PHOTO-MICROGRAPHS.

THE METALLURGY OF STEEL.

SECTION I.

INTRODUCTION.

During the last sixty years the introduction of the Bessemer and Open Hearth processes have not only revolutionised the steel manufacture of the world, but have compelled us to revise our definition of steel. Before 1856, the year in which Bessemer first published the particulars of his great discovery, there were practically only two varieties of steel in the market—viz., crucible or cast steel, and shear steel—although small quantities of puddled steel and steel made direct from the ore were produced.

Crucible or cast steel was made by melting blister steel bars containing different percentages of Carbon, according to the grade required, with small percentages of steel scrap in crucibles, and casting the fluid metal into small iron moulds, the ingots thus obtained being afterwards forged down to the required size and shape. The percentage of Carbon in such steels usually varied from ·25 to 1·75, although sometimes it was higher. Shear steel was made by piling and welding together plated, cemented, or blister bars into what was known as a "faggot," and afterwards forging and rolling this faggot down into thin strips, suitable for the manufacture of cutlery.

The distinguishing features of these classes of steels were, that by rapid cooling from a red heat by quenching in water, they became extremely hard and more or less brittle, and that by re-heating to different temperatures, or "tempering," this hardness could be modified, the brittleness removed, and great elasticity, combined with varying degrees of hardness conferred upon the steel. The maximum degree of hardness which each steel was capable of taking depended upon the Carbon content, the higher the percentage of Carbon, the greater the hardening power of the steel; and the use of crucible and shear steel was practically confined to the manufacture of cutlery, tools, etc., and some special parts of machines which required a material which could be hardened after it had been forged or machined into shape. For structural purposes wrought iron and cast iron were the materials almost, if not quite, exclusively employed, the former possessing properties which enabled it to be wrought or forged into any required shape, and the latter being moulded into different forms by pouring it, while in a molten condition, into moulds of the required shape. The chief distinction between wrought iron and steel was that the former was not hardened by rapid cooling in water from a red heat, and contained always less than 0·20 per cent. of Carbon, and generally less than 0·10. Cast iron, on the other hand, contained from 2·5 to 4·0 per cent. of Carbon, and was distinguished from both steel and wrought iron by being brittle at a red heat, and incapable of being wrought or forged, and by having a comparatively low melting point of from 1,075° to 1,276° C., against 1,500° C., or higher, for wrought iron. Thus steel at this period, as regards percentage of Carbon, was an intermediate product between wrought iron on the one hand and cast iron on the other.

The advent of the Bessemer process furnished a material which, as regards the process of manufacture, resembled crucible steel, being cast from a fluid condition into moulds, and afterwards forged into shape, while it possessed practically none of the properties of cast crucible steel, and both physically and chemically was almost identical with wrought iron. Thus it frequently contained 0·10 per cent., or less, of Carbon, and on quenching from a red heat in water did not appreciably harden. Such material, made by the Bessemer or Open Hearth processes, and containing less than 0·20 per cent. of Carbon, has become generally known as "mild steel."

Steel containing much larger percentages of Carbon, and, indeed, anything up to 2·0 per cent., can be made either by the Bessemer or Open Hearth process, and such steels, as regards hardening and tempering, possess similar properties to crucible cast steel; in fact, this capacity for hardening depends upon the percentage of Carbon present, irrespective of the process of manufacture.

It is very difficult to define the term steel as now generally employed, and almost impossible to frame a definition that shall include crucible cast steel, shear steel, and the numerous grades of Bessemer and Siemens steel, as to define them involves a description of each process of manufacture. It is possible, however, to give a general definition which will include all grades of Bessemer and Siemens steels, and distinguish these from wrought or puddled iron on the one hand and from cast iron on the other.

Definition of Steel.—Steel, using the term as applied to the metal produced by the Bessemer and Open Hearth processes, may be defined as purified pig-iron, which, unlike wrought iron, has been cast whilst in a molten state, and in which the Carbon and impurities present in the original pig-iron have been reduced (1) by oxidation alone, (2) by dilution with a previously purified metal, or (3) by oxidation and dilution combined, *to such a point that the ingot cast is capable of being forged or rolled into blooms, slabs,* etc. This definition does not define the extent to which the various impurities, such as Silicon, Sulphur, Phosphorus, Manganese, &c., present in the pig-iron must be removed before the finished metal can reasonably be regarded as steel. Unlike Carbon, they are not essential constituents of a given grade of steel, but simply impurities which usually have an injurious influence, and determine whether the steel is of good or bad quality, and suitable or otherwise for a particular purpose, without affecting the broad question as to the material being steel or not. The best condition for the decarburisation and the removal of the various impurities of pig-iron largely constitute what is understood by the Metallurgy of Steel, which may be defined as the art of decarburising and purifying pig-iron, and of producing cast ingots containing various percentages of Carbon as free as possible from impurities, and the subsequent manufacture therefrom of finished bars, plates, and other shapes of different degrees of hardness, strength, and ductility to suit the requirements of modern engineering practice. Such bars, plates, &c., must be free from "red-shortness"—*i.e.*, they must be capable of being forged at all temperatures from a red to a welding heat without showing any signs of cracking or other defects. They must further be free from "cold-shortness" —*i.e.*, must not show any signs of brittleness under sudden shock or under a steadily applied load in the cold condition, the stress which each steel may reasonably be expected to bear varying with its content of Carbon. Although it is impossible to draw an absolutely hard and fast line based on chemical analysis between steel and various forms of cast iron, so far as Bessemer, Open Hearth, Crucible Cast Steel, and Shear Steel are concerned, metal containing over 2·3 per cent. of Carbon may reasonably be classified as cast iron. The above limitation does not apply to some special varieties of steel, such as high carbon crucible cast steels, which occasionally contain nearly 3 per cent. of Carbon, and Indian Wootz in which the Carbon is sometimes as high as 2·70 per cent., but these, although true steels, are not of sufficiently common occurrence to affect materially the above definition.

CHAPTER I.

THE BESSEMER PROCESS.

So much has been written about the general history of the Bessemer process that it is not intended to devote much space to this aspect of the subject, while, happily, as regards the metallurgy of the process there is very little to relate. The process stands almost alone amongst our large manufacturing industries, in that it is carried on to-day substantially in the same manner as it was nearly sixty years ago, at the works erected at Sheffield by the late Sir Henry Bessemer and his partners; the only improvements that have been introduced being in detailed mechanical arrangements and larger appliances. Since Bessemer read his paper at the Cheltenham Meeting of the British Association on August 11th, 1856, on "The Manufacture of Malleable Iron and Steel without Fuel," and recognised the necessity of Manganese as an addition, the use of which was patented by R. Mushet in September, 1856, and proved the salvation of the process, it has not been appreciably modified. The Basic Bessemer process, which will be described later on, is simply the application of the Bessemer principle to the treatment of Phosphoric Pig-Iron, and the carrying out of the Bessemer process under special conditions, the fundamental principle of the oxidation of the impurities in cast iron by the blowing of air through it in a molten state remaining unaltered.

By the combustion or oxidation of the impurities—*i.e.*, the Carbon, Silicon, Manganese, etc., in the cast iron used—sufficient heat is developed to maintain the purified metal in a fluid condition, so that it can be cast into suitable moulds, and afterwards forged or rolled to any required form.

The Converter.—The molten cast iron from the blast furnace or cupola is transferred to a vessel, known as the "converter," lined with highly refractory silicious material in which there is, fixed in the bottom itself or through the sides near the bottom, a number of fire-bricks with small holes in them, known as twyers, through which the air under pressure from a blowing engine passes into the metal. The original Bessemer converter was a fixed vessel with air inlets at the sides, but this was at a very early date almost entirely replaced by a tipping converter, supported on trunnions, in which the air was injected at the bottom. Fig. 1 is a drawing of the original fixed converter used by Bessemer at his experimental works at St. Pancras in 1856. It was soon found that the air did not penetrate into the centre of the molten bath, but escaped through the metal at a very short distance from the orifice of the twyer, and rapidly cut away the brick lining. To overcome this difficulty a converter with a twyer at the bottom, with a varying number of air holes, was designed, and is shown in fig. 2. Fig. 3

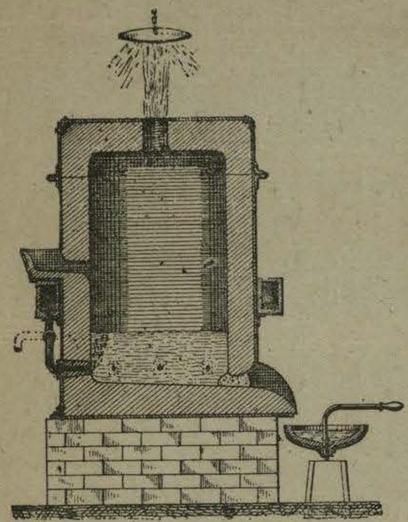

Fig. 1.—Original Bessemer Converter, lined with 4½-inch Stourbridge bricks. A cast-iron tubular ring, shown in cross-section, surrounds the converter, and from it six branch pipes descend to the twyers near the bottom of the converter. The branch pipes had elbow joints so that they could be moved into position, shown by dotted lines, to enable the twyers to be cleaned or repaired.

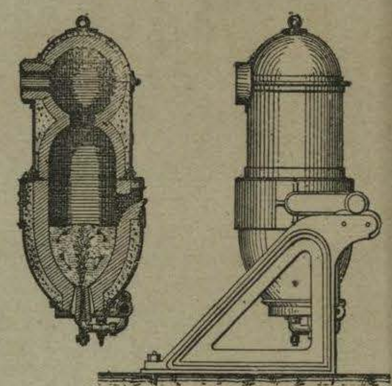

Fig. 2.—First converter with twyer at bottom. Covered at the top to prevent ejection of metal.

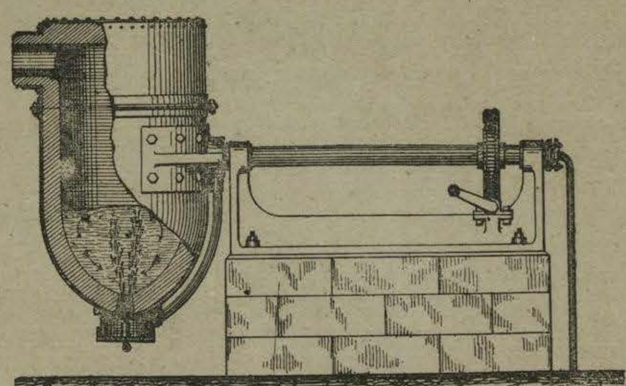

Fig. 3.—Converter designed so that blow could be stopped at any moment by rotating the converter into the horizontal position, and thus removing the centre twyer above the level of the bath of metal.

shows a further development of the same idea, the converter being tipped by worm-wheel gearing, and made of such diameter that when the converter was rotated into the horizontal position, the twyer would rise

above the surface of the metal, and enable the blow to be stopped at any particular moment. In Sweden, in these early days of the process, side-blowing fixed converters gave good results, but as the twyers were always beneath the metal, it was impossible to stop the blow without removing the fluid iron. To meet this difficulty, and still retain the side-blowing, the converter shown in figs. 4 and 5 was designed. This, when tilted

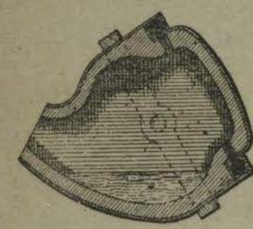

Fig. 4.—Converter at end of blow with twyer above the bath.

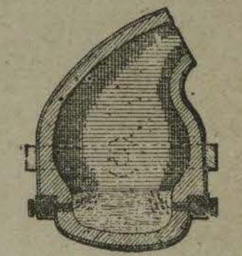

Fig. 5.—Side-blowing tipping converter in position for blowing.

into the position shown in fig. 4, raises the twyers above the bath of metal. Fig. 6 is a sketch of what may be regarded as the first Bessemer converter of the form now commonly employed. This converter was erected at the works of Sir Henry Bessemer, at Sheffield, and the drawing is a copy from the original plans.

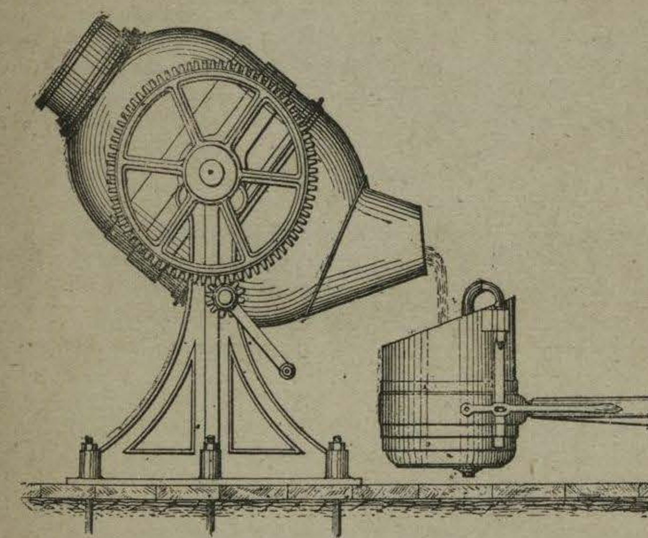

Fig. 6.—First converter of form now in general use designed by Sir Henry Bessemer for his works in Sheffield. Showing metal being poured into ladle after completion of the blow.

General Description of Process.—In carrying out the process, the molten iron is poured into a converter similar to that shown in fig. 7, and air is blown through the bottom twyer holes until practically the whole of the Carbon, Silicon, and Manganese has been oxidised, when an alloy of Iron and Manganese, known either as Spiegeleisen or Ferro-manganese, is added, and the liquid metal (which is now steel) is poured into a large cauldron or ladle, from which it is teemed into cast-iron moulds, usually rectangular in section with rounded corners, but of varying sizes, and known as ingot moulds. After a short time the liquid metal sets or "freezes," and is then drawn from these moulds, reheated, and rolled or hammered into any required shape.

The Modern Converter.—The modern converter is a pear-shaped vessel, built of mild steel, or of wrought-iron plates rivetted together, and is lined with siliceous material. This lining may be built up with silica bricks, or with a clay-like material, known as ganister, which may be rammed round the inside of the casing. The converter is supported on trunnions, one of which is hollow, and connected with the blast main through which the air from the blowing engine passes to the blast-box under the bottom of the converter (see figs. 7, 8, 9 and 10, Plate i.). The body of the converter is mounted in a trunnion ring, to which it is firmly bolted, as are also the trunnions. This ring may be a steel casting in one piece or in sections, or it may be built up of $1\frac{1}{2}$ to 2-inch mild steel or wrought-iron plates. In the case of small converters, a strong, heavy, cast-iron ring may be used. In all the early Bessemer converters the entire shell was rivetted together, but in the modern vessel the bottom portion is always, and the nose or upper part generally made detachable, being usually cottered, or bolted, to the centre portion of the vessel. The converter is thus divided into three portions known as the bottom section, the belly, and the nose. Owing to the very rapid wear which takes place round the twyers, probably no improvement in Bessemer practice has done more to facilitate rapid work than the invention of the detachable bottom by the late Mr. Alex. L. Holley, the well-known American Engineer. The full advantage of this device will be appreciated when it is mentioned that the lining in the bottom containing the plug or twyer portion is generally worn away in about 12 to 15 blows, and sometimes fewer, while the lining of the belly of the converter usually lasts for three or four, and sometimes for twelve months, or even longer. The nose of the vessel is not often removed, except when the converter is entirely relined, and not always even then, but it is a distinct advantage to be able to uncotter it if necessary. In the centre of the bottom section is what is known as the plug, in which are fixed a number of fireclay twyers, K, K, K (fig. 10), each containing about 12 or 18 holes from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch in diameter through which the air is forced into the molten metal from the blast main. The entire bottom section, with the exception of these twyers, is made of siliceous material, such as rammed ganister, and after drying is fixed on the vessel by means of lugs or links and cotter pins, as shown in fig. 7. G is the blast-box, underneath the bottom section, which receives the air direct from the blast pipe before it enters the twyers. It is very important that the bottom plate of this blast-box should be easily removable, so that the twyers can be readily examined and repaired or renewed if necessary during a blow, and at the same time it must be perfectly air-tight to prevent waste of blast. This is usually effected by having it faced true, giving a good wide bearing, putting yarn and clay packing round the bottom plate between it and the box, and securing the plate by a large number of cotters to the blast-box.

There are two forms of converters known as eccentric and concentric, according to the shape of the nose or upper section. They are shown in part section and part end elevation in figs. 8 and 9, and it will be seen that the eccentric has the upper part of the converter straight on one side, and curved on the other, while in the concentric one, this part forms a frustum of a cone, the sides being inclined equally to the axis of the converter.

PLATE I.— [To face p. 6.

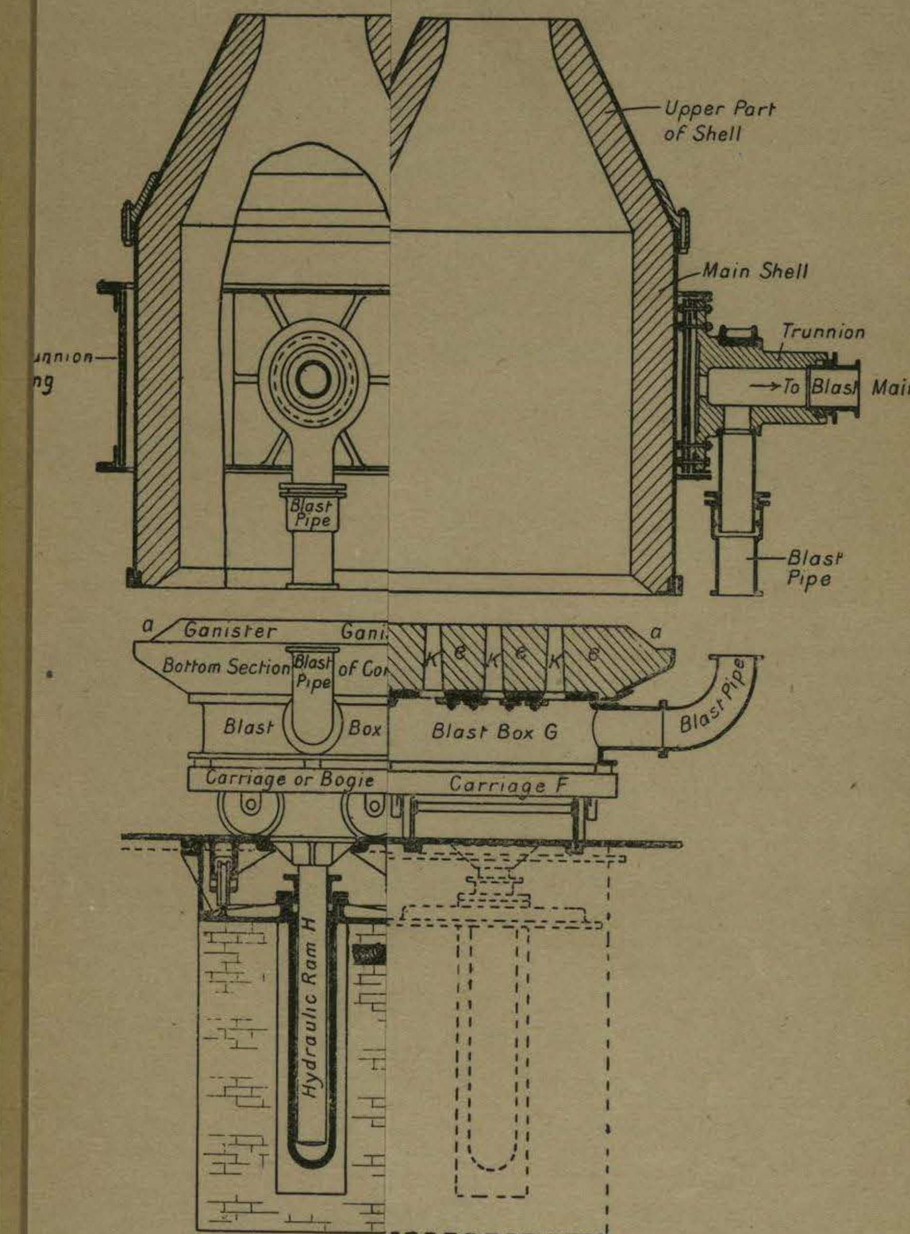

Fig. 8.—Concentric Converter in of Converter through the Trunnions, showing
end elevation, with bottom tom section shows the twyers in position.
ready to be lifted by hydraul rammed ganister.

PLATE I.—Modern 16-Ton *Bessemer* Converter.

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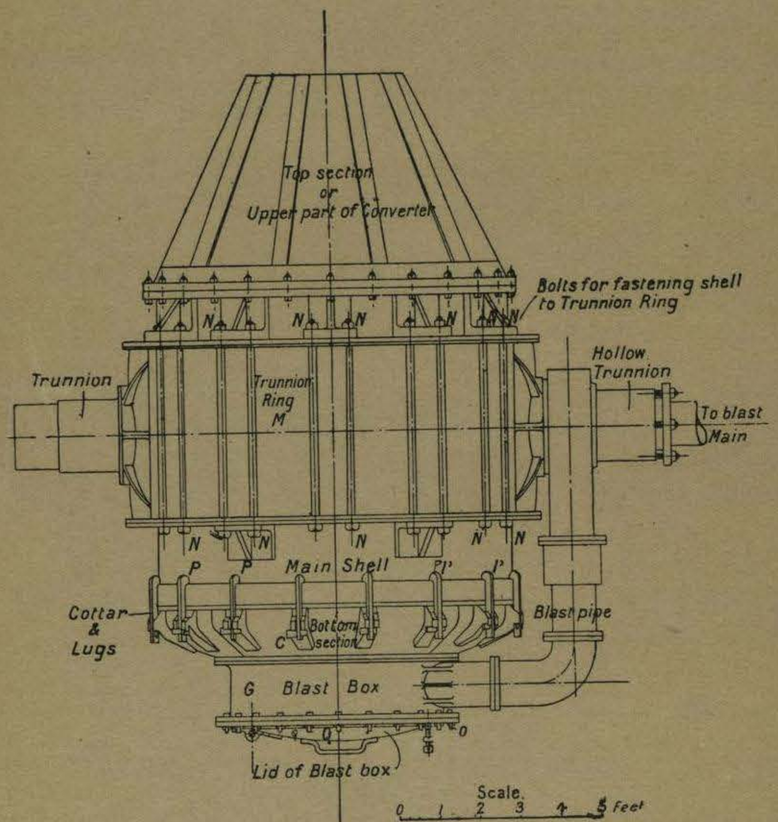


Fig. 7.—Elevation of Converter, showing blast main, blast box, details of shell; and method of fixing bottom section to the body of converter with lugs and cottars. N, Brackets and bolts for fastening shell to trunnion ring; P, lugs and cottars for fastening bottom section to body of converter; G, blast box; O, cottars for fastening lid on to blast box.

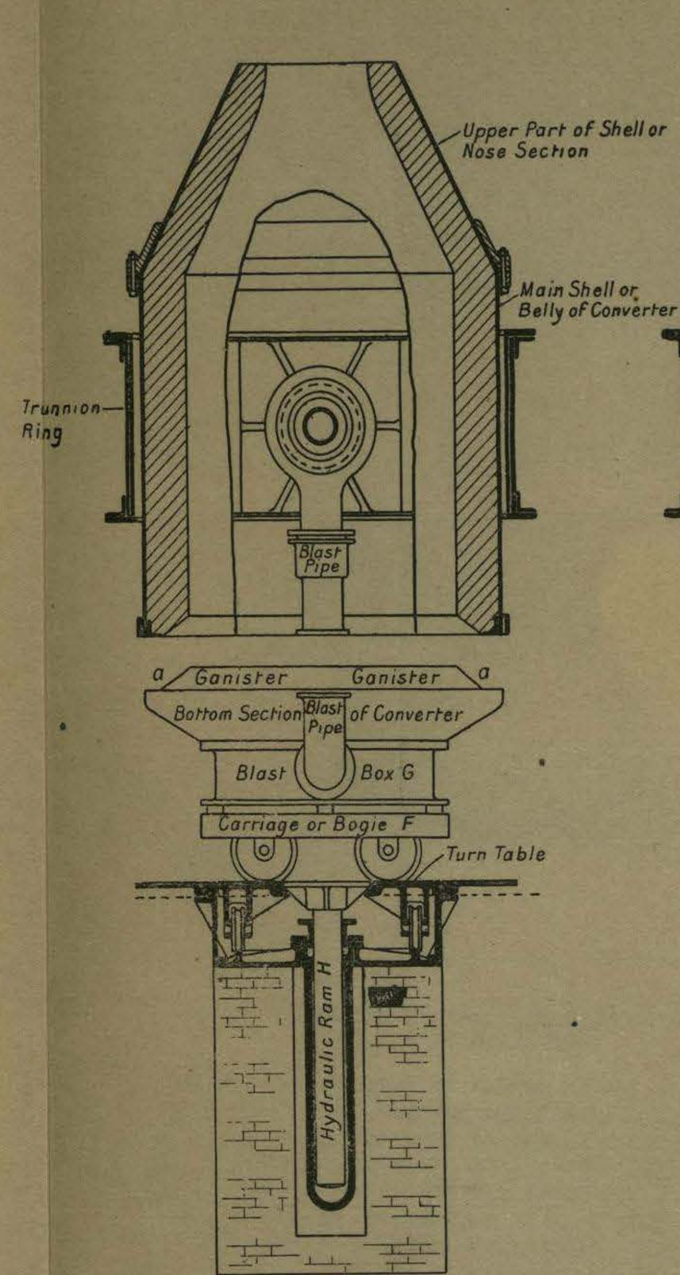


Fig. 8.—Concentric Converter in part section and end elevation, with bottom section on bogie ready to be lifted by hydraulic ram.

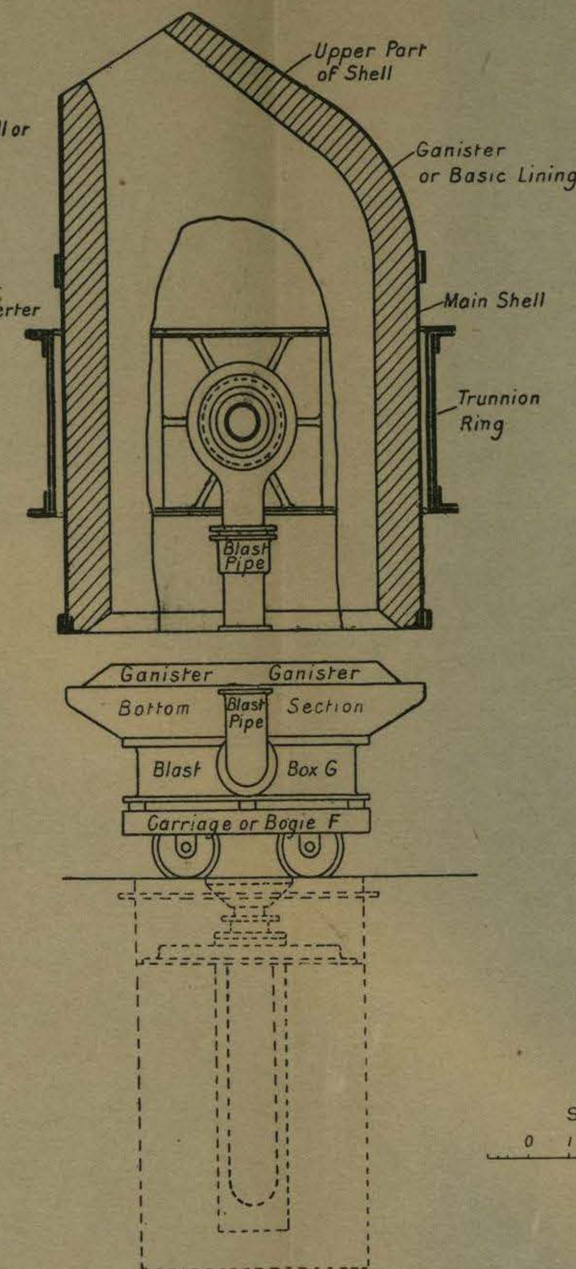


Fig. 9.—Eccentric Converter in part section and end elevation.

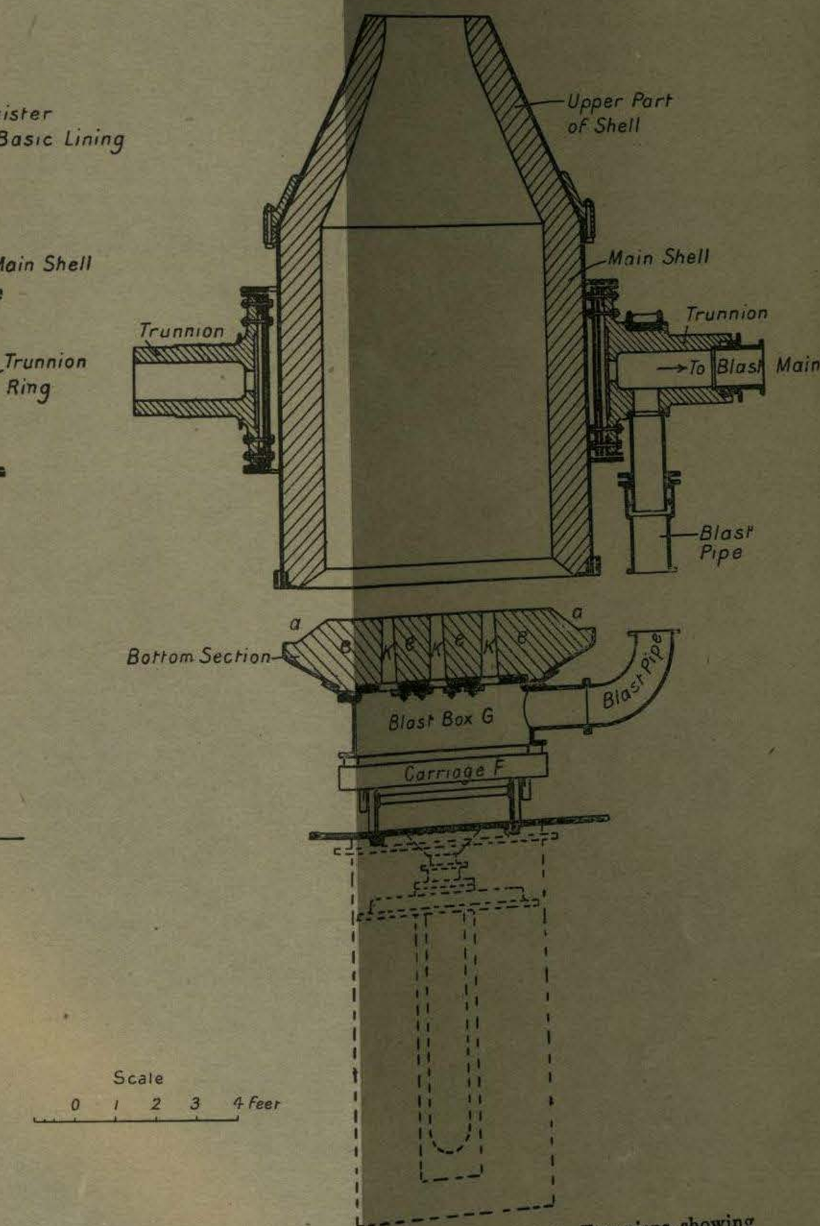


Fig. 10.—Vertical Section of Converter through the Trunnions, showing blast main. The bottom section shows the twyers in position. K K K, twyers; *e e e*, rammed ganister.

In fig. 10 a converter is shown in vertical section through the trunnion and blast main, the bottom section being detached but ready in position for fixing on to the body of the vessel. When fixing the bottom section to the converter, it is raised by the hydraulic ram shown underneath, and firmly secured by means of cotter pins and lugs.

Rotating the Converter.—A very strong iron framework supported on columns carries the converter on suitable bearings, so arranged that the vessel can be rotated on its trunnions through an angle of at least 180°. The rotation is usually effected by means of a pinion keyed on to one of the trunnions, gearing into a rack attached to the end of a double-acting hydraulic ram. The position of the hydraulic ram and cylinder may be either vertical above or below the level of the converter trunnion, or may be horizontal as shown in the sketch (fig. 11). Both the rack and

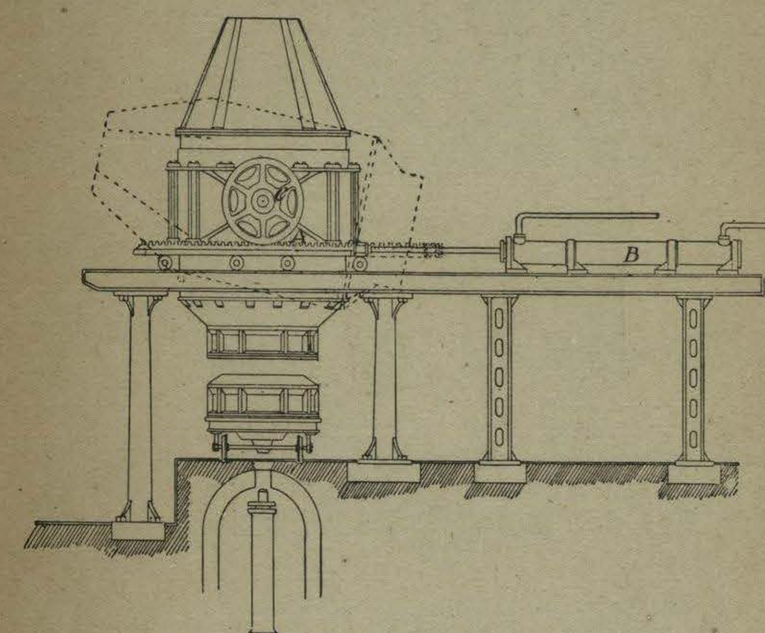


Fig. 11.—Method of Rotating Converter by Hydraulic Rack.—A, Rack ; B, hydraulic cylinder ; C, pinion.

pinion and the ram must be securely cased in sheet-iron to prevent injury by metal or slag splashing upon them. The valves of the hydraulic cylinder are usually controlled at some considerable distance from the converter, from a raised platform known as the pulpit. When the converter is ready to receive a charge of molten metal it is rotated into the horizontal position shown by the dotted lines in fig. 11, and the metal is poured in from a ladle through the nose of the vessel. When in this position the bottom portion of the vessel or converter containing the twyers is above the level of the metal bath, and before rotating to the vertical position for blowing, the air blast, which is of sufficient pressure to overcome the head of metal, is turned on, and prevents the latter from entering the twyer holes or air passages.

In some cases the rotation is effected by a worm and pinion gear, actuated by a hydraulic engine, or by a double or triple cylinder steam engine. In addition to some other advantages, this allows of a complete revolution of the vessel through 360°, while with a rack the movement is much more restricted. The simplicity and strength, however, of the rack and pinion arrangement, and the facility with which it can be manipulated, have made its adoption general, and there can be but little doubt that it is the more suitable for steel works practice.

Lining of the Vessel.—The vessel may either be lined with silica fire brick, built in with very thin Silica cement, making the joints as small as possible, or it may be rammed up entirely with moist ganister, a very infusible siliceous material with just sufficient clay combined with it to enable it to bind when well rammed in a moist condition. If bricked,

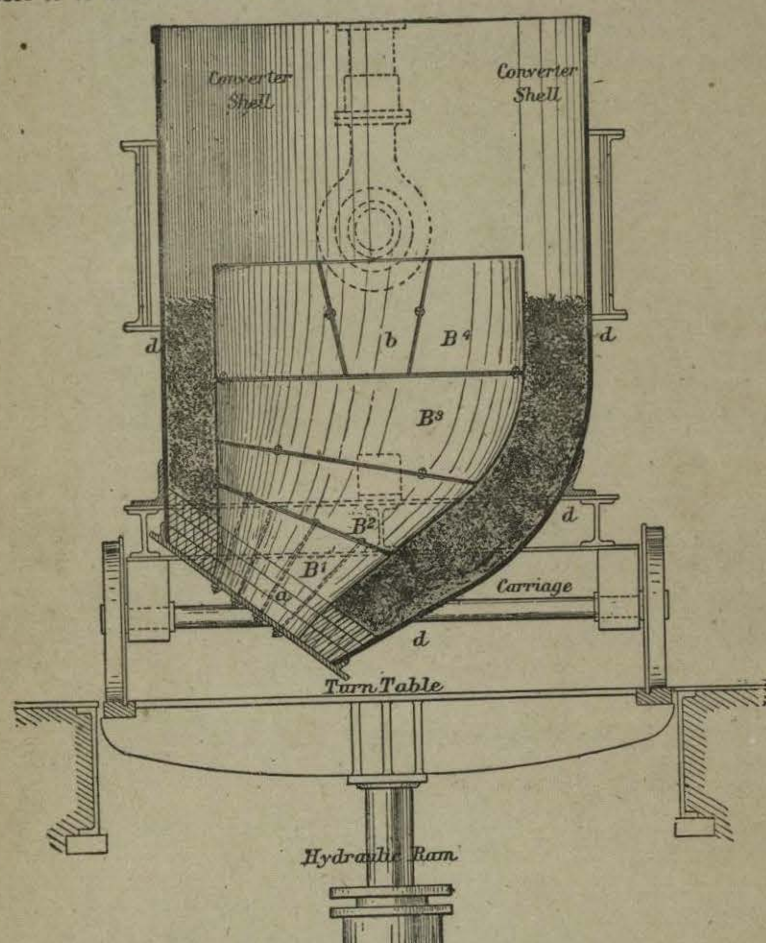


Fig. 12.—Ramming Converter. Core shown in position.

special bricks made to the sweep of the vessel are necessary to obtain a satisfactory result, as otherwise, more or less wide joints will be left in the brickwork, and the molten metal will soon find its way into these, and lead to the rapid destruction of the lining. Bricks, however, are now rarely used, a rammed ganister lining being almost universally employed. When a new shell is to be lined by ramming, the vessel is usually turned upside down, the bottom section having been previously taken off, and the mouth covered with boards or iron plates to afford a base, and two or three

courses of best silica bricks are built round the bottom of the nose section. Wooden or metal cores, made in sections to the sweep of different parts of the vessel, are then placed inside, and the annular space between these cores and the shell of the vessel is rammed with moist ganister by the aid of heavy iron rammers. The cores are generally made in taper segments, for easy withdrawal after the ramming is finished.

In some cases the lining of the vessel is done while it is supported in its bearings as usual, only in the inverted position, but when a plant is working up to the full extent of its output a spare converter is generally kept ready lined, the worn out one being removed and taken away to the repairing shop and replaced by the relined converter. The removal of the converter from its bearings may be effected by an overhead crane, or by a carriage on a hydraulic lift and a turntable underneath the converter as shown in the sketch (fig. 8, Plate i.) By means of the latter the converter is lifted up clear of the bearings, and the whole turned round through an angle of 90°, so that the trunnions will clear the girders supporting the bearings, and then lowered to the level of the rail track, and drawn away to the repairing shop.

Fig. 12 shows the method of lining a converter by ramming, and fig. 13 shows the core with taper sections in the cylindrical portions to facilitate removal after the ramming is completed. After a few rings of bricks have been built into the end of the nose section, for 18 inches to 2 feet, the first part of the core is fixed on these, and bolted to the plate *a* (fig. 12), and men, standing on a platform inside, ram up the ganister level with the core. Then another section of the core is bolted on and the ramming continued, and so on until the lining is completed to the required height.

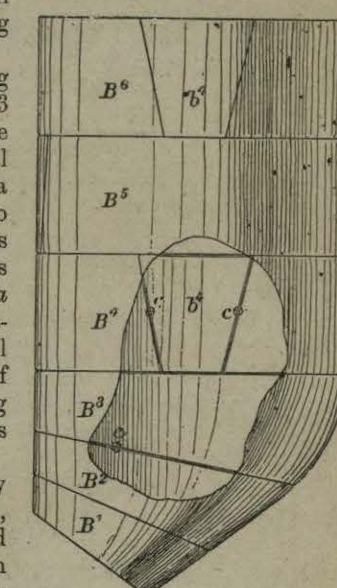


Fig. 13.—Metal or Wooden Core for Ramming Converter.

Instead of using cores sometimes a dry brick wall is built up inside the vessel, and the annular space between this and the shell rammed with ganister. When the lining of the vessel is completed, it is returned to its position in the Bessemer shop, a guard ring being fixed round the bottom to prevent the lining falling away. Having been rotated to its upright position, the bottom section is cottered on in the usual way, and a fire lit in the bottom of the converter, and urged by a gentle blast through the twyers until the whole lining is completely dried.

Details of Bottom Section.—The bottom section consists of the centre containing the fire-brick twyers, supported by a cast-iron plate known as the "bottom plate," and the surrounding portion, *a*, *a* (fig. 14), of rammed ganister, which beds on to the main lining of the converter. Figs. 16 and 17 show a fireclay twyer in plan and section; these twyers are made of best fireclay, like an ordinary fire-brick. The bottom or twyer plate is a cast-iron plate with from 12 to 20 holes from 6 inches to 8 inches in diameter, according to the size and number of the twyers. An inverted plan of this with twyers in position, showing lugs holding them, is given in fig. 15.

The holes in the bottom plate are tapered to correspond with the taper on the wide end of the fire-brick twyers, so that these can be placed in the plate only from the bottom side, and cannot be pushed through it. The

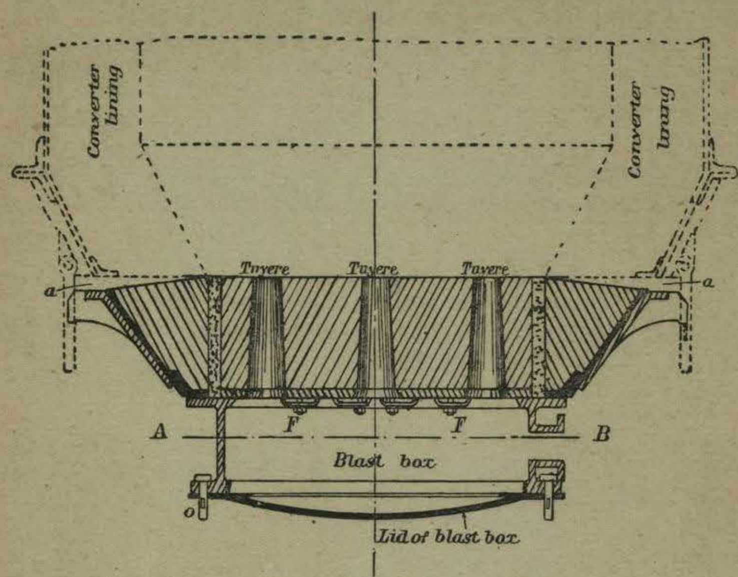


Fig. 14.—Bottom Section showing Twyers.

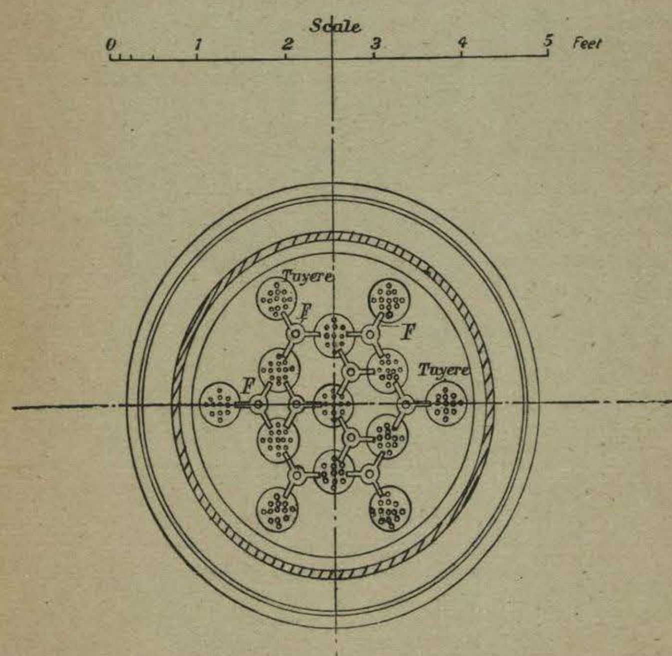
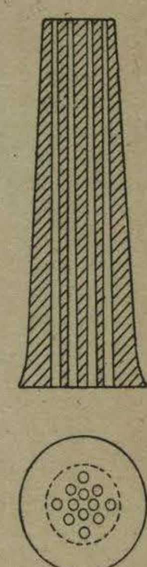


Fig. 15.—Plan of underneath side of Bottom Plate, showing lugs, F, for holding twyer bricks in position.



Figs. 16 and 17.—Twyer Brick for Bottom of Bessemer Converter.

twyers having been inserted in the plate when its under side is uppermost, are fastened in position by claws or lugs, F (fig. 15), held by cotters, screws, or any similar contrivance, none of which must, of course, interfere with the passage of the blast through the twyer holes. The plate is next inverted, and an iron casing, constructed as in fig. 70 (p. 63), or sometimes in two or three sections, is placed round the twyers and fastened to the twyer plate, the spaces round the twyers being rammed up tightly with moist ganister. The "plug" is now ready for drying and baking, and this is usually done in

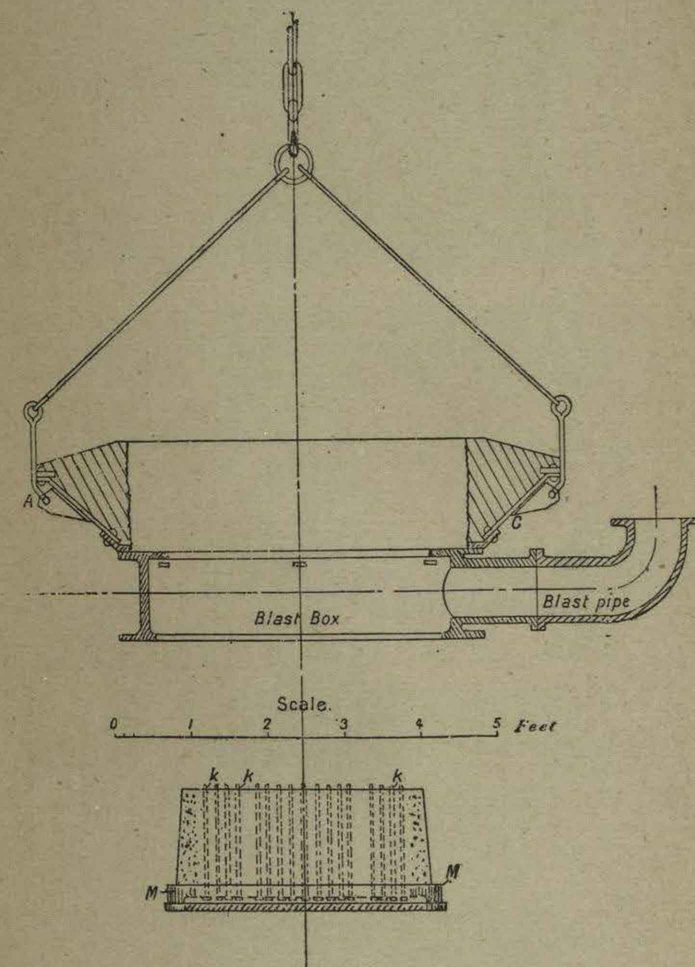


Fig. 18.—Sketch showing method of inserting rammed baked twyer plug in bottom section of the converter.

a special oven, or by means of a gas-heater, and great care must be taken with this operation, as upon this and careful ramming will largely depend its life, and consequently to a considerable extent the output of the converter. The plug may indeed be regarded as the weak spot in the Bessemer plant, for, without apparent reason, a failure may occur at the second or third blow, while at other times, and, apparently under similar conditions, a plug may last 15 or 20 blows, and sometimes more.

At the Barrow Works, instead of using moist ganister, dried ganister mixed with tar is employed, and, it is stated, with better results. Careful drying and baking at a barely visible red heat is required. The plug, having been dried, is drawn on a trolley to a bottom section, from which the old plug has been cut out, and the bottom section is raised by a crane and lowered over the "plug," as shown in fig. 18. In this case a "basic plug" is shown. This will be described later, but the method of fixing the plug is the same in either case. The space "*a*" in fig. 19 between the plug and the ganister lining in the bottom section is now made good by ramming in moist ganister, and the whole bottom section is ready, as shown in fig. 14, for fixing on the converter. It is very important that an air-tight joint should be made between the bottom plate and the top of the blast box at *b* (fig. 19), otherwise the blast will find its way between the two, and force out the ganister ramming at "*a*" between the plug and bottom section; this joint is made by putting a thick daubing of clay round the flange of the bottom plate at *b* before it is in position in the bottom section, and screwing up the set pins, L, very tightly. The weight of the bottom plate is carried by stout pieces of iron which fit into recesses cast in the blast box, and are held up against the bottom plate by set screws, L, as shown.

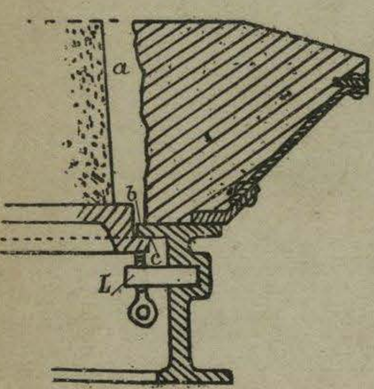


Fig. 19.—Bottom Section, showing method of holding plug in position.

In many Acid Bessemer Works, instead of ramming the plug in an iron casing and drying separately, the old plugs are cut from the bottom section, and a bottom plate with a new set of twyers is put in position, and the whole rammed up with moist ganister. The bottom section and plug are then dried together, but in basic practice the method of making the plug *separately* is always adopted.

Bottom sections are now always made interchangeable, and a number are kept in readiness, so that when one gives out, it can be at once removed and replaced by a new one. The usual method of doing this is to place a trolley on the table of a hydraulic ram, which is generally fixed under each converter, and then to raise the trolley, uncotter the bottom section, lower it by means of the ram, and remove it to the repairing shop. The arrangement for removing and replacing bottom sections is shown in figs. 8, 9, and 10, Plate i.

Replacing a Bottom Section.—In fixing the new bottom it is run on a carriage to the table of the ram, a mixture of fairly wet ganister and fireclay is placed all round the bottom section at *a*, *a* (fig. 10) to form a jointing material, and the bottom is pressed up tightly against the converter by the hydraulic ram and cottered on. The fireclay thus makes a good firm joint, and to make this quite secure, it is generally rammed all round the joint from the outside with small iron rammers. If placed on a vessel already hot from a previous charge of steel, the bottom soon gets sufficiently hot to take another heat, but in the case of a cold vessel, both the vessel and bottom have to be heated with a coal fire previous to blowing.

In some works where there is no hydraulic ram under the converter, the bottom section is hoisted into position and pressed home by powerful screw jacks, and in other cases the vessel is inverted, the bottom hoisted by an overhead crane, the ring of fireclay and ganister placed round the edge of the converter, and the bottom merely cottered on tightly. The old method of placing the bottom plug in and making the joint from the inside by throwing in balls of ganister through the nose of the vessel, and then ramming with long hammer-headed bars, has been generally discontinued, owing to the loss of time and the risk of bad joints.

Repairing "Plug."—Sometimes it happens that *one* particular twyer in a plug fails or gives way from some unknown cause, and as this will leave a large hole in the plug, before the heat can be finished, there may be considerable risk of the molten metal breaking through the bottom plate. The vessel is then turned upon its side, the blast-box cover removed, the defective twyer cut out, and generally a "dummy" or blind twyer (*i.e.*, a twyer without holes) daubed with ganister inserted, and well rammed round with the same material, or the entire twyer-hole may be completely plugged with ganister.

Materials for Lining.—The life of the lining of the vessel depends upon the composition of the material used, the quality of metal blown, pressure of blast, and rapidity of working, but in well-managed works it should, with occasional repairs, average 600 to 800 blows.

When it can be obtained, the best material to use is good Sheffield, or some similar ganister, which should contain 90 per cent. of Silica, and be practically free from alkalies; in some cases it contains as much as 95 per cent. of Silica. The following may be taken as typical analyses of high-class ganister:—

	Per cent.	Per cent.	Per cent.
Silica	92·05	94·60	95·20
Alumina	2·70	1·40	·59
Oxide Iron	1·85	·90	·74
Lime	0·60	·48	·40
Magnesia	0·20	·16	·16
Alkalies	·20	·14	·18
Water	2·00	2·60	2·70
	99·60	100·28	99·97

In many places where ganister of good quality cannot be procured, excellent results have been obtained by mixing together about 50 to 70 per cent. of finely-crushed quartz rock or old Silica fire-brick, with refractory fire sand, and just sufficient good fireclay to act as a binding material. The whole is ground together, so that the largest pieces are not bigger than hazel nuts, and is thoroughly mixed with just sufficient water to make it plastic.* The twyer bricks are made of best fireclay, Stourbridge fireclay, containing from 60 to 75 per cent. of Silica and from 20 to 35 per cent. of Alumina, being largely used in England. They should be thoroughly kilned. In some cases the lining is cut away by the action of the slag and metal, and in other cases it gathers or thickens owing to some metal and slag setting on the sides and near the bottom of the vessel. These accretions can to some extent be prevented by modifying the composition of the slag by the addition of a little lime or other base to form a double Silicate and more fluid slag. Another plan, where possible, is to blow hotter metal—*i.e.*, metal containing more Silicon—by which the heat is increased, and a more fluid slag obtained. Sometimes an increase in the weight of the charge and more rapid blowing will remove these accumulations, or if this fails coke may be put into the

* Howe, *Metallurgy of Steel*, p. 351.

vessel and blown up; the intense heat thus developed will usually have the desired effect, but if it should not, the only course is to allow the vessel to cool and then chip the lining.

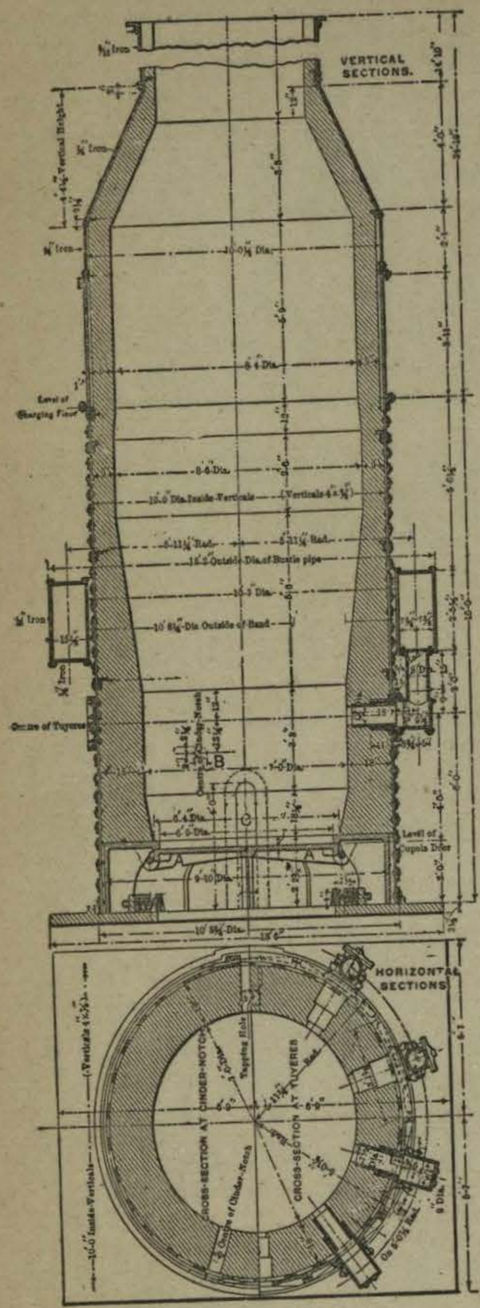


Fig. 20.—Cupola Furnace.

On the other hand, when the lining gets cut away by the action of the slag and metal, it can generally be repaired by throwing balls of ganister through the mouth of the converter to patch the badly worn places; although sometimes it may be necessary to allow the vessel to cool so that the men can get inside to do the necessary repairs.

Cupola Furnace.—The molten metal for supplying the converter may either be melted in cupolas, taken direct from the blast furnace, or taken from the latter and passed through a receiver or mixer before finally passing to the vessel.

The modern cupola is really a small blast furnace. In some cases the outside shell will be 10 to 12 feet in diameter, and the blast pressure as much as 2 or 3 lbs. per square inch. It is lined with fire-brick as a backing and then rammed, usually with ganister or some similar silicious material. The height of the cupola platform should be such that when the cupola is "dumped," or raked out, all the debris falls upon the floor level, and ample room should be left to enable the men to readily remove this. Cupolas with drop bottoms are now generally made and found very convenient. Fig. 20 is a sectional plan and elevation of a modern cupola with leading dimensions, and fig. 21 shows the general arrangement of a large cupola working in America, charged by a Wellman charging crane, but the latter is not in use in England for cupola work. A moderate sized cupola, about 6 to 7 feet diameter, outside of

shell, with 5 or 6 twyers and a pressure of blast of 1½ to 2 lbs., will melt 200 to 250 tons of pig-iron per twelve hours.

Position of Cupola.—The position of the cupola in relation to the converters is a matter of considerable importance, and must in the first case depend upon whether it is proposed to tap molten iron direct into the converter by runners, or into a ladle on the same level as the converters, or whether the metal is to be tapped into a ladle on the ground level, and the ladle then raised by a lift or other mechanical appliance and the metal poured into the converter. It may be taken, that in all modern works the latter plan of having cupolas arranged to deliver the molten metal on the ground level is almost universal, and the older plan of tapping direct into the converter, or into a ladle on the converter level, has been discarded. It only remains therefore to select such a position for these furnaces as may be most convenient for receiving the raw material, and for the delivery of the molten metal to the converter platform. This may be either behind or at one end of the converter platform, but should be more or less in a line with the converters, and as near as convenient to the lift.

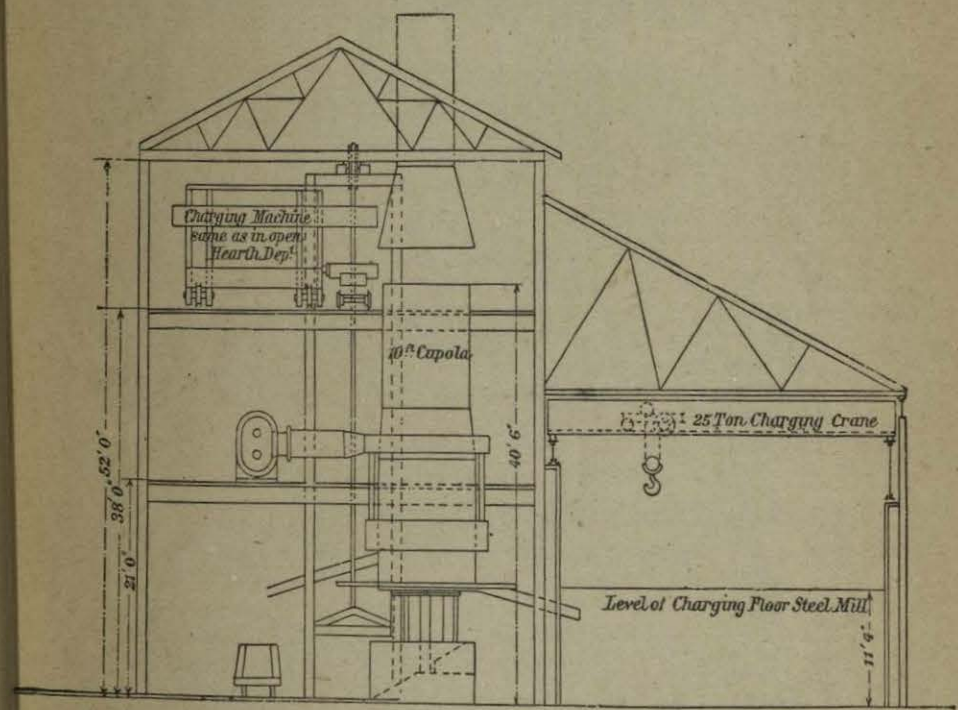


Fig. 21.—Cupola with Wellman Charging Machine. The boxes are taken up on lift full, lifted by machine on cupola platform and emptied into cupola.

The Metal Mixer or Receiver.—From an economic point of view, both as regards labour and fuel, the ideal method is to take molten iron direct from the blast furnace to the converter, and so save the cost of re-melting in a cupola; but owing to the irregularity in composition of such metal, although it has been frequently attempted and in some works is still done, it has been in most cases discontinued. Unless iron of fairly regular composition is used for Bessemer practice, the irregularity in the quality of steel produced, coupled with the decrease in yield, has been found to more than neutralise the saving in re-melting. It has been found, however, that if runnings or tappings from several blast furnaces can be mixed together, high Silicon or Sulphur in the metal from one furnace is compensated for by low Silicon or Sulphur in the iron from another, and this together with a certain amount of purification, due to chemical action, produces a metal of fairly uniform composition. For some years now it has therefore been the practice to pour the molten blast metal from a number of furnaces

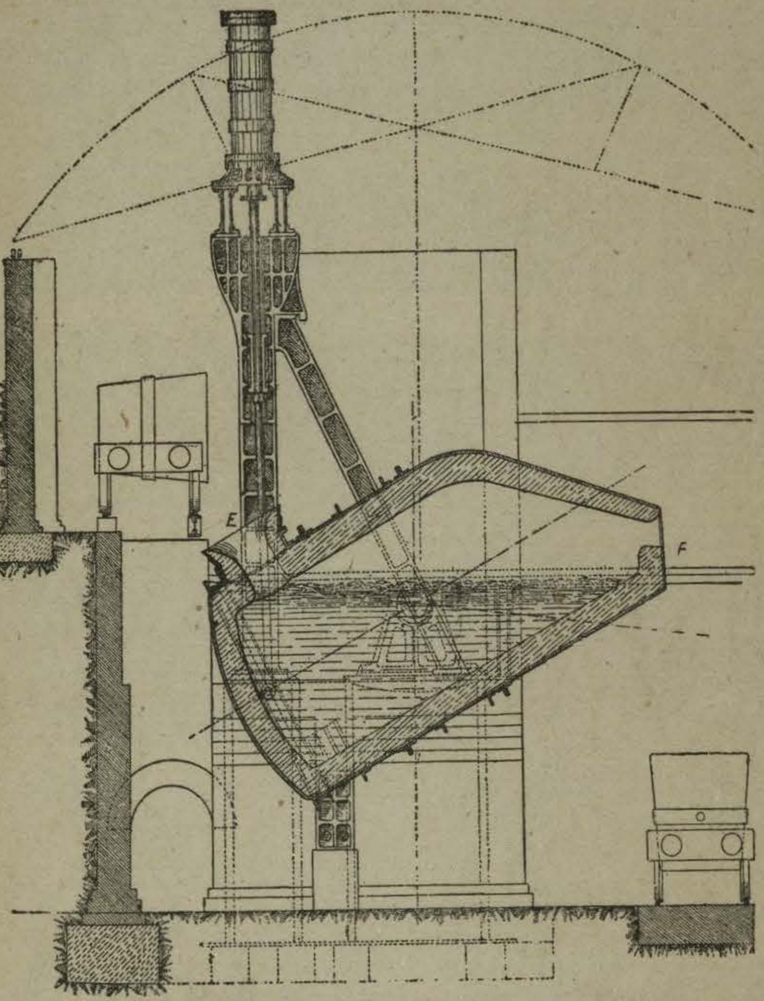
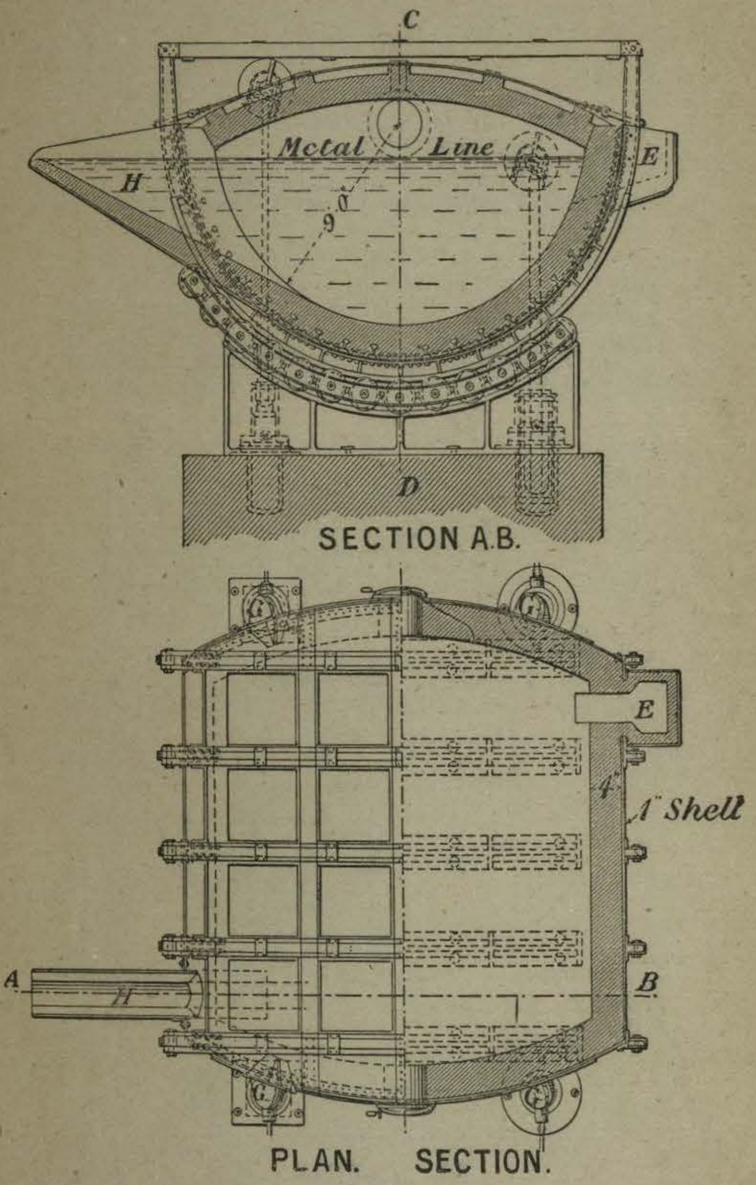


Fig. 22.—150-ton Metal Mixer at North-Eastern Steel Works. It is tilted by a hydraulic cylinder above the mixer. The blast furnace metal is poured in at E and discharged at F into ladle on ground level.

into a large vessel known as a "mixer or receiver." The receivers originally designed were large converter-shaped vessels lined with ganister, and capable of being tilted by powerful mechanical gearing. Fig. 22 shows the 150-ton mixer, erected some years ago at the North-Eastern Steel Works, Middlesbrough, the tilting gear being above, so that in event of the metal breaking out it will not be damaged. The various casts of metal from the blast furnace are transferred in ladles to the mixer, and poured in through

an opening at the top. When the vessel is nearly full, sufficient metal for a "blow" is poured out into another ladle and taken to the converter, additions of blast furnace metal being made to replace that removed from time to time.



Figs. 23 and 24.—300-ton Metal Mixer—E, Filler; H, pouring spout.

By means of this mixer metals of varying grades, as has been described, can be mixed together, so that a product of fairly uniform composition is obtained. Thus, if a blast furnace is from some accidental cause making white iron—a metal unsuitable for conversion into steel, firstly, on account of the low heat it would yield, and secondly, on account of its high content