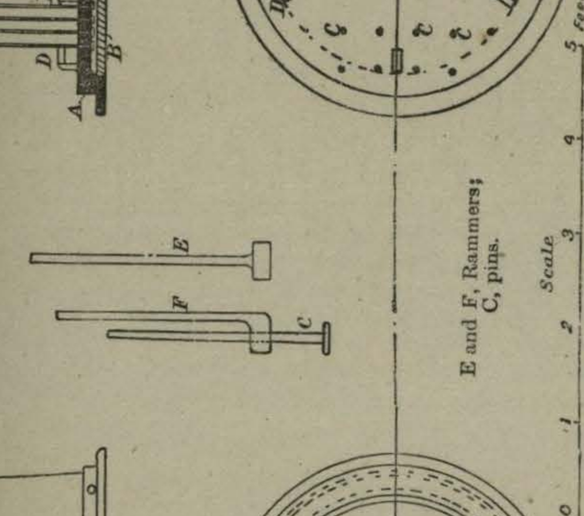
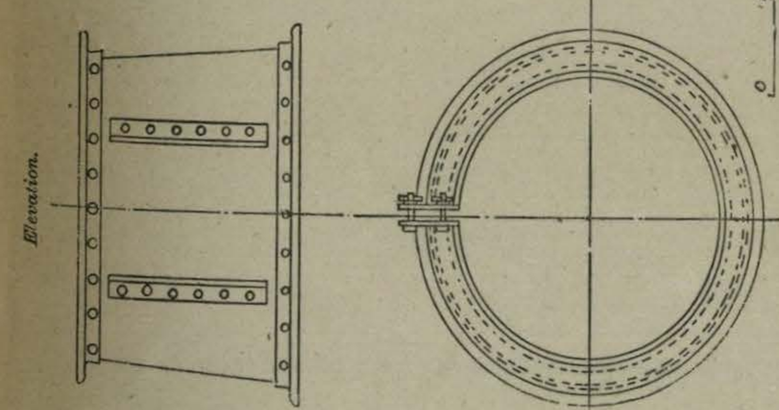


Fig. 71.—Plan and Elevation of Bottom-Plate, with twyer pins in position ready for iron casing to be fixed round previous to ramming.—D, Lugs on bottom-plate to hold basic material; C, pins,



E and F, Rammers; C, pins.



Plan.

Fig. 70.—Plan and Elevation of Wrought-Iron Casing for fastening round bottom plate.

* Wedding, *Basic Process*, p. 75. This was their practice some years ago, and probably, with larger converters, they now have greater total twyer area. The particulars at other works represent present practice.

In preparing the bottom section, the baked plug is removed from the furnace, the casing taken off, and the bottom section dropped over it as shown in the sketch (fig. 72), and the space between the two is well rammed with basic material. The bottom section is then ready for fixing on the converter.

The method of fixing on the bottom section to the converter is similar to that in vogue in the acid practice, the only difference being that instead of moist ganister, basic material with excess of tar is used to make the joint between the bottom section and the body of the converter.

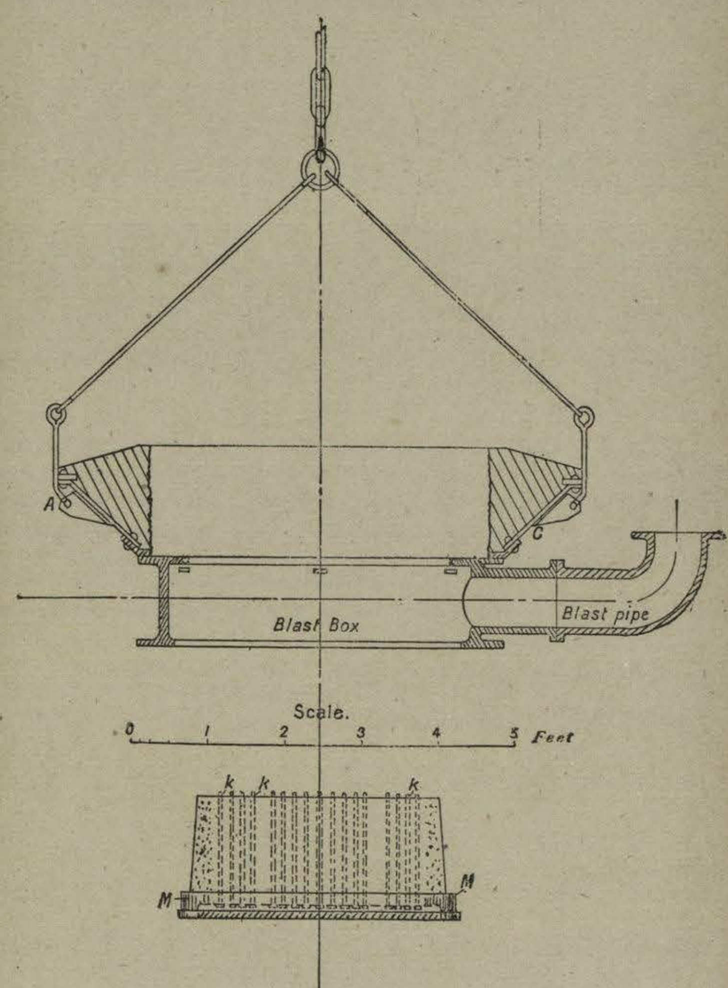


Fig. 72.—Sketch showing method of inserting rammed baked twyer plug in bottom section of the converter.

The tar should be mixed with shrunk Dolomite until it has the consistency of very soft india-rubber; it is then spread all round the circumference of the bottom section, and the latter is pressed hard by the hydraulic ram against the converter, and cottered on to it in the usual way.

Disposition of Plant.—The general arrangement of converters and cupolas, as also of the casting and ingot cranes, is exactly the same as already described for acid work, the only two points that require special attention being facilities for conveying large quantities of lime to the converter, and for removing the large quantities of slag produced. The former is usually shot down a shoot from an overhead platform above the converter through the nose of the vessel, which is brought underneath the shoot by rotating it to the proper position. By this arrangement lime can be added in the required quantity at any time by turning the vessel down for a few seconds only.

In some works the lime is conveyed to the converter in a special carriage, which travels on the converter platform. But this is not to be recommended, as the lime carriage cannot be run backwards and forwards during the blow without interfering with other operations, and if further additions of lime are required, either during the ordinary or the after blow, these have to be thrown in through the nose of the vessel.

Removal of Slag.—The removal of the slag is effected in various ways. In some works it is poured from the converter on to the pit floor on the same side as the steel casting pit, watered to cool it, broken up with bars, and wheeled away in iron barrows while still red-hot.

In other works it is poured off from the converter either on the same side as, or on the side opposite to, the casting pit, more generally the former, into large iron bogies running on rails. When one or two heats have been poured, the bogie is drawn away by a small locomotive to the slag-house for grinding.

The slag from all basic Bessemer works is now always ground to the finest powder for manure, and this method of removing it in bogies is much to be preferred, as it keeps the casting pit free from slag and steam, and costs less. Although it is more dense and compact than when poured on the ground, there is no great difficulty in breaking up these slag balls into sizes suitable for fine grinding in the mills. If the slag is deficient in lime, or contains an excess of Silica or Oxide of Iron, it may form dense, hard masses, somewhat difficult to break up, but if of normal composition there is no serious trouble in this direction.

Description of the Process.

The converter having been thoroughly heated, either from previous charges or by means of a coal or coke fire blown up by the blast, about 3 to 4 cwts. of lime per ton of metal to be blown, are shot in from the overhead shoot, and the molten metal from the blast furnace, mixer, or cupola is at once poured into the vessel, the blast turned on, and the vessel rotated into the vertical position. The various stages of the blow are very similar to those described in the preceding Chapter, but during the boil even larger quantities of slag are ejected from the vessel than in the acid blow. The difference between the processes is not very noticeable until the flame drops, indicating the complete removal of Carbon. Instead of turning the vessel down and stopping the blast, as in the acid process, blowing is continued for some three or four minutes longer. This is termed the after-blow, and it is during this period that practically all the Phosphorus is removed. It is frequently necessary to add more lime during this after-blow, the length of which varies with the percentage of Phosphorus and Silicon in the pig-iron, and, to some extent, with the temperature of the bath of metal. If the Silicon much exceeds 1 per cent., it not only increases the length of the after-blow by raising the temperature of the bath, but it combines with the lime, and thus makes the slag less basic, further retarding the removal of Phosphorus.

In some works, hammer scale, tap cinder, or briquettes made of iron oxide, hammer scale, &c., with lime as a binder, are added during the blow; briquettes made of Manganese ore are also used. The effect of these is to reduce the quantity of scrap, and in some cases the final lime additions, and to produce a fluid oxidising basic slag which oxidises the Phosphorus to some extent during the earlier part of the blow, and thus shortens the "after blow."

In basic practice, to insure a steel of uniform quality, it is of the greatest importance that the pig-iron should be of regular composition, and hence the great advantage of using a mixer or receiver (p. 15), or carefully selecting the metal and re-melting in a cupola. The Silicon should not, to give the best results, exceed 1 per cent.; best practice in England is obtained with about this percentage of Silicon and from 2·5 to 3·0 per cent. Phosphorus, although metal as high as 4 and as low as 2·14 per cent. Phosphorus has been regularly used in some cases.

In most works the mixer metal is used either alone or with a certain proportion of selected iron melted in the cupola, and probably the combination of metal mixer and cupola gives the best results as regards regularity of make. Although metal of regular composition is of the greatest importance for economic work and production of steel of regular quality, it must not be supposed that it is impossible to make basic Bessemer steel from pig-iron containing more than 1 per cent. of Silicon, as many thousands of tons in this country are made every year from pig-iron containing 2 per cent., or even more, and probably the great bulk of basic pig-iron used contains 1·5 per cent.; but, provided the pig-iron is low in Sulphur, there can be no doubt that it is a great advantage in every way when Silicon does not exceed 1·0 per cent.

Sampling the Metal.—Given a pig of regular composition, even if somewhat silicious, the heat of the bath will vary very little in different charges, and a good blower will be able to judge the length of the after-blow to within 30 to 40 seconds. The after-blow is usually continued for a given time for normal metal, the vessel then turned down, and a sample taken with a hand ladle through the nose of the vessel and poured into a cast-iron mould. This, immediately it has set, is taken to a small steam hammer, hammered till about ½ inch thick, quenched in water, and broken with an iron bar over a V-shaped anvil block.

The blower judges from the fracture the percentage of Phosphorus present, and decides whether it is necessary to add more lime before continuing the blow. Very frequently the charge will not require more than another 30 seconds blowing, and the vessel will be turned up for this time, when another sample is taken and examined by fracture before making the Manganese additions. An experienced blower, working with good metal, rarely has to take more than two samples besides the final one, and generally only one; he can detect by the fracture the difference between 0·06 and 0·07 per cent. of Phosphorus in the steel, and very seldom makes a mistake in judging the percentage of Phosphorus present. The fracture of a high Phosphorus sample is very characteristic, long bright crystals interspersed in the material being very noticeable, while, when the Phosphorus is practically all removed, the sample has a fine close granular structure, and the outside edges are smooth. If much Sulphur is present in the metal, the appearance of the fracture is very different from metal free from Sulphur; the characteristic long Phosphorus crystals are masked somewhat, the fracture is dull and non-crystalline, and the outside edges of the sample crack and have a rough appearance.

The blower being satisfied with his sample, the slag is poured off as far as possible and the Ferro-Manganese, &c., added, the steel allowed to stand for a few minutes, and then poured into the casting ladle and teemed into ingot moulds. Although it is most desirable to have a pig-iron of regular composition, still with practice it is extraordinary how steel of great regularity is made even from very variable furnace metal. But, with the greatest care and experience, the losses caused by occasional high Phosphorus steel, and cold heats, and the wear and tear on the converter linings, are so great that they cost probably far more than it would do to make a pig-iron of the required composition.

Addition of Ferro and Spiegel, &c.—The addition of Ferro-Manganese is usually made in the vessel, and not in the ladle; when low Carbon steel is required, it is generally broken to pass through a 4-inch to 6-inch ring, and heated to a red heat in a special furnace.

It is a common practice to add some hematite iron or low-grade spiegel or Silico-spiegel before the Ferro, as this assists in the deoxidation of the metal, and so saves the Ferro. For mild steel 80 per cent. Ferro-Manganese is generally used, although probably 70 per cent. is more economical, as the higher the percentage of iron in the Ferro the less tendency there is for the Manganese to pass into the slag. A small percentage of Phosphorus always passes back from the slag into the metal, on adding these Manganese alloys, owing to the reducing action of the Carbon and of the Manganese; and the blower has always to allow for this, and blow the metal down, so that the Phosphorus is somewhat lower in his final sample than is required in the finished steel. Provided the slag is sufficiently basic, the amount passing back should rarely exceed 0·02 per cent., and is generally less.

When high Carbon rail steel is required, this can be made by adding molten spiegel in the ladle, or by recarburising the metal by the Darby or some similar process (see pp. 102 and 189). The difficulty is to keep the slag back from the ladle; for although this is always poured off from the converter as much as possible before transferring the metal, some always remains behind and passes with the metal into the ladle.

The CO evolved on the addition of Ferro or spiegel always causes a violent agitation of the bath, and brings slag and metal into contact, and thus, apart from any direct reducing action, facilitates the reduction of the Phosphorus. To avoid this reaction as much as possible, it is customary in some works to use Silico-spiegel, high in Silicon and low in Carbon, of which the first three analyses following are examples:—

Carbon.	Silicon.	Manganese.		Carbon.	Silicon.	Manganese.	
1·74	9·76	30·14	Low Carbon.*	4·55	3·35	48·20	High Carbon.
2·13	8·81	28·89	Low Manganese.	5·79	0·43	68·74	High Manganese.
3·65	4·58	27·13	High Silicon.	5·59	0·12	70·10	Low Silicon.

It will be noticed that, in Ferro-Manganese, the Carbon and Manganese increase, and the Silicon decreases, as illustrated by the last three analyses.

The amount of Manganese "additions" required for dead soft steel will vary greatly with the pig metal used, and according to whether this is high or low in Manganese, Silicon, and Phosphorus.

If the metal contains about 1 per cent. of Silicon and 2 per cent. of Manganese, from 0·2 to 0·35 of the latter will be left in the bath after the completion of the after blow, and, consequently, less Manganese will have to be added. On the other hand, if the metal is very silicious and low in

* Wedding, *Basic Bessemer Process*, p. 98.

Manganese, it will blow very hot, there will be a tendency to over-oxidation, and more Manganese additions will be necessary.

Assuming *no* Manganese to be left in the blown metal, and that *all the Manganese added passed into the bath*, a 10-ton charge of steel would require 140 lbs. of 80 per cent. Ferro to give 0·5 per cent. Manganese in the finished steel, as can be seen from the following calculation :—

200 cwts., or 10 tons, of metal require 1·0 cwt. metallic Manganese to give 0·5 per cent.

To yield 1·0 cwt. of metallic Manganese, 1·25 cwts. or 140 lbs. of Ferro containing 80 per cent. Manganese are required; 1·25 cwts. or 140 lbs. distributed over 10 tons, give 14 lbs. of Ferro required per ton of metal.

This calculation is based on the assumption that no Manganese is left in the blown metal, but as from ·10 to ·20 nearly always remains, less than this quantity should be required. As a matter of actual practice, however, owing to some Manganese being oxidised by Oxides in the slag, and some by the Oxide left in the bath of metal, a considerable amount of the added Manganese is lost in the slag, and instead of 14 lbs. per ton being required, 18 to 20 lbs. is about the usual quantity required, and sometimes as much as 25 lbs. per ton of metal *charged* is added, which is considerably more than 25 lbs. per ton on the metal left in the converter.

CHAPTER III.

MANUFACTURE OF STEEL IN SMALL CONVERTERS.

Survival of the Small Converter.—Notwithstanding the almost universal tendency to increase the capacity of converters, and the general adoption of bottom blowing in rotating converters, the small converter, both fixed and rotating, is still in use in Sweden, in this country, and in America, and under special conditions, where small outputs only are required, very satisfactory results are obtained. These converters may be divided into two classes, fixed and rotating; and while the former are all, of necessity, side blown, the latter may have twyers either through the bottom, or arranged in different ways round a part of the circumference. The small bottom-blown converter is confined almost entirely to Swedish practice; the other converters, most of which are named after the designers or patentees, being used to produce either very soft, low Carbon steel, or more especially steel for the manufacture of castings.

The Swedish Bessemer process, Clapp Griffiths, Robert, The Walrand Legénisel, and the Tropenas processes, which it is proposed to describe, vary more as to shape of the converter, arrangement of twyers, valves for regulating the blast, and other details, than in any essential differences in the processes themselves.

The Swedish Bessemer Process.—To Sweden belongs the honour of having first carried out the Bessemer process on a commercial scale, and in considering the manufacture of steel in small converters, the process, as carried out in that country, will be first described.

The earliest form of converter used in Sweden was the fixed converter, similar to that shown in fig. 73, except that the body was carried on masonry foundations instead of being supported on cast-iron columns, but for more than 35 years rotating converters have been almost exclusively employed. The converters are generally about 4·92 to 5·25 feet in diameter at the widest part, and 3·94 to 4·26 feet at the bottom, while the interior varies in height from 6·56 to 8·2 feet. They are made with as small a mouth as possible, generally about 8 to 10 inches in diameter, for the better preservation of the heat of the metal. The amount of metal charged is generally from about 3 to 3⅝ tons of pig-iron, and the pressure of the blast varies from 7·8 to 9·6 lbs. per square inch. The twyer area is usually from 4·65 to 5·43 square inches per ton of metal, the total area varying from 12·4 to 18·6 square inches in different converters. The twyers are divided up into from 70 to 200 holes generally from 0·35 to 0·39 inch in diameter, but sometimes as small as 0·25 inch, or as large as 0·59 inch.* A very large twyer area is found to be of special importance in blowing these small charges, the pressure of the blast being of very secondary importance provided it is sufficient to keep the metal out of the holes. In the early experimental days Sir Henry Bessemer was of opinion that high pressure of blast was the important factor, and it was not till G. F. Goransson adopted a large twyer area, thus securing an abundant air supply with corresponding shortness of the blow, and, at the same time increasing the temperature of the bath, that successful results were obtained; previous to his experiments the metal was generally too cold to cast satisfactorily into ingots.

The pig-iron used is always low in Silicon, usually about 1·00, and generally high in Manganese, frequently containing 3 per cent., and often 4 to 5 per cent. of this metal. Typical analyses of Swedish Bessemer pig are given in Table v.

TABLE V.—ANALYSES OF SWEDISH BESSEMER PIG-IRON.

Combined Carbon,	1·13 per cent.	1·42 per cent.
Graphite,	3·23 ,,	2·99 ,,
Total,	—— 4·36 ,,	—— 4·41 ,,
Manganese,	2·98 ,,	3·06 ,,
Silicon,	0·95 ,,	0·97 ,,
Phosphorus,	0·019 ,,	0·019 ,,
Sulphur,	Trace	Trace

The universal practice is to take the metal direct from the blast furnaces, which, owing to the great care taken in charging and working, produce a pig of very regular quality. Instead of blowing until the metal is completely decarburised, and adding Spiegeleisen, Ferro-Manganese, &c., which is the usual Bessemer practice in most countries, it is customary in Sweden to blow until the required degree of decarburisation has been reached, which is judged by the appearance of the flame. In the case of the higher carbon steels, the character of the sparks is the chief guide, although before pouring into the ladle, the converter is usually turned down and a sample hammered out and examined for fracture, after which a few seconds extra blowing may or may not be given as required. Very large quantities of steel are made in Sweden without any additions of Ferro or Spiegel at all, the metal with, say, 0·3 to 0·5 per cent. Carbon retaining from 0·2 to 0·35 per cent. of Manganese at the end of the blow. Where dead soft steel is required with 0·15 per cent. of Carbon and under, small Manganese additions are usually made.

The Manganese in the pig-iron plays a most important part in Swedish practice, as besides increasing the temperature of the bath, it increases the

* Akerman, *Trans. American Mining Engineers*, vol. xxii., p. 276.

fluidity of the slag, tends to remove Sulphur from the metal, and protects the bath from over-oxidation. It has, on the other hand, a cutting action on the lining, and decreases the life of bottom and twyers, and, as it all practically passes into the slag, the waste is increased; but the other advantages probably more than compensate for these drawbacks. The waste in Swedish practice varies with the grade of steel produced, being from 9 to 10·5 per cent. for high Carbons, and for low Carbon steel, made from Manganiferous iron, as high as 12 to 12·5 per cent. Owing to the coldness of the metal, due to low Silicon, small charges, and not very rapid work, there was, in the early days, considerable skulling in the ladle, but this has been largely obviated by the use of Caspersson's converter ladle, introduced in 1880. This consists of a narrow ladle furnished with the ordinary stopper and nozzle for teeming, but having at one side, near the bottom, a lateral opening which is the same size as the mouth of the converter, and to which it can be securely and tightly fixed by cotter pins, a fireclay joint being made between the ladle and the nose of the vessel. When the blow is finished the converter is turned down, the ladle swung round on a crane, and fastened on to the mouth of the converter. The converter is then turned down a little more, so only a small portion of the metal flows into the ladle, the rest remaining in the vessel. By this means the metal can be allowed to stand for a reasonable time to permit gases to escape without any fear of chilling, and as the depth of metal in the ladle can be kept low, there is less head of metal when teeming, and consequently the stream passes more slowly into the ingot moulds, both of which conditions tend to produce metal free from blow holes. In some works it is usual to add a little aluminium to the charge before or during teeming to increase the solidity of the ingots. When the Caspersson ladle is used the ingot moulds are carried under the ladle on cars, or on a turntable. In the case of hot blows occurring, owing to the small mouth of the converter, and the small charges worked, scrapping is difficult, and Mr. Caspersson finds, according to Professor Akerman, that finely-crushed ore added during the blow gives very satisfactory results, as besides the direct chilling there is the absorption of heat due to the reduction of the Oxide of Iron. The high quality of the Swedish product is due to the very regular composition of the pig-iron used, to its great freedom from Sulphur and Phosphorus, and its high Manganese content, and also to the smallness of the charges worked. The regular composition of the pig-iron and the small charges mean a low and regular temperature in the finished steel, and are most important factors in producing metal free from blow holes and red shortness.

Some fixed converters are still used in Sweden and are usually about 4 feet in diameter, holding from 25 cwts. to 2 tons, and having about 20 twyers, with one hole ⅞ of an inch in diameter, arranged round the circumference at equal distances apart. The twyers are usually horizontal, but instead of pointing to the centre of the vessel are sometimes slightly inclined from the centre, with the object of giving rotation to the molten metal during blowing. This arrangement of the twyers has now, however, been practically given up, owing to the rapid wearing of the linings due to the abrading action of the metal. The blast-box may either be a belt round the vessel with branch pipes to the twyers as in an ordinary cupola, or form part of the converter bottom, each twyer being connected with this. The vessels are all acid lined, and about 6 to 7 lbs. pressure of blast is used.

When the blow is finished the steel is tapped out through a tap-hole, which is opened in the usual way with an iron bar, otherwise the same practice is adopted as in the case of rotating converters.

The following may be taken as typical analyses of *high-class* Swedish steel of all grades of Carbon made by the Bessemer process from 0·10 to 1·30. The Sulphur is given as "trace to 0·005 per cent.," and although occasionally it will be a little higher than this, it rarely exceeds ·010 per cent.—

TABLE VI.—General Analyses of Swedish Bessemer Steel.

Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.
0·10	0·16	0·008	0·028	Trace to 0·005 per cent.
0·15	0·18	0·012	0·027	
0·20	0·20	0·016	0·026	
0·30	0·22	0·018	0·026	
0·40	0·24	0·020	0·025	
0·50	0·26	0·024	0·025	
0·60	0·28	0·028	0·024	
0·70	0·29	0·030	0·023	
0·80	0·30	0·032	0·022	
0·90	0·32	0·036	0·021	
1·00	0·34	0·040	0·020	
1·10	0·36	0·044	0·020	
1·20	0·38	0·046	0·020	
1·30	0·40	0·048	0·020	

The Clapp-Griffiths Converter.—This is a fixed side blowing converter very similar to the Swedish form, the chief difference being that the twyers are placed higher, about 8 or 10 inches from the bottom of the converter, and have a valve attachment for partially shutting off the blast from each twyer during tapping to prevent over-oxidation of the metal. There are usually only six twyers, and these are about 1⅛ inches in diameter. An improved form of this type of converter, patented by Mr. Geo. Hatton, is shown in fig. 73, in which the solid bottom is replaced by a movable one, and a much simpler form of valve is used for partially shutting off the blast. In actual practice these valves are rarely used except in cases of a hard tap. The movable bottoms were a distinct improvement and greatly facilitated repairs. The bottoms have to be removed after about 30 to 40 blows, but the twyers are renewed, as a rule, after every 12 or 15 blows. The vessels are usually rammed with ganister, the bottom sections being repaired in the same way. Burnt fire-brick twyers are used with a slight taper, so that they can be readily put into position. The steel produced is very soft, and with iron of regular composition excellent results are obtained, but the waste by oxidation is very great, being not less than 20 per cent., including cupola loss, and frequently more. The pig used should contain about 2·0 to 2·25 per cent. of Silicon, much less than this giving cold heats, and much more tending to produce wild over-blown metal. This converter is exclusively used for the production of dead soft steel, and it is not adapted for the manufacture of varying grades of Carbon steel. The blow lasts from 12 to 15 minutes, and is similar in all respects to an ordinary Bessemer blow, and immediately the flame drops the metal is tapped into the ladle which stands ready under the tap-hole. When the pig-iron is being run into the converter, and during the tapping of the steel, dense brown fumes, due to the oxidation of the iron, are very noticeable.

The following may be taken as a fair representative analysis of the steel produced :—

Carbon,	0·100
Silicon,	Trace
Sulphur,	0·050
Phosphorus,	0·050
Manganese,	0·400 to 0·600

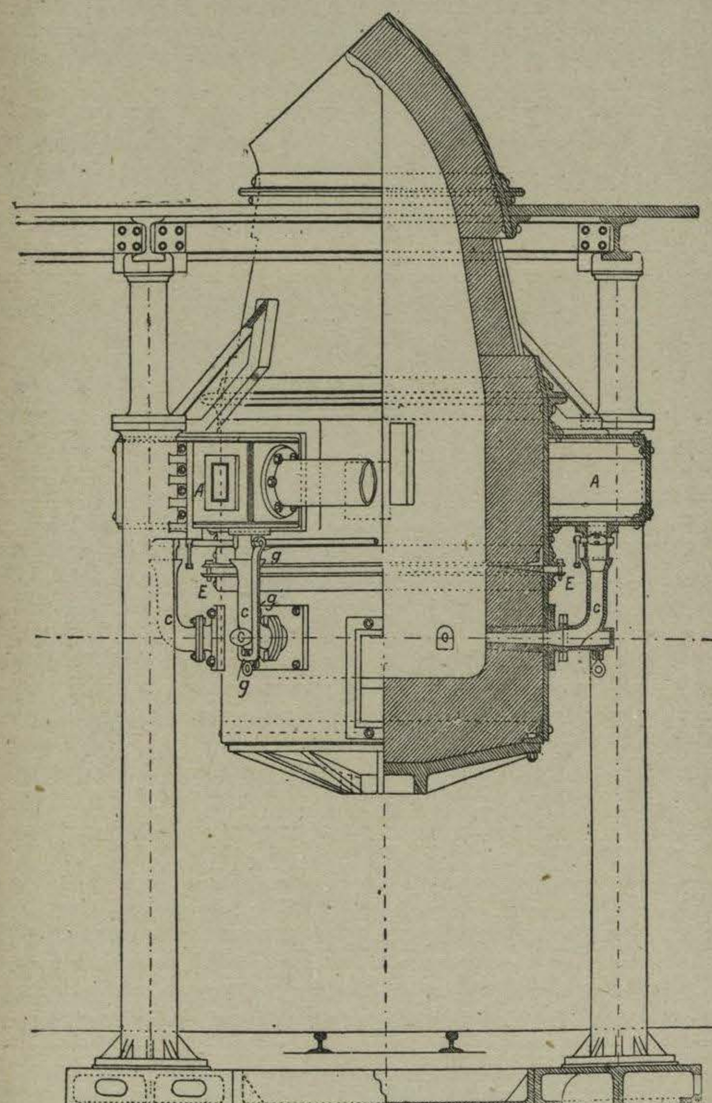


Fig. 73.—The Hatton Fixed Converter, showing movable bottom, which is fixed on the body of the vessel by bolts and cotters at E. The blast belt, A, extends round the entire converter. The branch pipes, C, are connected by a ball and socket joint to the blast belt, and can easily be turned to one side when it is necessary to replace a twyer. These pipes are held in position by a screw and pivoted yoke shown at *g*. There is a hydraulic ram under the converter, which is used for removing and replacing the bottoms.

The Robert Converter.—This is a small tipping converter, with twyers arranged on one side only, and in transverse horizontal section is D-shaped, as shown in the sketch. The twyers are placed horizontally, but are inclined at different angles to the flat side, P, of the converter, which gives a rotary motion to the bath, and brings all parts of the metal successively under the action of the blast, thus causing equal decarburisation throughout the entire mass. The molten metal is poured into the converter in the usual way in sufficient quantity to fill it to just above the twyer level, the blast turned on, and the vessel rotated to the vertical position by any suitable gear. By raising or lowering the vessel, the blast is either blown

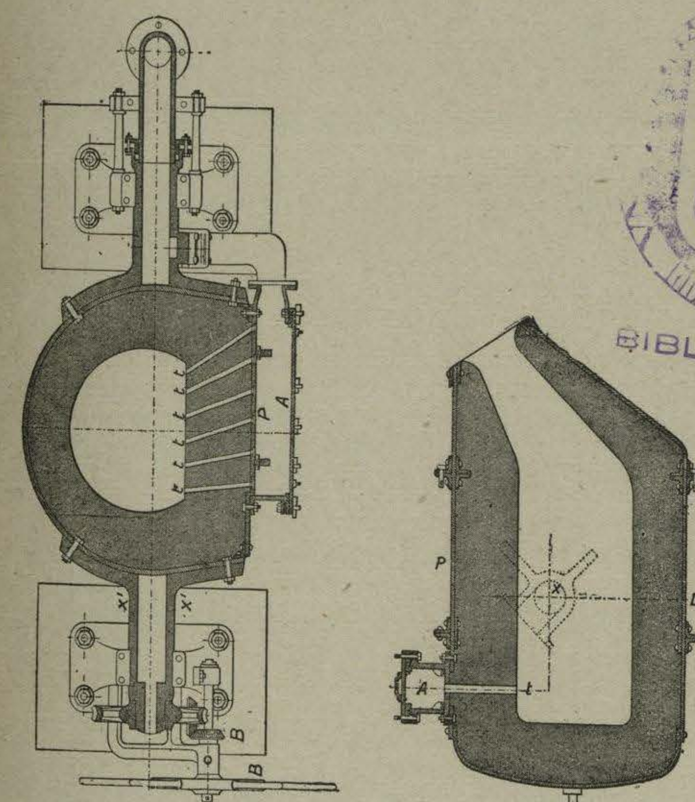


Fig. 74.—Vertical Section and Sectional Plan of Robert Converter, showing the inclination of the twyers on the flat side, P, the blast-box, A, and rotating gear, B, B.

through the fluid iron or made to impinge upon its surface. It is claimed that even while quite vertical the blast does not penetrate the bath, or only the very thinnest layer of molten metal, but forces the metal away from the twyers, so that refining is effected by surface action. The excess of air injected into the twyers is also said to burn the Carbon Monoxide evolved to Carbon Dioxide, thus greatly increasing the temperature of the metal. The pressure of the blast employed is usually about 4 lbs., and this can be regulated at will by means of a valve; and by tilting the converter the resistance to the blast can also be varied, as all the twyers having the same height of metal to support, the pressure on each is the same. The first period of the blow lasts from 7 to 8 minutes, and the second from 3 to 4, when the flame disappears. Blowing, however, is continued from $1\frac{1}{2}$ to 2 minutes more, during which time the flame re-appears, and then suddenly drops, when the finishing metal, consisting of Ferro-Manganese with or without Ferro-Silicon, is added, according to the product required. The pig-iron used at the Oberkampf Works, Paris, had the following composition :—

*Carbon,	3·50	Sulphur,	0·05
Silicon,	2·00	Phosphorus,	0·05
Manganese,	1·00		

When working the acid process, the converter is usually lined with best silica bricks, although there is no reason why it should not be rammed with ganister. Burnt fireclay twyers are generally used, tapered to permit of easy insertion and removal; in small 1-ton vessels, they are usually five in number. When the twyers are worn out, the wind-box is removed, the old twyers are cut away, ganister and fireclay are rammed in, a hole is pierced in this with a mandril the size of the twyer, and a new twyer inserted directly the clay has set hard. The converter has been used with a basic lining, and is said to have given good results, but very considerable trouble might be expected to arise in repairing the linings and in maintaining the twyers in good condition. The apparatus is one which is obviously more adapted for production of steel castings than for mild steel ingots, and there seems little reason for complicating matters by using basic linings, as small converters can never compete, as regards cost of production, with large vessels in the manufacture of mild steel. The waste in the Robert converter is said not to exceed 12 per cent. in acid work, and 13 to 18 per cent. in basic, and all one can say is that these results are very good, and far better than general experience with other small converters would lead one to anticipate. The following may be taken as typical analyses of soft Robert steel :—

	1.	2.
Carbon,	0·122	0·102
Silicon,	0·022	0·035
Sulphur,	0·048	0·032
Phosphorus,	0·052	0·049
Manganese,	0·411	0·307

The Walrand Legénisel Process.—This process is carried out in a small tipping converter, and is especially adapted for use for steel castings, as a hot very fluid metal is obtained which can readily be cast into any required form. The great difficulty in dealing with very small charges in Bessemer converters is to obtain the metal sufficiently hot, so that it can be readily dealt with in large or small quantities without skulling the ladles. Walrand obtains this result by introducing melted Ferro-Silicon after the Carbon has been practically removed, and then turning the vessel up again for a short *after-blow*, generally varying from $1\frac{1}{2}$ to 2 minutes. The heat generated by the combustion of the Silicon added, produces a very fluid metal, as all the heat is concentrated in the bath just when it is most needed, and, the Carbon having been previously removed, less heat is carried away in the escaping gases than if the Silicon pig had been added earlier in the blow, or if highly-silicious pig-iron had been charged at

* *Iron and Steel Inst. Journ.*, 1889, vol. ii., p. 272.

the commencement. Another objection to using a very silicious pig-iron is the great risk of leaving a very considerable percentage of Silicon in the finished steel (see p. 89), whereas by additions, and removal by an after-blow, the Silicon is reduced to a trace. The process is conducted as follows :—Pig-iron containing from 2·5 to 2·9 per cent. of Silicon is melted in a cupola, run into the converter, and the metal blown in the usual way to the drop of the flame, when a weighed quantity of Ferro-Silicon previously melted in a

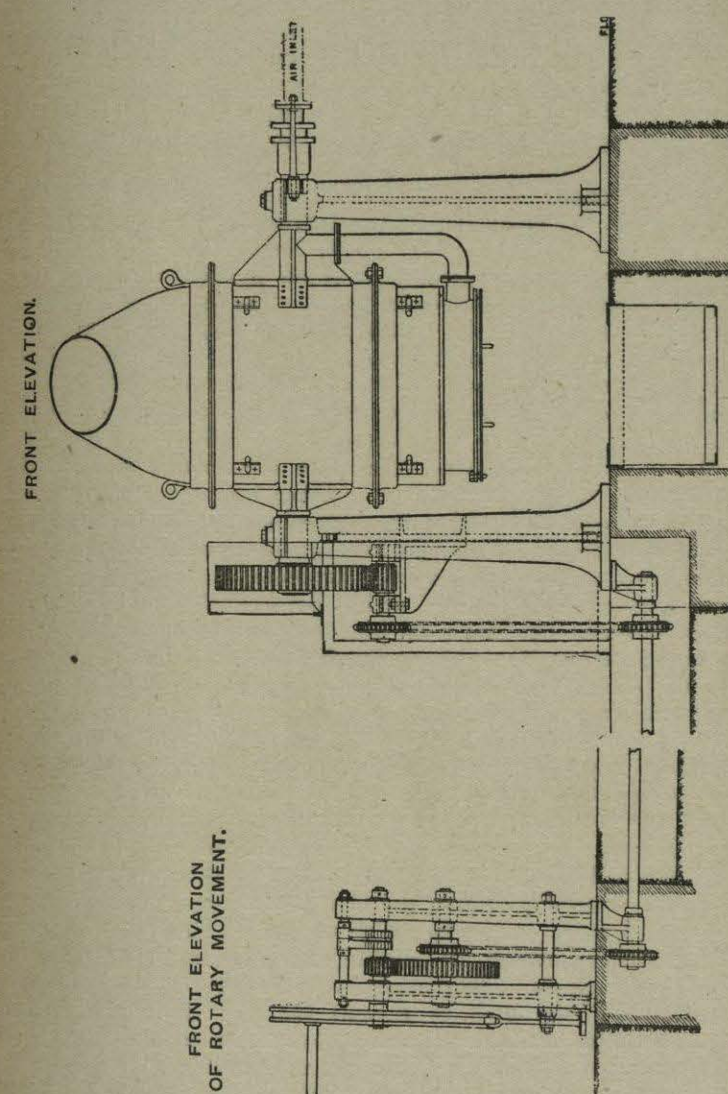


Fig. 75.—Walrand Legénisel Converter, showing hand rotating gear.

small cupola is added, and the blow continued until the whole of the Silicon is burnt out, which usually takes less than two minutes. Ferro-Manganese is then added, and the metal is ready for casting. The two vessels in use in Paris blow charges of 300 and 600 kilos. respectively, and are turned down by hand gearing, as shown in the sketch (fig. 75). There are six twyers in the small and eight in the large vessel. The metal is generally poured from the converter into small hand ladles, and rapidly carried to the different moulds ready to receive it. From a small converter of similar construction some few years ago the author saw some extremely small castings, weighing only a few pounds, cast from practically Carbonless steel, and they were perfectly sound. The nose of the converter is usually covered up during the time of casting to retain the heat as much as possible.

The pressure of blast used varies from one to two atmospheres. Snelus* says the waste is about 10 to 12 per cent. in the converter, and about 15 to 17 including cupola waste, which is exceptionally low, considering the small charges. Practically any grade of steel from 0·08 of Carbon up to ·80 can be obtained, and the Silicon, &c., can be varied at pleasure by suitable additions. Whatever the grade of steel required may be, it is always obtained by completely decarburising first, and then recarburising with additions to the extent required.

Tropenas Process.—This, like the Walrand Legénisel and the Robert processes, aims at the production of small quantities of steel which shall possess great fluidity owing to the high temperature obtained during the process. The twyers are especially arranged to effect this, and also to eliminate the impurities by surface oxidation. The Tropenas converter in general form is similar to the ordinary side-blowing converter, but the bottom is somewhat conical, so that the bath of metal may present as large a surface as possible to the blast, and at the same time not be shallow. The air-blast instead of being injected into the molten metal is made to impinge upon its surface, the twyers being arranged above the metal line on one side of the converter. By having a deep bath, the metal is kept as still as possible, and not violently agitated as in other systems of blowing, when the blast is introduced at either the bottom or sides beneath the metal. This has the advantage of allowing a very low pressure of blast, 2 to 4 lbs. being employed, and according to Mr. Tropenas, a material very much freer from occluded gas is obtained, and in fact a metal equal in all respects to open hearth steel. The heat of the bath is greatly augmented by the combustion of the Carbon Monoxide formed from the oxidation of the Carbon in the metal by means of a subsidiary twyer above the slag line, through which air is injected. The form of converter and arrangement of the twyers are shown in figs. 76 and 77. The principal blast is introduced through the bottom row of twyers, which are known as the "twyers of reaction," and oxidation takes place on the surface only, air being admitted through the top twyers, or "twyers of combustion," when the Carbon commences to be oxidised. During the first period of the blow, the converter is kept in the position shown in fig. 76, no air being admitted through the top twyers; but as soon as the second period of the blow commences, as shown by the appearance of a flame at the mouth of the vessel, the valve of the top twyers is cautiously opened, air admitted, and the converter moved into position shown in fig. 77. The bottom twyers must be raised sufficiently above the level of the bath to prevent the slag chilling and closing the twyers, but some of the slag generally becomes cooled, and forms hollow projections which, although slightly closing the air inlets, do not seem to affect the operation appreciably; in fact, these slag nozzles protect the twyers which last about 30 to 40 blows.

The process is very similar to the Robert; both claim surface oxidation, and both that CO produced by oxidation of Carbon is burnt to CO_2 with corresponding increase of temperature of the bath, the only difference apparently being that the Robert converter is especially designed to give a

* *Iron and Steel Inst. Journ.*, 1894, vol. i., p. 34; 1896, vol. ii., p. 105.

rotatory motion to the metal, while the object of the somewhat deep conical bottom of the Tropenas converter is to keep the bath as free as possible from any mechanical disturbance. The combustion twyer above the reaction twyer is certainly a more effective way of insuring the combustion of the Carbon Monoxide than depending upon the injection of excess of blast by twyers at one level as in the Robert; but with this exception there would appear to be no great difference in the converters. The highly oxidising slag formed on the surface, combined with the circulation currents

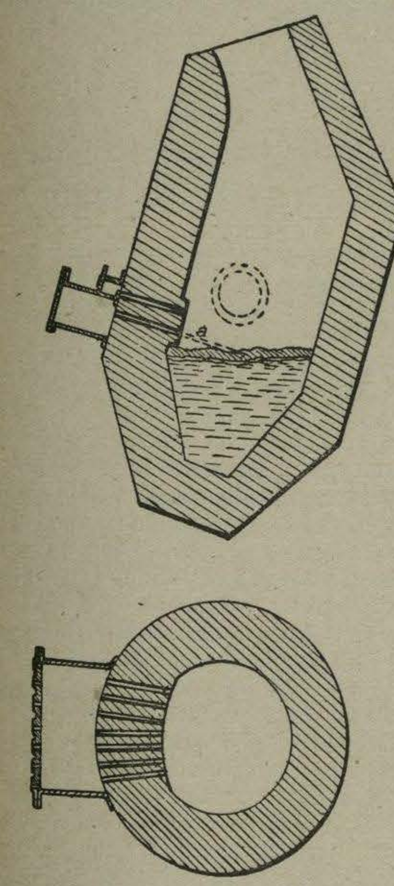


Fig. 76.—Tropenas Converter, showing position of Converter during early part of the blow when blast is entering only through twyers of reaction, a a.

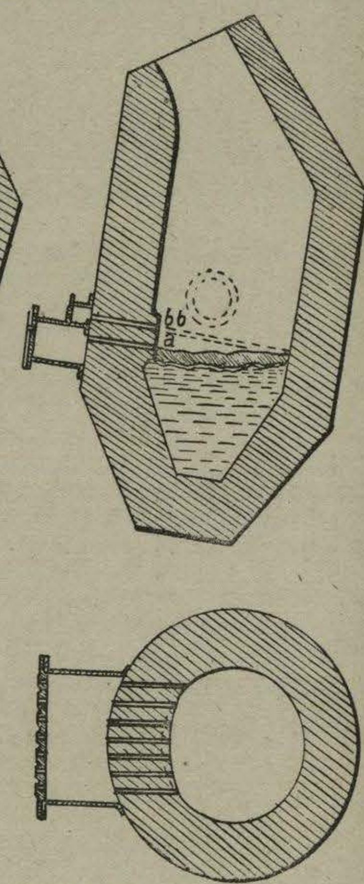


Fig. 77.—Showing position of Converter during the second period of the blow when air is admitted through bottom twyers, and also twyers of combustion, b.

set up in the metal bath, rapidly oxidise the impurities present. The inventor claims that the metal produced is equal in all respects to Siemens steel of the highest class, and the conditions in the converter are not dissimilar to those of an open hearth furnace, as there is a comparatively large surface of metal exposed to a very oxidising slag. The slag is probably far more oxidising, especially towards the end of the blow, than in an ordinary open hearth furnace, and the rapidity of the oxidation of impurities is undoubtedly assisted by the circulation of the metal induced by the injected air currents. It might be expected that these conditions would greatly increase the liability to produce over-oxidised metal as compared with the open hearth process, especially as it seems the custom to decarburise completely, and to produce the required grade of steel by addition of Ferro-Manganese, Spiegel, Ferro-Silicon, &c. Converters to blow only 10 cwts. of metal can be used successfully, and generally speaking the process lends itself to the production of small castings. With a 2-ton converter large castings can, however, be made, as it is possible to keep the metal from one charge in the ladle while another charge is being blown, and in this way with two 2-ton converters, castings up to 10 tons can be made, or with a single 2-ton converter, 3 to 4 tons casting can be produced. The waste is said not to exceed 14 per cent., which is exceptionally little for such small heats, and is certainly surprising considering the large amount of surface oxidation. The process can be worked either as an acid or a basic one, but there would appear to be little advantage in using the latter, and many difficulties would arise in regard to linings and in dealing with the slag. The process is at work at Woolwich Arsenal, where there are three converters which are said to give extremely satisfactory results.

The Stock Converter.*—This is a combination of an oil-melting furnace and small side-blown converter. Materials are charged cold into the previously heated converter; oil fuel under a pressure of about 40 lbs. to the square inch is supplied through flexible tubing to small tubes about $\frac{1}{12}$ of an inch in diameter, let into the main blast twyers, which are about 2 inches in diameter, and air for combustion, at a pressure of about $1\frac{1}{2}$ lbs., is admitted. When the charge is melted, which takes about $1\frac{1}{2}$ hours for a 3-ton charge, the converter is rotated to the blowing position, the oil shut off, and the bath of metal subjected to a blast of air on the surface for about 16 to 19 minutes, when the vessel is rotated into the teeming position and finishing metal added in the usual way. The waste gases formed during the melting of the charge pass through an economiser containing iron pipes through which the blast passes on its way to the converter, and in passing through which it is heated up to a temperature of 700° F. During the actual blow the waste gases are allowed to escape, as they contain so much solid matter that they would be injurious to the regenerative apparatus. Owing to the intense heat developed during melting and blowing with heated blast, the converter has to be lined with magnesite bricks, but low phosphoric iron is used and no attempt is made to dephosphorise. The advantages of this converter are that no impurities are taken up by the pig-iron during melting, as in case of coke melting in cupolas, and owing to the hot blast being used a very high temperature is obtained, insuring a very fluid metal, which makes the process particularly applicable for manufacture of steel castings. The vessel is mounted so that it can be rotated into the different positions for charging, blowing, and teeming.

Small Converters Considered generally.—Although these small converters still have some enthusiastic supporters, with the few exceptions where manufacturers find it necessary to make their steel in comparatively small quantities under their own supervision, these converters are used almost exclusively for steel castings, and even under such circumstances the general consensus of opinion seems to be that a small open hearth plant gives better all-round results. For castings, especially where small ones have to be made, and metal has to be kept extremely hot and fluid, these small tipping converters undoubtedly offer certain advantages over a Siemens furnace. Steel can be made in smaller quantities, the converter can be used as a ladle to distribute the steel in small ladles for different castings, and thus the metal be kept very hot until the whole heat has been cast. Frequent charges can be made during the day, instead of one charge as in the open hearth furnace. Less space is required in the moulding shop, for as soon as one set of castings is set, they can be removed and moulding recommenced, whereas for a Siemens furnace sufficient moulding space must be available to take an entire charge, probably of not less than 5 or 6 tons. At all events, whatever may be the future of small converter plants, it is in the direction of steel founding that they are most likely to develop, as they cannot hold their own against the large outputs of Siemens or Bessemer plants for ordinary steel manufacture, and are also handicapped by the large waste which occurs during conversion.

* For further details, see paper by P. P. Dowden on "The Manufacture of Steel," read before the Institute of Marine Engineers, Feb. 17, 1913.

CHAPTER IV.

CHEMISTRY OF THE ACID BESSEMER PROCESS.

General Considerations.—The reactions taking place in the acid-lined Bessemer converter, under various working conditions, have been carefully studied by Snelus in this country, by Kupelwiesser and Ledebur on the Continent, and by F. Julian in America, while the thermo-chemistry of the subject has received special attention from Jordan, Akerman, Pourcel, and, later, from Professor Hartley.

To arrive at the chemical history of the Bessemer blow it is necessary to examine the bath of metal at repeated intervals, and note the changes produced; also to examine the products of oxidation, and to consider the thermal conditions existing at each period when samples are taken. The products of combustion are either gaseous or liquid, the former passing away with the Nitrogen at the mouth of the converter, and the latter fusing at the intense heat developed to form a more or less fluid slag, which, being lighter than the molten metal, floats upon its surface.

Three Stages Involved.—The reactions taking place in the acid Bessemer blow are usually divided into three stages or periods—1st, the slag-forming period; 2nd, the boil; and 3rd, the finishing period. During the first period the greater portion of the Manganese and Silicon are oxidised, and unite with some Oxide of Iron simultaneously produced to form a double Silicate of Iron and Manganese slag; and under normal conditions of working the Carbon is not appreciably attacked until a considerable portion of the Silicon has been removed, such proportions as are oxidised passing away mostly as Carbon Dioxide (CO_2). This period is marked by an irregular violet-coloured flame at the mouth of the converter, which gradually becomes more steady in character and changes to a yellow colour as the temperature of the bath increases. After about five or six minutes from the commencement of the blow, the Carbon begins to oxidise rapidly, and, the bath being very fluid owing to the high temperature produced by the combustion of a relatively large proportion of Silicon, the second period, known as the boil, commences. During this period the oxidation of the Silicon and Manganese continues, and the greater part of the Carbon is also removed, mostly in the form of Carbon Monoxide (CO), as the percentage of CO_2 formed in the early part of the blow rapidly decreases, while the CO increases, as will be seen from the curves in fig. 79. It is the formation and escape of this gas which causes the violent agitation of the bath, and is attended with a very large flame issuing from the mouth of the converter, and with the ejection of considerable quantities of metal and slag, and a further increase in the temperature, and consequently in the fluidity of the metal. Some Hydrogen is found in the gases issuing from mouth of converter during this part of the blow, derived from the dissociation of water vapour in the blast.