the gas escapes varies from 100 to 200 lbs. on the square inch, and enables it to be taken great distances. It gives excellent results in steel making, being practically free from non-combustible gases, and of such high calorific power, that no regeneration of the gas is necessary, the air only being superheated. The foregoing table gives typical analyses.

Unfortunately we have not so far discovered any large stores of natural gas in this country, and we have to rely entirely upon gas made from coal or coke for steel manufacture, and in this respect are seriously handicapped in competing with American manufacturers.

CHAPTER VII.

THE OPEN HEARTH OR SIEMENS PROCESS.

THE process of manufacturing steel in the open hearth regenerative furnace, which we owe chiefly to the genius of Sir William Siemens, is the only process which has in any way proved a serious rival to that of Bessemer. The difficulty of obtaining a sufficiently high temperature to maintain a large quantity of decarburised iron in a fluid condition was the chief obstacle to the solution of the problem, and it was only after many experiments, involving great expense and labour, that the efforts of Sir Wm. Siemens and his brother were crowned with success. They first gasified the fuel in a separate furnace called a producer, and then raised this and the air necessary for its combustion to a high temperature by means of the waste heat derived from the previous combustion stored up in fire-brick checkered chambers, which they called regenerators. They then conducted the superheated gas and air by separate flues to the hearth of the furnace, where combustion took place with the production of an extremely high temperature. Great difficulties were experienced in the early days in obtaining for the roofs of the furnaces refractory materials which would both withstand the high temperature and the contraction and expansion; but these were gradually overcome, and in 1867 to 1868 the success of the process was demonstrated at an experimental works at Birmingham, large quantities of steel being made from old rails and similar material. Gradually the problem of desiliconising and decarburising pig-iron, with and without steel scrap, by means of iron ore as the oxidising agent, was worked out, and in 1868 the Landor Steel Company was started. In France, Messrs. P. & E. Martin also attacked the problem; but, instead of using ore, they worked with steel scrap and pig-iron alone, dissolving the scrap in a bath of molten pig until, by the diluting down of the impurities combined with their partial removal by oxidation, they produced a steel of the required grade. This process was known as the Siemens-Martin, as distinguished from the Siemens process, in which ore and pig alone were used; but the distinction has long ceased to be of any importance, the almost universal practice now being to use both ore and scrap with the pig, especially in this country.

The original furnaces built at Landore were only of 3 to 4 tons capacity, but now it is by no means uncommon to find furnaces working charges from 40 to 50 tons, and some metallurgists anticipate that the 100-ton furnace will be the one of the future. Furnaces of a larger capacity than this are now in operation working the Talbot process, which is a modification of the Siemens process.

General Description of Furnace.—The Siemens furnace consists of a large hearth built of refractory material, upon which the metal is melted without contact with any solid fuel. At each end are arranged two chambers filled with checker fire-bricks, through which the air and gas pass on their way into the furnace, and through which the products of combustion pass at the other end on their way to the stack. One of these regenerators on each side is called the gas, and the other the air regenerator, and they are separated by substantial walls to prevent the air and gas mixing in any way before it reaches the hearth of the furnace. The furnace and regenerators having been heated up, gas and air are admitted through their respective regenerators on one side of the furnace, and these, by circulating amongst the hot brickwork, become heated, and finally meet in the hearth of the furnace where combustion takes place. The products of combustion then pass indiscriminately through the gas and air regenerators at the other side, and give up the greater part of their heat to the brickwork through which they circulate on their passage to the stack. At regular intervals, depending somewhat upon the way the furnace is working, the direction of the gas and air is reversed by means of valves, so that the regenerators are alternately heated up by the products of combustion and cooled by the incoming air and gas. There are altogether four valves apart from the chimney damper; two are ordinary mushroom valves, one of which controls the admission of the air and one the gas, and two are known as reversing valves for altering the direction of the current of air and gas respectively.

The diagrams in Plate vii. illustrate the general arrangements of the furnace, showing how both gas and air are admitted to the furnace, and the arrangement of valves for controlling and reversing the direction of both.

The Siemens process, like the Bessemer, can be worked either with an acid or a basic lining, Hematite or Phosphoric pig being used according to the lining adopted. The removal of the impurities in either case depends broadly upon the same principles as in the Bessemer—viz., the oxidation, the retention, and removal of such impurities in the slag. In the basic Siemens lime additions are made to form a stable Phosphate exactly as in the basic Bessemer.

Before describing either process in detail, the plant employed, which is common to both, will be described, as the gas producers, regenerators, furnace, valves, &c., are the same for both acid and basic, except in some minor details.

The Furnace.—Variations in the construction of furnaces to meet special requirements are very numerous, but after many experiments with round and elliptical furnaces, experience has demonstrated that a rectangular furnace, as originally used by Sir William Siemens, gives by far the best results in actual practice. The body of the furnace should be built of iron or mild steel plates, lined internally with the best silica bricks, and should be carried on steel girders quite independent of the regenerator arches, so that air can freely circulate underneath the bottom of the furnace, as shown in Plate viii. If an open space is thus left under the furnace bottom, and regenerators are kept well to each end, in the event of the metal breaking through the bottom there is no danger of its getting into the regenerators. In the old type of Siemens furnace it was usual to build the hearth (as shown in fig. 113) over the regenerators, and to use the regenerator arches to support the furnace, but this is never done now. The whole structure must be most strongly braced together by tie-rods to control the expansion of the refractory materials, and probably the best plan is to encase the entire body of the furnace in steel plates, well rivetted together and strengthened by strong supports secured by tie-rods across the top of the furnace. The bottom of the furnace is usually made of cast-iron plates, but these may be of steel. The walls, roof, and the whole of the interior except the actual hearth on which the molten metal has to rest, are built up with best silica fire-bricks (as shown in the accompanying sketch), the hearth itself being lined either with silica sand or with basic material, according to conditions of working.

On Plate viii., figs. 123-126, are given the sectional elevations and plan of a modern Siemens furnace, designed by the late Mr. Bernard Dawson for basic work, but equally applicable for acid steel manufacture. The body

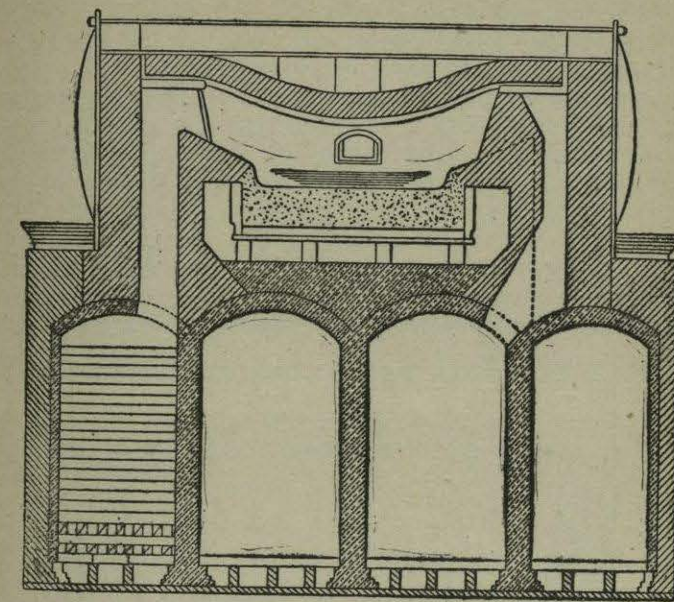


Fig. 113.—Old-fashioned type of Siemens Furnace, with dip roof and body of the furnace supported on the regenerator arches.

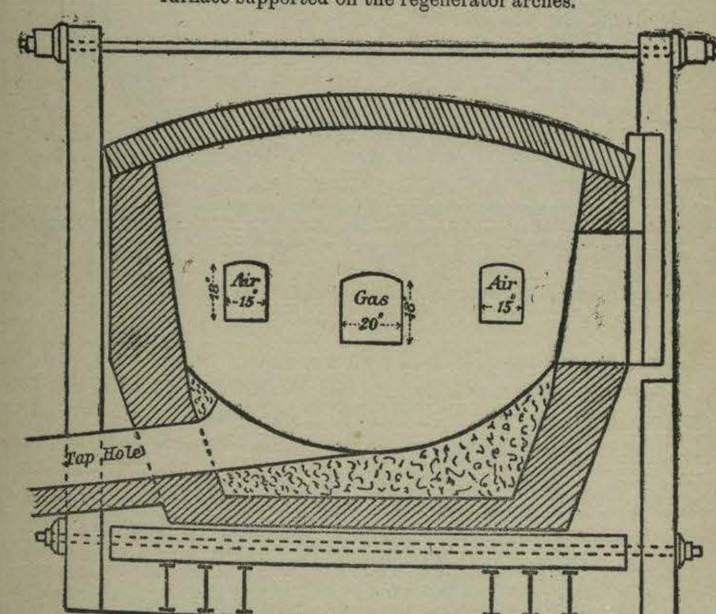


Fig. 114.

of the furnace is rectangular, supported on girders independent of the regenerator arches, and the air regenerators are $\frac{1}{4}$ to $\frac{1}{3}$ larger than the gas. The gas enters the hearth of the furnace from the regenerators through two openings known as " ports," and the air through three, and these are arranged side by side. The section on J, K shows these "ports;" the solid brickwork through which they pass is known as the " block," and must be very strongly built to prevent the " ports " giving way, owing to the intense heat and contraction and expansion to which they are subjected.

It is of the greatest importance in furnace work that the combustion of the gas in the furnace hearth should be as perfect as possible, for not only will the calorific efficiency of the furnace as a heating machine depend upon this, but also the calorific intensity of the flame, so important for rapid production of good steel. That the combustion is largely affected by the way the gas and air enter the furnace—that is to say, by the position of the " ports " and by the form of the roof—there can be little doubt; but as to what is the best arrangement, considerable difference of opinion exists. We find furnaces doing very good work with one large gas port, and with

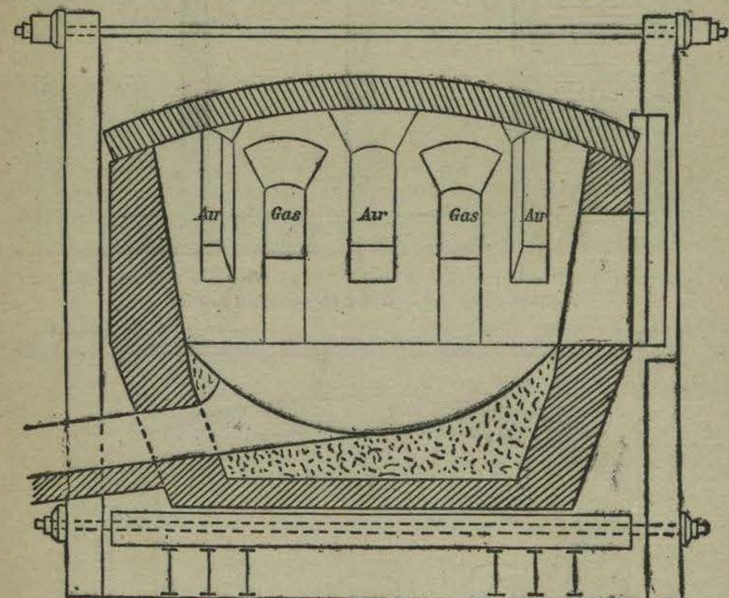


Fig. 121.

an air port on either side (as shown in fig. 114); others with two gas and three air ports, as shown in fig. 121 and in the diagrams of the Dawson-Siemens furnace (Plate viii., figs. 123-126); and others with two gas ports, the usual height above the fore plate, and two air ports near the roof (fig. 122); or, again, others with two gas ports and two air ports above them, as shown in Plate vii., fig. 117. The position of the ports will to some extent depend upon the roof. In Sweden very high-roofed furnaces, with dome-shaped arches, and so-called " gallery ports "—*i.e.*, gas and air ports side by side at the same level—are said by Mr. Odelstjerna * to give very good results and to induce very perfect combustion. Taking all things into consideration, the arrangement of ports, shown in fig. 122, is as good as any, and it admits of the blocks being made very solid and strong, a very important matter from a practical point of view. In the original form of Siemens furnace,

* *Trans. American Inst. Mining Engineers*, 1894.

ns Regene

and are best handled by an overhead

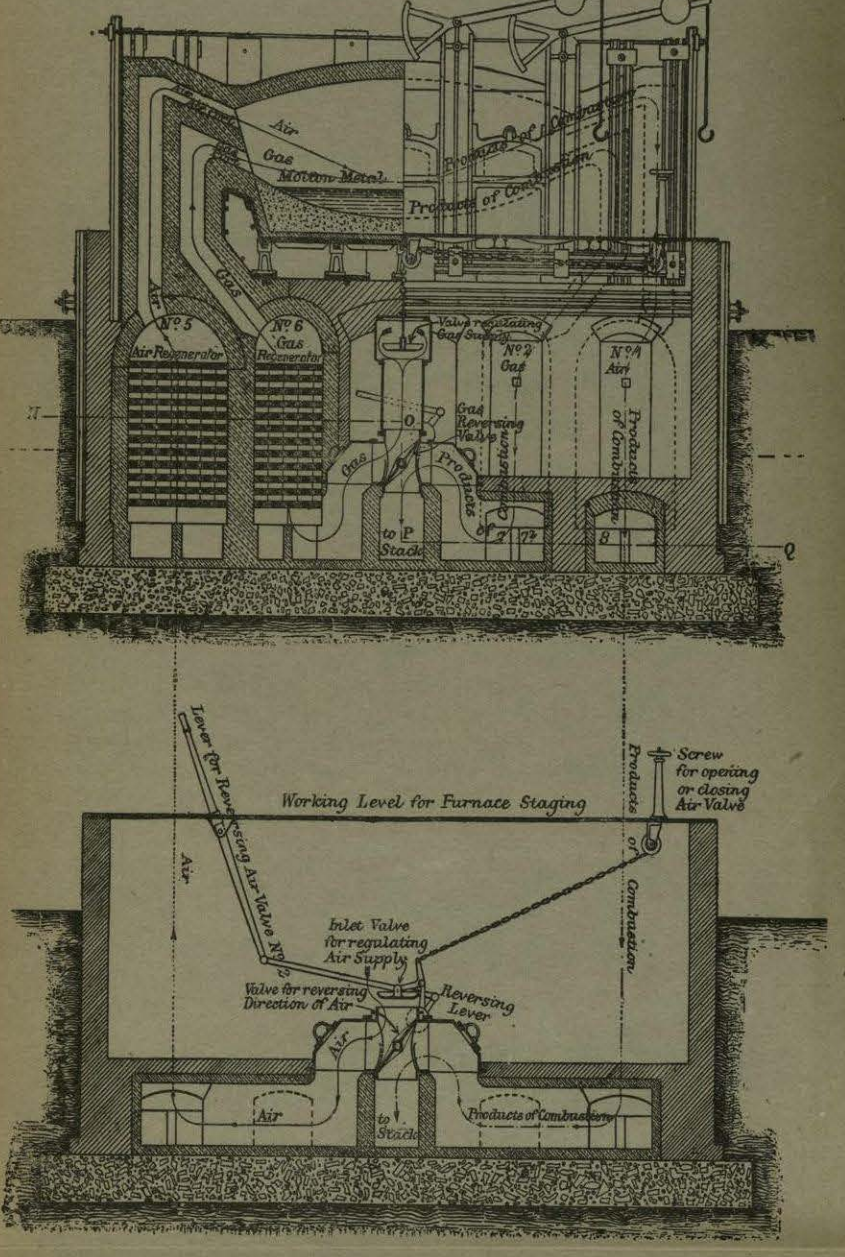
Valves.—Valves marked gas inlet and air inlet are for regulating the quantity of gas and air admitted. Valves marked gas and air reversing valves are for reversing the direction of the gas and air in the furnace, and are quite independent of the inlet valves. The general valve arrangement for controlling the supply and reversing the direction of the current is shown in separate sketches (figs. 119 and 120). There are four valves in all—one gas and one air inlet, and one gas and one air reversing. By raising or lowering the gas or air inlet by means of the screws G and A, more or less gas and air is admitted. By swinging the reversing valves over into the position shown in these figures, the direction of the gas and air is reversed, and instead of passing through the left-hand regenerators on their way to the furnace, as shown by arrows in figs. 115 and 116, they pass through the right-hand regenerators.

Fig. 115 is a longitudinal view of the furnace, partly in section and partly in elevation. The gas inlet and gas reversing valves are shown, but the air valves being behind the gas valves cannot be seen in their actual position, so are shown in a separate sketch projected below (fig. 116), the arrows indicating the direction taken by the air and products of combustion. The actual position of these gas and air valves in relation to each other will be seen by referring to the transverse section (fig. 117), and the sectional plans (fig. 118).

In the diagram gas and air are shown entering the furnace through the ports or inlets from the regenerators on the left-hand side of the sketch, and the products of combustion passing through the regenerators on the right-hand side on their way to the stack, as indicated by the arrows. When the reversing gas and air valves are swung over into this position, shown in figs. 119 and 120, the gas and air enter on the right-hand side and the products of combustion leave by the left. The inlet valves are not altered when reversing.

Fig. 117 shows a transverse section through the tapping hole of the body of the furnace, with ladle in position, ready for casting, and is intended, aided by more detailed drawings given elsewhere, to give a general idea of the construction of the furnace.

Pig-iron and scrap steel are charged in the cold state on to the hearth of the furnace, and when it is melted iron ore is added to oxidise the impurities. When the conversion into steel is complete an iron bar is driven through the taphole, shown in fig. 117, by means of sledges, to remove the stopping of fireclay which has been rammed in previous to starting the furnace, and the metal flows down the spout into a ladle standing in the position shown. When the metal has all passed into the ladle, the support to the metal spout near the furnace is knocked away, the spout swings over on the hinge shown, and the slag flows into the slag hole.



Figs. 115 and 116.

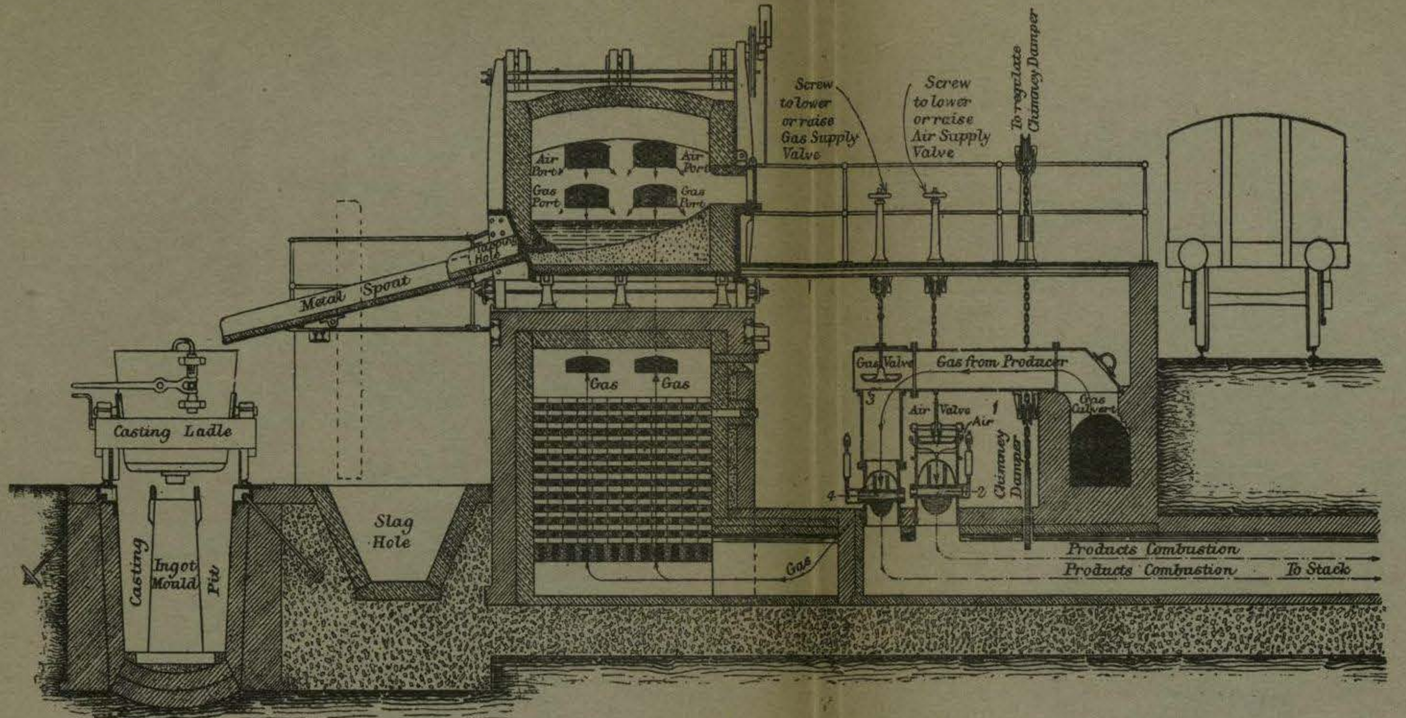
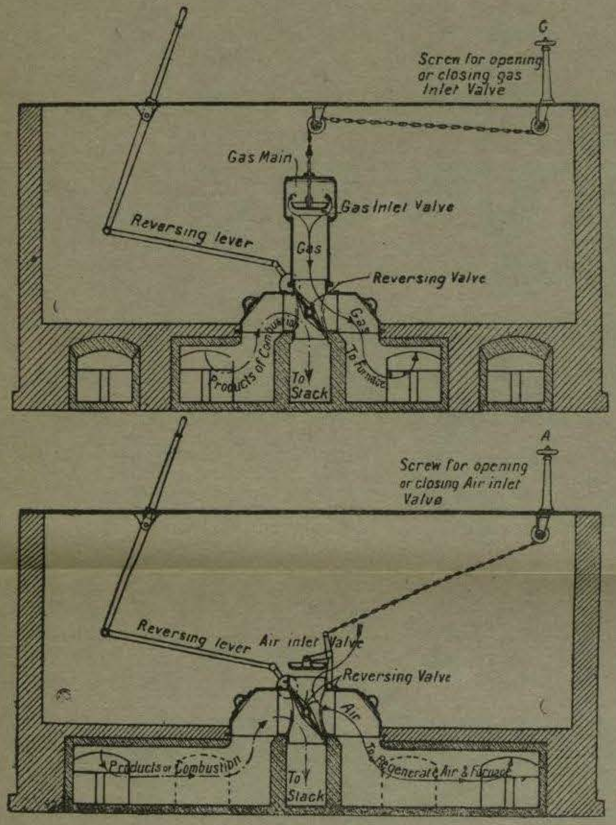


Fig. 117.



Figs. 119 and 120.

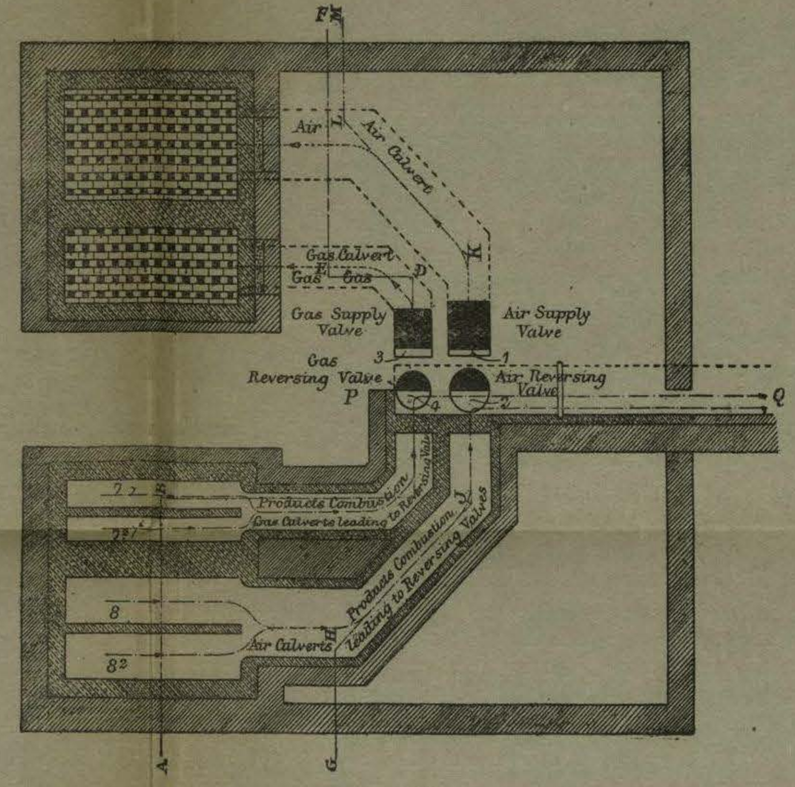


Fig. 118.

Trans. American Inst. Mining Engineers, 1894.

the roof was made with a dip to the centre (as shown in fig. 113) with the object of deflecting the flame on to the bath of metal, but the roof was found to be rapidly burnt away; and in all modern furnaces the best results are obtained with fairly high roofs, the inclination of the gas and air ports being quite sufficient to cause the flame to impinge on the bath. With a large arch thrown over the entire hearth, springing from walls about 3 feet 6 inches to 5 feet above the fore-plate level, according to the size of furnace, and with a rise of about 15 inches in the centre, a large combustion chamber is provided, in which perfect combustion can take place with the least possible destructive action on the roof.

The increase in the dimensions of modern furnaces, together with the more general use of molten metal in Basic practice, has put a very severe strain on the refractory linings of the furnaces, and considerable attention has been given to modifications in construction with a view to increasing

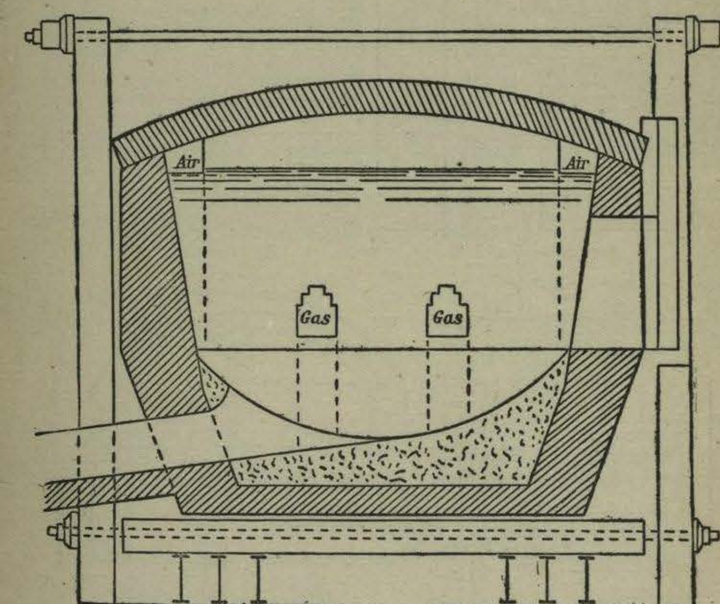
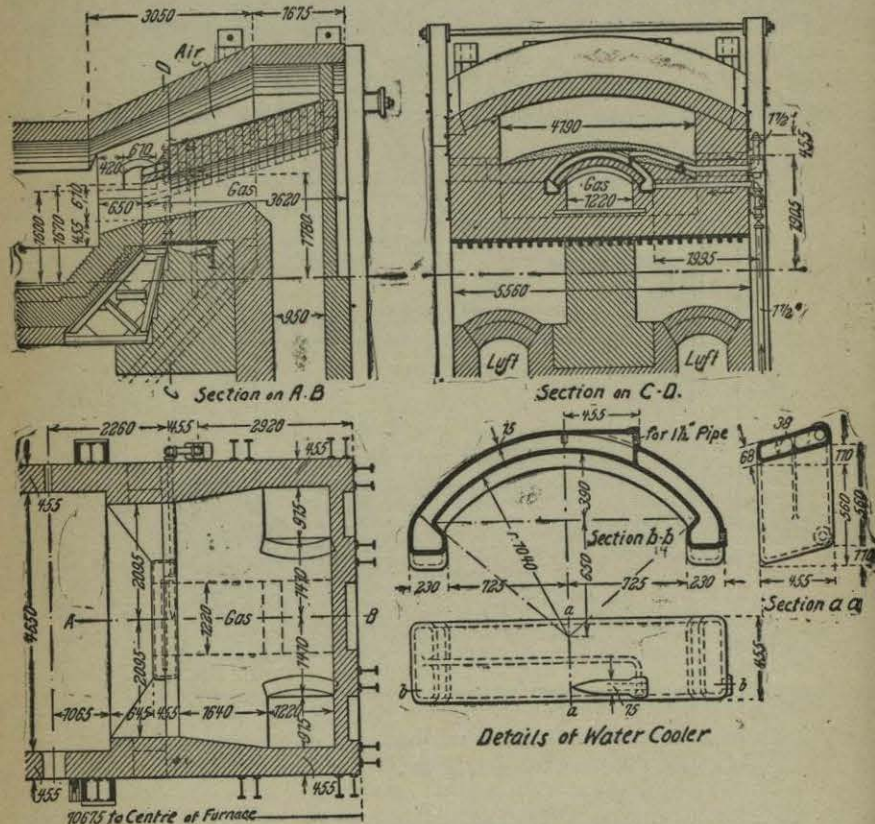


Fig. 122.

the life of the furnace. The "blocks" in which the ports are built are especially subjected to the cutting action of the flame, and the fluxing and abrading action of solid particles of ore, lime, &c., carried by the gases, and require frequent repairs compared with the body of the furnace, and various devices have been tried to facilitate such repairs and to reduce the wear and tear as much as possible. In some cases air-cooled hollow castings are introduced into the "block," which help to prolong the life of this part of the furnace under the extremely high temperature to which it is exposed, combined with contraction and expansion due to cooling down more or less after every charge (see Plate ix.). Owing to the great difficulty of repairing the "block" while the furnace is still hot, interchangeable blocks, which can be removed and replaced bodily by new "blocks," have been introduced at several works with good results. These blocks weigh from 9 to 10 tons, and are best handled by an overhead crane.

Water-cooling of the face of the arch between the gas and air ports has also been practised for some time in America, and is also being used in this country in the large Talbot furnaces. The latest device is to use bronze water-coolers, which, although more expensive, are said to give more satisfactory results; mild steel pipes of not less than 2 inches diameter, however, give very good results, provided a very rapid flow of water is maintained, and every precaution taken to prevent any obstruction getting into the pipes. Fig. 122a shows the details of a "block" with bronze water-coolers in use at Gary Works in the United States.*



(*Dimensions in Millimetres.*)

Fig. 122a.—Sectional Elevations, Plan, and Details of an Open Hearth Furnace "Block," with Bronze Water Coolers, in use at Gary Works, U.S.A.

The Maerz Port.—A new form of port recently tried on the Continent is shown in fig. 122b, and is said to give very good results. Instead of the air port being above the gas ports, as is usual in most modern furnaces, the gas comes in at the top, and the air is led in through vertical ports, as shown in fig. 122b, and meets the gas just as it enters the furnace chamber. It is claimed that complete combustion takes place at the entrance ports, an intense flame is formed before the gas has travelled any distance, the flame is kept away from the roof by direction given to the incoming gas, and the risk of the flame cutting the port block at the other end of the furnace is greatly

* *Stahl und Eisen*, 1910, No. 2, and *Iron and Coal Trades Review*, February 18, 1910, p. 259.

reduced. The gas and air flues are very accessible, so repairs can be easily effected, and being largely air-cooled on the outside, withstand the intense internal heat better than the ports in the ordinary open hearth furnace. The air ports are built as high as possible, and are protected by a bridge to prevent the slag overflowing into these during the reaction. A 30-ton furnace working with molten metal has been in operation at the Ostrowiec Works

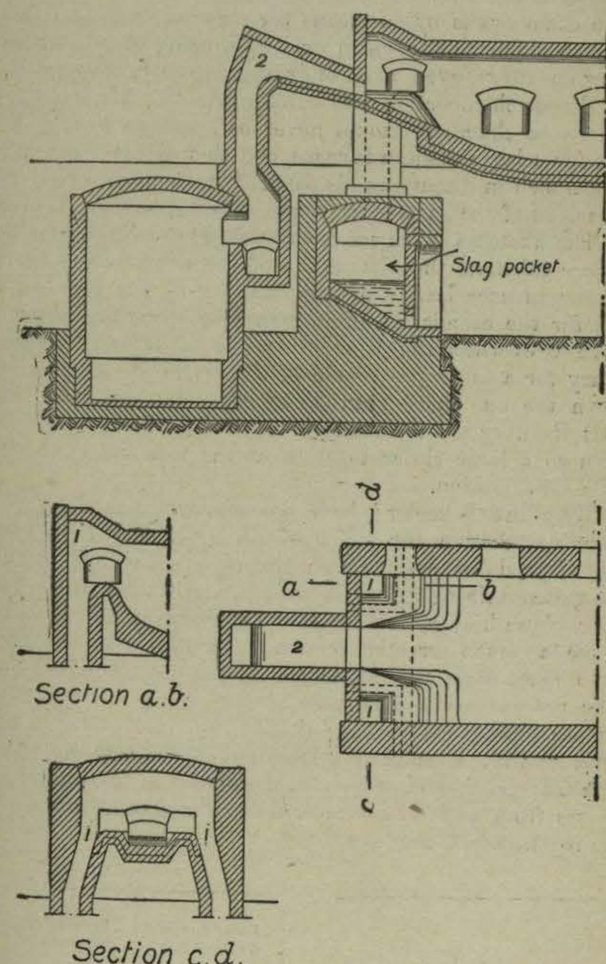


Fig. 122b.—Maerz Port.

1, 1, Air Ports; 2, Gas Ports.

since 1912, and the results obtained were so satisfactory that they decided to alter all their furnaces and erect this form of port.

The Regenerators.—The regenerators, as will be seen from the sketch, are filled with checker brickwork, put in dry, arranged so that bricks and air spaces occur alternately. The best size for the regenerators for air and gas is a somewhat disputed point, and must depend to some extent upon the conditions of working. In some furnaces the gas and air regenerators are made the same size, but it is far more usual to make the air the larger, and this is very much the better practice, as the temperature of the air has more influence on the perfect combustion of the gas than the temperature of the latter. There is, however, no great disadvantage in making gas and air of equal size, provided both are large enough, but sufficient regenerative surface is *most essential to economic working*. The mere cubic contents of regenerative chambers is by no means the only factor to be considered, the relation of the depth to the width or length being of greater importance; thus, shallow chambers, even when of greater capacity, may not be nearly so efficient as deeper chambers of less cubic contents. Mr. H. C. Macmillan considers that the chambers should never be less than 15 feet deep, preferably 20 feet for a large modern furnace, and this opinion was confirmed by other practical men in discussing his paper;* he further considers that the relative capacities of the gas and air regenerators should be in proportion of 1 to 1·37. The sketches given are from working drawings, and the student can from these calculate the dimensions of the regenerators in relation to the size of the furnace hearth or the capacity of the furnace, and make this a basis for the calculation of regenerative space for larger or smaller furnaces. In cases where the regenerators are of different sizes there may be a tendency for a large proportion of the waste products of combustion to flow down the one more than down the other on their way to the chimney, but if an excess is found to be passing down one, a few courses of bricks placed a little closer together at the top will generally effect a more equable distribution.

Messrs. Bone and Wheeler † have pointed out that changes according to the reversible reaction $CO + H_2O \rightleftharpoons CO_2 + H_2$ may take place during the passage of producer gas through the regenerator. Thus, during the passage of a gas containing steam, Hydrogen, and Oxides of Carbon through a regenerator whose highest temperature lies between 1,086° and 1,205° C., there will be a much greater tendency for the Carbon Dioxide and Hydrogen to react with the formation of Carbon Monoxide and water than for the reverse reaction to take place.

It therefore follows that a gas initially rich in Hydrogen and Carbon Dioxide will exhibit a marked disposition to change in the direction $CO_2 + H_2 \rightarrow CO + H_2O$, and Mr. J. H. Darby ‡ has shown that the composition of gas from a Mond producer does change considerably on passing through the regenerators, thus—

	Entering the Regenerator.	Leaving the Regenerator.
	Per cent.	Per cent.
Carbon Dioxide, ...	17·8	10·5
Carbon Monoxide, . . .	10·5	21·6
Hydrogen, ...	24·8	17·7

* *Proceed. Institute Cleveland Engineers*, January, 1903.
† *Iron and Steel Inst. Journ.*, 1908, vol. iii., p. 228.
‡ *Ibid.*, 1896, vol. i., pp. 1-26.

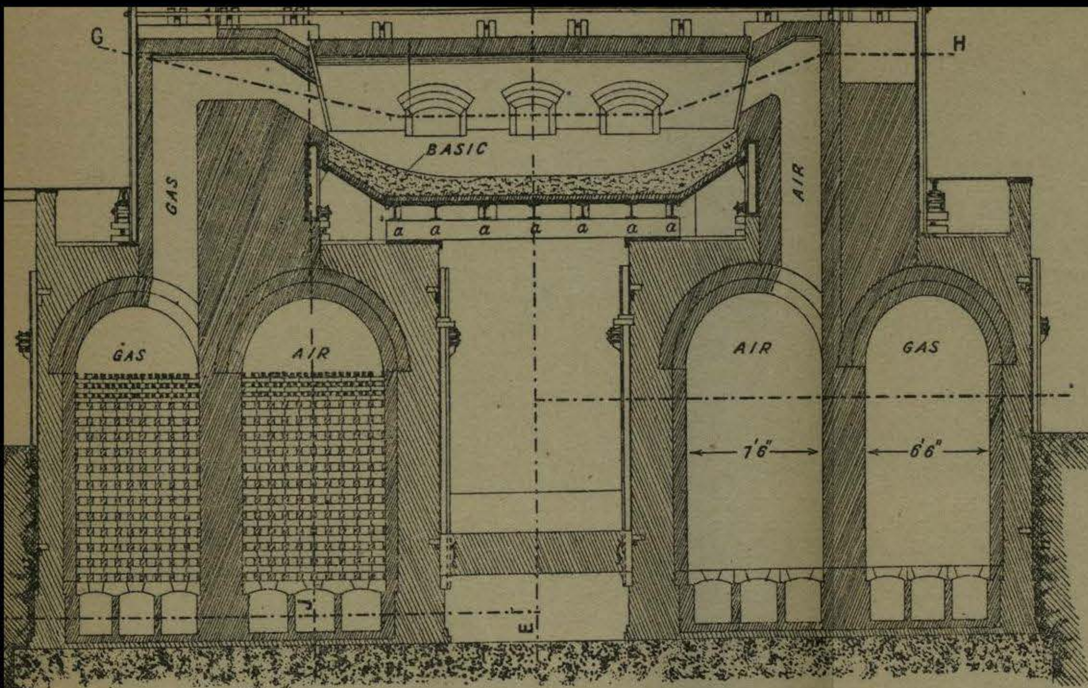


Fig. 123.

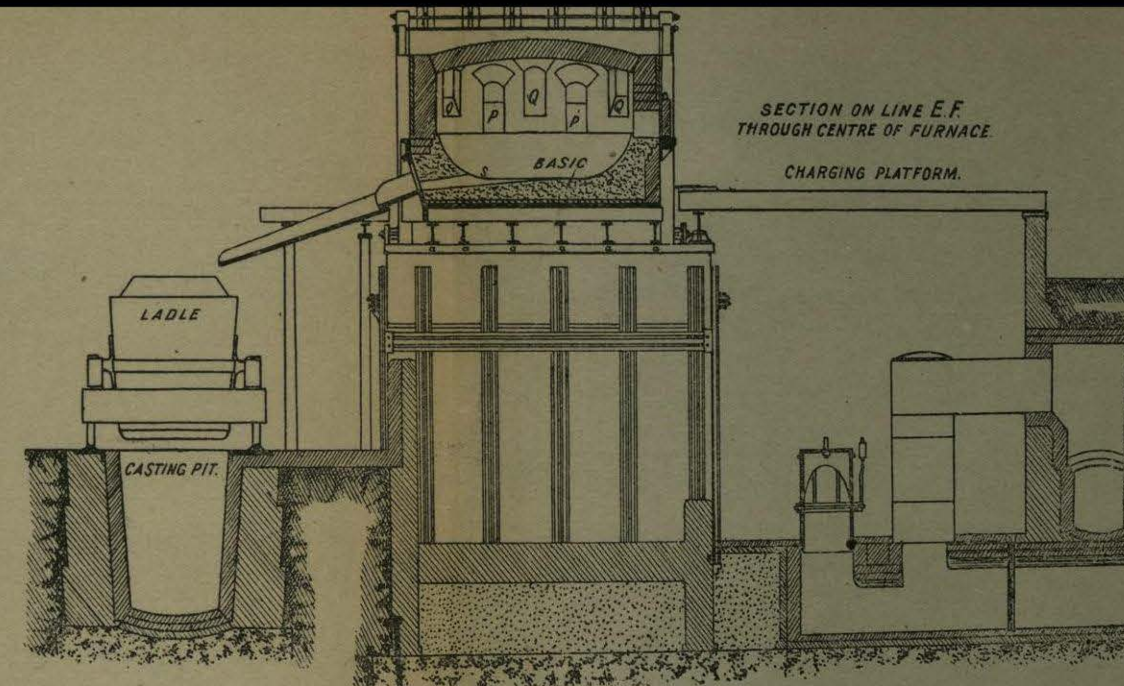


Fig. 125.

NORMAL SECTION ON LINE N.O

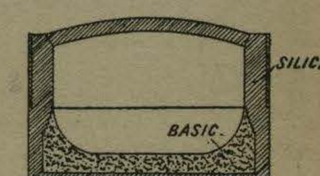
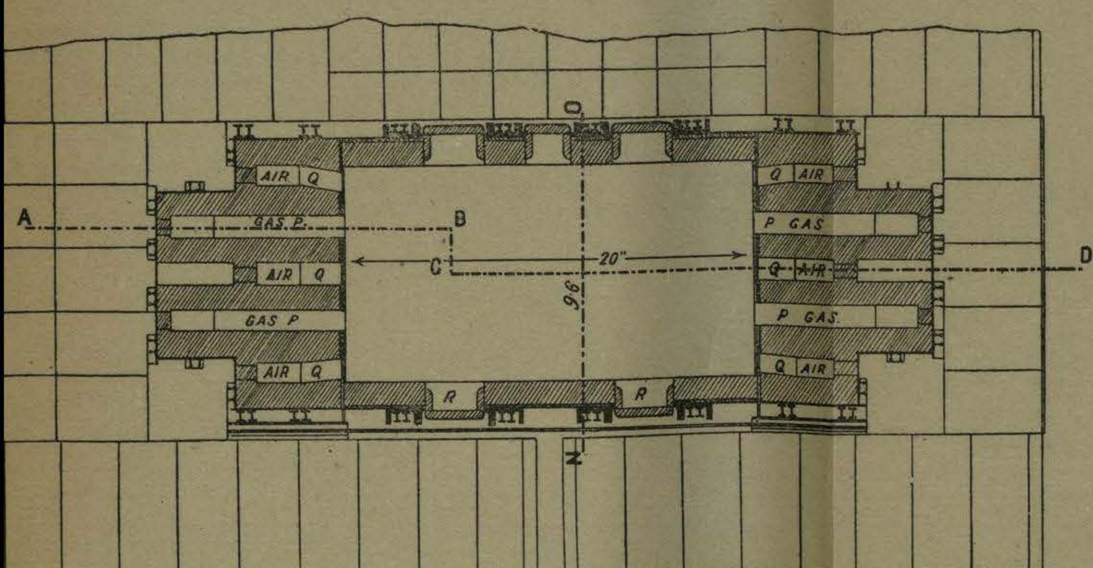
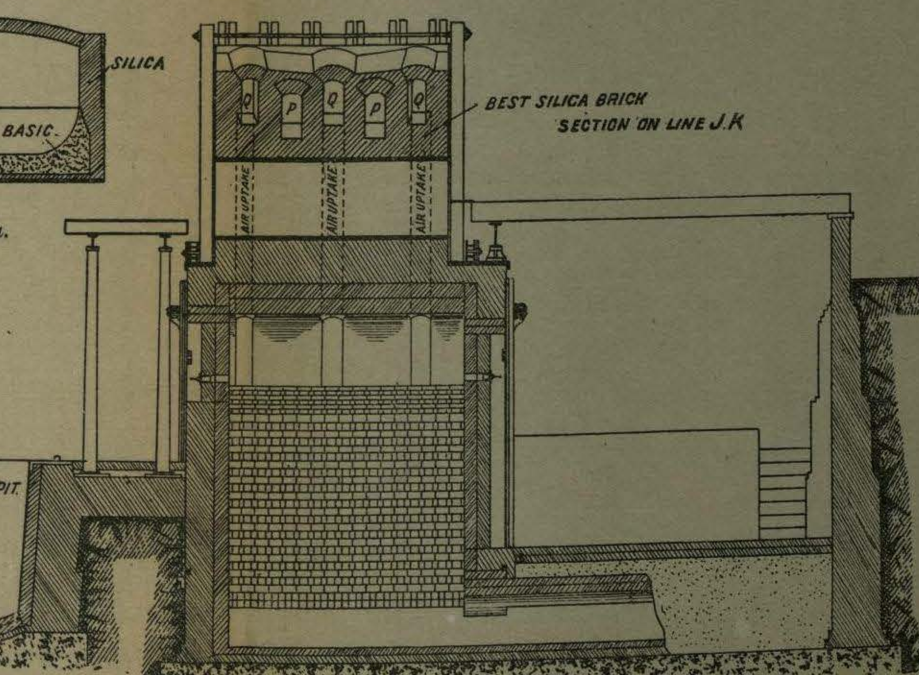


Fig. 124a.



SECTION ON LINE G.H

Centre Line of Casting Pit



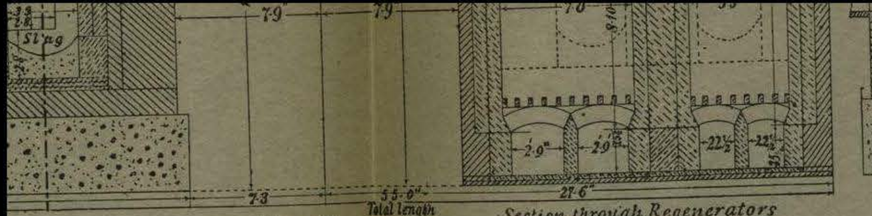


Fig. 127.

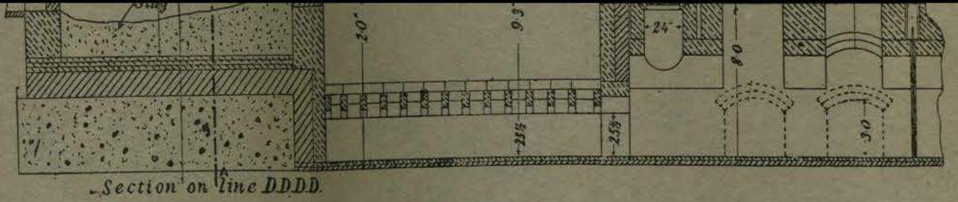


Fig. 129.

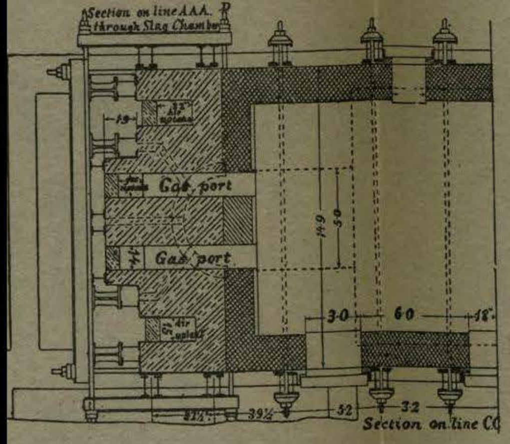


Fig. 128.

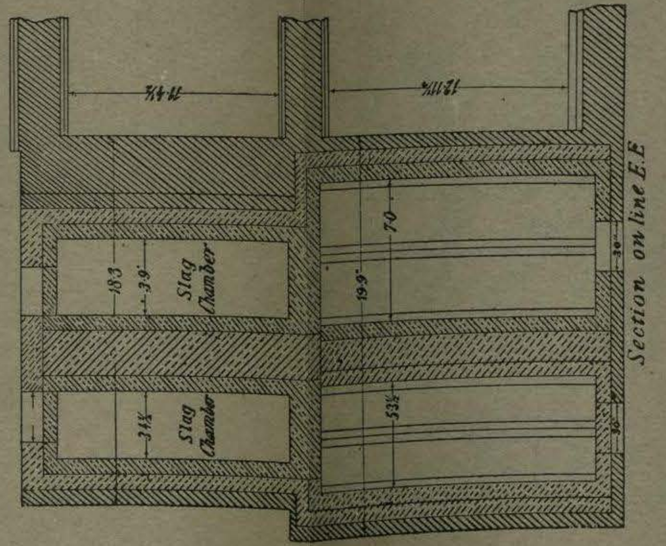
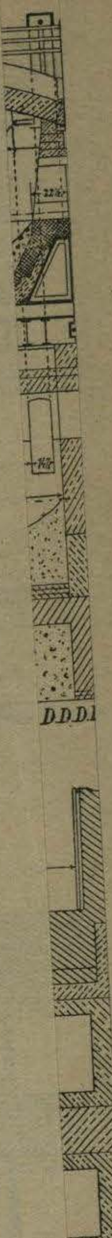


Fig. 130.

Modern 40-ton Basic Open-Hearth Furnace, showing dust catchers or slag chamber, and Talbot patent air-cooled hollow castings built into the "blocks."



From figures given by Bone and Wheeler, it would appear that the gas obtained with a steam saturation temperature of 50° would undergo no change in passing through the regenerators. With gas obtained with a saturation temperature of 70° and more, there would be a marked tendency to increase the Carbon Monoxide and steam content at the expense of the Carbon Dioxide and Hydrogen in passing through the regenerators; while such a substitution of Carbon Monoxide for Hydrogen would be advantageous, the consequent large increase in the steam content would be detrimental from a furnace point of view.

Dust-Catchers.—In all open hearth practice a considerable amount of fine dust from the iron ore, or lime dust in the case of the basic process, is carried over mechanically with the gases, and often very seriously fluxes the regenerator bricks, causes them to run more or less together, and chokes the regenerators. To obviate this many furnaces are now built with a supplementary chamber between the ports and the regenerators to act as a slag and dust-catcher. By allowing the gas after leaving the furnace to pass into this dust-catcher, the greater part of the highly-heated dust particles is deposited before the gas reaches the regenerators, and in the event of slag from the furnace boiling over into the ports at any time, it is similarly prevented from reaching the regenerator brickwork.

In modern practice where very large furnaces of from 40 to 50 tons capacity are used, especially in basic practice, these dust-catchers are found to be an important detail in the construction of the furnace, as it is not merely a question of saving the brickwork in the regenerators, but the far more important one of increasing the length of time which a furnace can run before it has to be cooled down for repairs. Apart from this, directly the regenerators become more or less choked, the furnace begins to work sluggishly, with the result that a longer time is taken to work the charge, and there is also considerable danger of getting cold heats which may cause endless trouble and expense, so that any device that helps to keep them clear and prevent fluxing of the brickwork, even to a small extent, is an important matter. Figs. 127, 128, 129, and 130 (Plate ix.) are drawings of a modern 40-ton furnace, showing the dust-catcher or slag chamber.

The Tilting Furnace.—In America, of late years, furnaces built on rollers, or on rockers, have been used to some extent, so that the hearth section of the furnace can be tilted to enable the charge of finished steel to be poured into the ladle, thus avoiding the trouble of tapping. These furnaces probably offer greater advantages where the basic process is in operation than they do with the acid, as they enable a highly phosphoric or silicious slag to be poured off during the operation, and fresh slag to be formed by further additions. In the event of holes being formed in the bottom, the furnace can be tilted and more easily repaired than a fixed furnace, but one disadvantage of this type of furnace is, that if the bottom should be cut away under the taphole it is almost impossible to completely drain out the metal. The pouring hole, being above the level of the metal, is not rammed up with ganister, as in the ordinary furnace (Plate ix.), but a little sand is put loosely in, just sufficient to close the hole. The hole can be opened by merely pushing a bar through, without any sledging, and consequently all risks of hard taps are avoided, and the metal can be poured immediately it is ready. This latter is important in making steels of special grades, as if the metal is kept in the furnace owing to a hard taphole, after the required re-carburisation is reached, oxida-