basic Bessemer process, nor is the silicon low enough. Indeed, these ores produce a pig difficult to work even in the basic open-hearth process, as the pig contains too much silicon, which is a handicap in basic open-hearth practice, for the same reason as in basic Bessemer; namely, because it requires a great deal of lime to slag the $SiO_2$ produced, and the heavy blanket of slag makes it difficult to work the heats. "Duplexing" has successfully handled these pigs; the silicon, manganese and carbon being removed in an acid Bessemer converter, and the carbonless steel then purified of phosphorus and sulphur in a basic open-hearth furnace.

As the basic Bessemer process has been several times attempted in this country, and uniformly proved a financial failure, we shall not again refer to it in these pages.

## CHAPTER V

### THE OPEN-HEARTH PROCESS

The open-hearth or Siemens-Martin process for making steel was developed in England about 1867 by Sir William Siemens, and independently in France by Martin. The process consists essentially of the melting down of steel scrap and some pig iron in a furnace of the bath type, oxidizing out the carbon, silicon and manganese of the metal by means of additions of iron ore, and adjusting the composition by proper additions.

In order to maintain in a fluid condition the nearly pure iron produced by the elimination of the metalloids from the bath, a high temperature has to be attained in the furnace, much higher than can be secured by the direct combustion of coal. To meet this essential condition, the regenerative principle was invented. By the use of checker chambers such as have been described in the chapter on the crucible furnace, producer gas, resulting from the partial combustion of coal in a gas producer, is fed very hot to the hearth of the furnace, meets sufficient preheated air for its combustion, and heats the furnace chamber and bath to a very high temperature. So intense a heat can be attained that when a furnace is "hot," the operator has to be constantly on his guard lest the brickwork be melted away.

Besides producer gas, other fuels can be used. Natural gas, when obtainable, is excellent for the purpose and does not have to be preheated, but is piped directly into the hearth, only the air passing through regenerators. Fuel oil is used in the same way. On the continent of Europe, coke-oven gas has been tried, and of late experiments are being made with powdered coal.

Whatever the fuel, and whatever the method of working, conditions in an open-hearth furnace are pretty much the same. The reasoning that has already been given in discussing basic Bessemer steel making shows us that a basic lining and a basic slag are necessary, if dephosphorizing of impure material is to be attempted. As in Bessemer work, therefore, we have to consider both acid and basic methods; and as both are used in the steel foundry to a large extent, a somewhat extended consideration of each is necessary.

In the acid open-hearth process, pure materials have to be used in order to produce pure steel. Low phosphorus pig and scrap are melted down in the furnace, losing part of their carbon, silicon and manganese (and some iron) in melting, and forming a slag of FeO, MnO and $SiO_2$. There is a very slight gain in phosphorus as in the other acid processes due to loss of iron, etc., and when producer gas is used as fuel, there is also a gain of from about .01 per cent. to .03 per cent. in sulphur, which is picked up from the gas. When the metal is all melted and covered with the fluid slag, iron ore is thrown into the furnace in proper amounts, and a slag very rich in FeO is the result. The excess oxygen of the flame, and the oxygen of the iron ore, oxidize carbon, silicon and manganese in the bath, the last two entering the slag, the first boiling out as CO. The bubbling produced by the evolution of CO keeps the bath in circulation, and aids in heating up the metal. As a bath must boil vigorously in order that it may readily be heated up, some pig iron to provide carbon is essential. The silicon and manganese of the pig are also an advantage, since they tend to protect the iron from excessive oxidation in melting down. The ore is added in amounts sufficient to run the carbon down to about what is desired in the finished steel (the silicon and manganese having been first removed), and the good melter does not add so much ore to his heat that the carbon "races" down, but brings it to what he desires by progressively slower steps. In this way the last 10 or 15 "points" of carbon are removed very slowly, and probably are oxidized mostly by the excess oxygen of the gases. By this procedure the available iron oxide of the ore is largely used up, and as much of the oxide as possible boiled out of the steel. If the bath is hot enough, the usual recarburizers are then added, and the heat tapped and poured.

In basic practice, limestone is charged with the pig and scrap, and lime is used freely with the ore, whereby a basic slag is maintained throughout the process, and phosphorus largely eliminated. Sulphur is also removed to some extent, but this action is erratic and not as much sulphur is removed as phosphorus. If very low phosphorus and sulphur are desired, the steel is generally run down to very low carbon, about .06 to .08 per cent., and subjected to the action of a very limey slag for some hours. In making steel of ordinary grade, the heat is tapped soon after the desired carbon is



reached. In any case, however, the slag in the basic furnace contains a great deal of FeO throughout the process, and hence is strongly oxidizing. The steel, therefore, is never so well cleared of oxide as in acid practice. Moreover, in order to avoid "rephosphorizing," the recarburizers are generally added in the ladle, so that they have less time to act in reducing oxides than in the best acid practice.

Open-hearth steel, therefore, especially basic steel, contains oxides to quite a large extent; but probably not as much, even in the case of basic open-hearth, as Bessemer converter metal. The quality of the steel produced, is therefore, generally intermediate between that of electric or crucible steel, and that of Bessemer metal.

The comparative freedom of open-hearth, especially acid open-hearth steel, from gases and oxides, would make it suitable for the production of small, intricate castings. But, as we have stated in the introductory chapters, the rather low initial temperature of the metal, and the size of the heats, which in ordinary practice are tapped out in one lot and have to be poured off before the metal has time to chill, forbid the use of the process for any but heavy castings. For light work, the process as generally carried out is at a prohibitive disadvantage as compared to Bessemer, crucible or electric methods.

For castings averaging over 50 lb. each, the advantages of the open-hearth process far outweigh its disadvantages, and make it the most suitable process for such work. The quality of the steel is quite high enough for the castings desired, and it will pour them readily; the cost of the steel is low; the output is very large, so that the total profit on a year's output of comparatively cheap castings is considerable; and the process can be worked with a variety of fuels and raw materials.

The disadvantages of the process are the lack of flexibility in making different kinds of steel at one heat, which has already been discussed; the heavy installation expense; and the fact that the furnace must be kept going at full capacity day and night. These disadvantages tend to make the process unsuitable for the foundry producing light castings, but for the tonnage foundry they are either unimportant, or positive advantages. For such work, the lack of flexibility is of little moment; the heavy installation expense is distributed over a great tonnage; and continuous operation is a necessity in a tonnage shop in order that the interest and depreciation cost of the plant may be spread over the largest possible output.

### THE FURNACES

The scope of this work does not permit of an extended discussion of the design of furnaces now in use, but a few general remarks upon this head must suffice.

The essential parts of a regenerative furnace are the enclosed working chamber, or hearth, with a bottom lined with refractory material, where the flame is produced and heats the charge; the four regenerative chambers (sometimes only two, when only air is preheated), filled with the brick "checker work," where the heat of the products of combustion leaving the hearth is absorbed, to be returned to the incoming gas and air when the direction of flow is reversed; proper

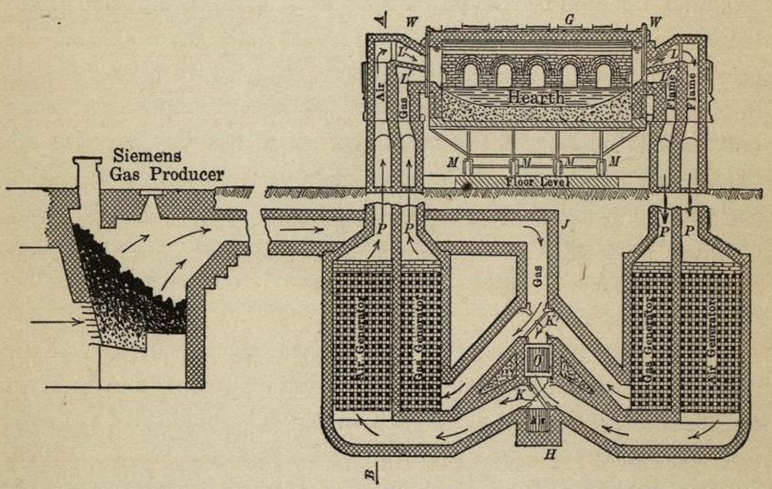


FIG. 9.—Diagram of open-hearth furnace. From Howe, "Iron, Steel and Other Alloys."

passages or flues connecting the hearth with the regenerators, and the latter with the gas producers; throttling valves to control the amount of gas and air admitted to the regenerators; reversing valves to admit air and gas to each pair of regenerators alternately; and a stack of sufficient size and height to carry off the cooled gases leaving the regenerators. The general arrangement of the component parts is too well known to require extended description.

The principal changes that have been made in the building of furnaces since they were first introduced are the increase of size and capacity, the moving of the regenerators back from under the ends of the furnace, the design of special gas reversing valves, the measures that have been taken to protect door frames, ports and other



parts from burning out (water cooling), and the use of tilting furnaces. Furnaces are now built up to 60 tons capacity for ordinary practice, and for the special Talbot process 200-ton furnaces are in use. The regenerators, when placed directly under the ends of the furnaces with the uptakes leading vertically from them, fill up rapidly with dust, slag, etc., and require frequent cleaning and renewal. By placing open chambers at this point, called "slag pockets," and setting the regenerators back of them, the dust and slag are collected in a convenient place where they can easily be removed, and the life of the checker works is greatly increased.

A few of the essential points that should be insisted upon in the design of a furnace are as follows:

Man holes should be provided for each flue, gas as well as air, between the reversing valves and the checkers; and a man hole in the stack flue, between the reversing valves and the stack, or a door in the base of the stack—if the latter is far from the valves, both will be desirable. There should be ample space around the valves so that they are easily accessible. The checker chambers should be amply tied together; insufficient bracing results in a checker chamber roof so leaky that no amount of grout poured into the cracks will stop the leaks.

In the superstructure of the furnace, the roof should be entirely separate from the side walls; some builders will practically rest the roof on the walls, either by setting the "skew backs" directly on the walls, or by supporting on the walls the channel irons that hold the skew backs. The result is that the wall cannot be cut away to patch it when worn thin without danger of bringing down the roof. The channels that hold the skew backs should be clamped to the buck stays of the furnace so that the roof is supported entirely by the framing.

It is well to avoid "dry" door frames; water-cooled frames much more than pay for themselves in less frequent renewal of frame and doors and in the comfort of the men. The door frames should be so designed as to be readily replaced. Some builders, if allowed, will hold them in place with the buck stays. Water-cooled "ports" (or, more properly, the space between gas and air flues where they enter the hearth), if properly designed, are well worth while; if badly designed, for instance by merely running water pipes through from front to back of the furnace, they are not worth their expense. The pipes will protect but a very small thickness of brick, so that the port cuts back to them as rapidly as if not water cooled at all. Then the bricks above and below each pipe cut away, leaving a sort of shelf of hanging bricks. This shelf soon falls and exposes the pipe, which then burns away in a very few moments and is of no further service.

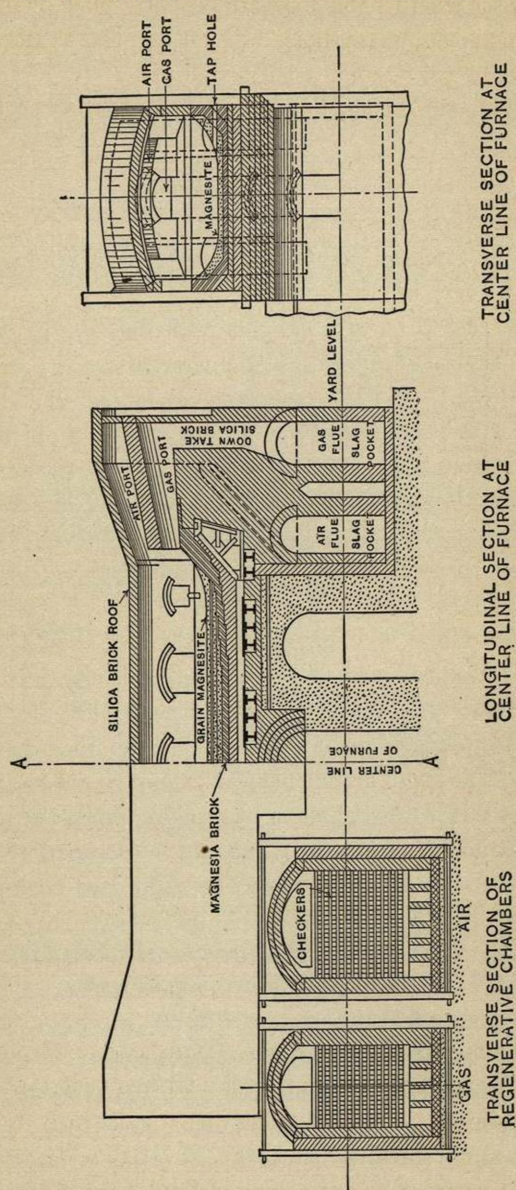


FIG. 10.—Typical basic open-hearth furnace. From Harbison and Walker, "A Study of the Open Hearth".

If possible, even in a very small furnace, there should be one or more doors on the tap hole side. Even if kept bricked up and opened only when making bottom, these doors are a great conven-



ience, and make it possible to be sure of the condition of the banks under the charging doors. Without them, the sand used to patch the front banks has to be rolled down with a sand spoon, and the men cannot see whether the holes are properly filled or not. Under such circumstances, many holes will not be filled as they should be and break outs will be unpleasantly frequent.

The tap hole should not be placed so low that when the bottom

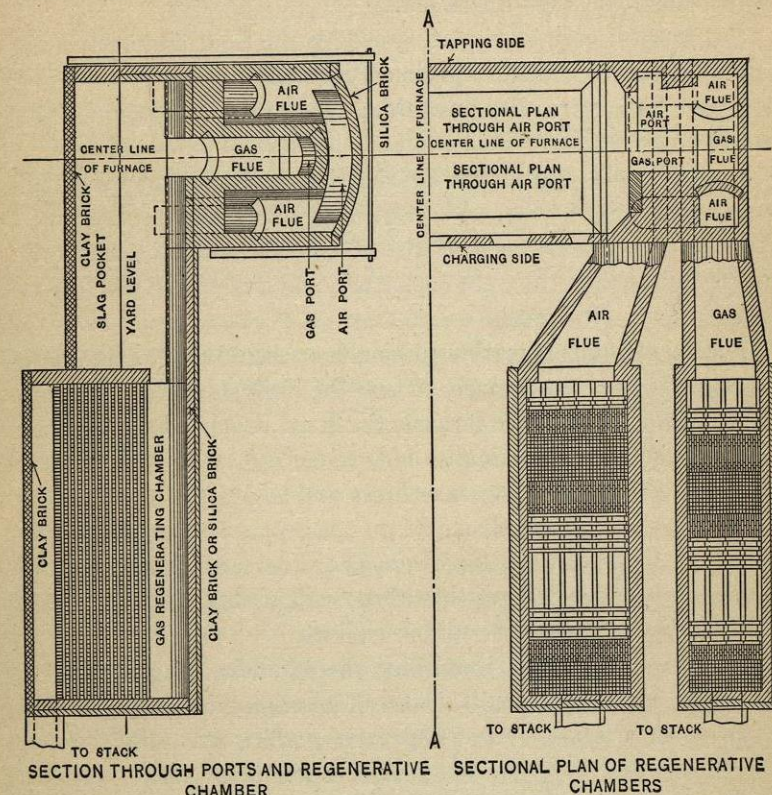


FIG. 10*A*.—Typical basic open-hearth furnace. From Harbison and Walker, "A Study of the Open Hearth."

is made the slope to it is very steep. If placed too low, it is well-nigh impossible to scrape it clean after a heat has been tapped, and the slag and drainings of metal running into it will result in the freezing of the hole and numerous "hard taps." It should, of course, be so placed that practically everything will run out when the heat is tapped, but should be so located that when the furnace is empty the last drainings do not run to the hole, but have to be splashed out with a rabble.

The height of the furnace from hearth to roof should not be too great; the working of some furnaces is greatly improved by taking off a foot at this point. The "head," or opening where the air comes into the furnace, should be ample to take waste gases down through the air checkers as well as the gas checkers. It is essential that the hot gases should go down through both sets of checkers, and contracted passages prevent this. If the air checkers are too cold it is impossible to get the furnace hot.

Too much iron or steel plating outside the front and back walls is a nuisance, as it renders it almost impossible to get at the walls to patch them when they grow thin. Bare walls as far as possible are to be preferred.

Double jambs and arches for the charging doors are essential, especially double arches. When a single arch burns out and falls, it brings the wall over the door with it; a double arch, when the lower course falls, leaves the walls supported, and a new arch can be put in at the end of the week.

The beams supporting the working floor should never come close past the front of the furnace, or near the buck stays. If the main floor beam is close to the furnace, the metal running from a break out may cut into it seriously and, worse still, may form a great chunk of cold steel welding floor beam and buck stays into an inextricable tangle. There should be an open space in the floor, below the front of the furnace, large enough so that a break out may run into the pit under the hearth without striking obstructions. This hole can be kept covered with loose plates.

The throttling valves controlling the admission of gas and air generally consist of a simple "saucer" lowering into a seat, and require no description. Reversing valves, which were originally of the "butterfly" type, are now made in numerous styles, some of which are very complicated. The butterfly valve, especially if provided with a water-cooled seat, does very well for the air, but its strong tendency to warp and leak make it unsuitable for the gas. Of the many designs of gas reversing valves, some are open to the criticism that they warp and stick, while others give trouble from accumulations of soot. The rule that the simplest design is the best cannot be followed in the case of these reversing valves, since those that give the least trouble are generally rather complicated.

The gas mains, valve chambers of regulating valves, and gas reversing valves, should be provided with clean-out doors of ample size for the removal of soot.



**Tilting Furnaces.**—There are two types of tilting open-hearth furnaces, known as the Wellman and the Campbell, in both of which the hearth portion of the furnace tips up for pouring. In the former, the furnace is tipped forward upon rockers like a rocking chair, while the latter is revolved by means of rollers under the rockers, the center of the gas port opening being the center of rotation. As a result of the motion of the Wellman furnace, the gas port is brought out of line with the gas flue in the stationary end of the furnace, so that while the furnace is tipped forward gas has to be shut off, and the furnace is greatly cooled down. This cooling off wracks the brickwork severely. The Campbell furnace, on the other hand, can be left tilted over and fired as long as necessary, and the furnace is not cooled off in tilting.

Firing the furnace while it is tilted over is resorted to chiefly in continuous processes, where molten pig is poured into a bath containing a great deal of hot ore or scale. The violence of the resulting boil makes it necessary to tip the furnace in order to keep the bath from running out the doors, and in some cases it is an advantage to be able to fire the furnace while a strong boil is going on. If the tilting furnace be used in the ordinary manner, or if the tilting feature be taken advantage of only to pour successive small lots, it is not so essential to be able to fire while the furnace is tilted.

Tilting furnaces are more expensive to install and maintain than stationary furnaces, and should not be used except when there is good reason for incurring the extra overhead and operating expenses. The fact that occasional small lots of steel of special composition have to be made does not justify the installation of a tilting furnace, as should there be enough of such work to make it worth going after, a special small furnace can be installed to take care of it. Continuous working to take off small lots from a large furnace for small castings (generally with an electric furnace to refine and warm up the steel), or pouring a heat in successive small lots, can best be carried out in a tilting furnace, as the use of a stationary furnace with several tap holes at different levels is not very convenient and involves the tapping of the slag each time, while with a tilting furnace a skimmer in the spout can be used to hold most of the slag back.

For a furnace of 15 to 20 tons capacity, the crew on each shift consists of two or three furnace men, generally known as first, second (and third) helper, a gas man and helper (if producers are used), and a melter, who may have charge of five or six furnaces. When there are several furnaces, a ladle man and one or two helpers take care of the ladles; for a single furnace, the furnace men can do this work. When the furnace is charged by hand, the crew naturally has to be larger than when a charging machine is used. A 5-ton gas furnace, charged by hand, can be run with six men, who will charge the furnace in from 20 to 40 minutes. The floor crane is then, of course, used to swing the piel for charging heavy chunks. Such a crew would consist of a melter and two helpers, two gas men, and a ladle man, on each shift.

**Lay-out.**—The lay-out of an open-hearth shop, involving the handling of great quantities of materials, must be considered carefully in building the plant. If gas producers are used, the coal cars should if possible be able to dump their coal directly to the place where it is wanted, without any hand shoveling. Furnace space and gas producer space should be arranged so that in hot weather the sides can be thrown wide open to let in all the air possible. The open-hearth building should be high and airy, and plenty of floor space in front of the furnaces should be provided. If a charging machine is used, the wide track necessary compels the designer to make this space ample.

Accessibility of all parts of the furnace, valves, flues, etc., is an essential feature of the general lay-out. In view of the fact that checker works have to be frequently blown out to get rid of accumulated slag and dust, and that when the furnace is being repaired many of the checker brick are taken out and replaced, it seems superfluous to state that the checkers should be entirely above ground. So arranged, and with a shop that can be thrown open to the air, checkers can be cooled off rapidly, so that the time consumed in top repairs and changing checkers is reduced to the minimum. Yet in numerous instances furnaces are built in a sunken pit like a crucible furnace, and to make matters worse, in many such cases only a very small free space is left at the front and sides of the checkers.

The floor should be commanded by a crane of ample capacity to handle any lifts needed. Generally it is better not to span both pit and charging floor with the same crane.

The ladle should never be down in a pit; if the furnace is built with checkers all above ground it will not be necessary to have it so, and the ladle will even have to be raised above the casting floor level on a car or a saddle. With this construction the space provided for the slag that slops over the ladle, and for catching slag or steel boiled out of the doors by incautious oreing, or resulting from



a break out or a leaky ladle, is easily got at and cleaned out; and any skull from a break out or leaky ladle can be hooked to the pit crane and dragged out. The dragging of a heavy skull out of a steep-sided pit is a job that few care to undertake a second time.

Yard arrangements for an open-hearth shop are generally quite easy to make, if ample space is available. The straight-line plan is of course the most desirable. Either a locomotive crane or overhead cranes may serve the yard, preferably the latter. Magnets should be used for unloading pig and scrap, and for loading furnace charges on the narrow gauge cars sent to the furnaces. If the furnaces are machine charged all material will be loaded in charging boxes and the open-sided "piels" used for charging ingots and heavy crop ends. The magnets can load these very handily. For hand-charged furnaces small flat cars serve the same purpose, and are readily loaded with magnet and crane. Generally, unless a favorable difference of level can be taken advantage of, the furnace charging floor is considerably above the yard. Elevators or the cranes can be used to lift cars to the furnace floors if only one or two furnaces of small capacity are installed, but for any considerable tonnage they will prove rather slow, and it will be better to run the cars up an incline to the floors.

**Starting a Furnace.**—Operations of course begin with a new furnace, and the first thing is to get the furnace heated up and set a bottom. It is especially important to heat up a new furnace carefully and slowly, to guard against the spalling and cracking of the silica brick of which it is built. First throw the reversing valves on center and close the air and gas inlet valves; then build a wood fire in the hearth and feed it constantly (or use a hard coal fire in a stove). Build a second fire at the base of the stack to create the necessary draught. Have a pile of sand ready for use, and if the fire gets too lively and the flames touch the roof (before the roof has became hot), shovel in sand to deaden the fire. Keep the fire going night and day till the furnace walls and roof are thoroughly dry and hot.

A better and quicker way to warm up a furnace is to use oil burners introduced through the doors, or through the gas ports. If natural gas or oil be the fuel, the main burners of the furnance can be used for warming up; they can best be lighted by means of a small wood fire in the hearth. In heating up with oil or gas burners, care must be taken to bring the furnace up very slowly, turning on tbe fuel sparingly at first.

In one or two days the furnace will be hot enough to light producer gas with a wood fire; oil burners will reduce this, or get the furnace up to much greater heat in the same time. Have the producers making good gas before any attempt is made to turn gas into the furnace. Throw the reversing valves over, admit gas cautiously to the furnace and keep the wood fire going until the gas lights. When a furnace is not very hot it is well to open the doors when gas is first put on. At first there will be only a fitful dull red flame almost lost in the black gas. The first reversals should be made carefully, at intervals of about $1\frac{1}{2}$ hours, preferably shutting off the flow of gas before reversing in order to avoid hard kicks. On the first few reversals, new fires may have to be made to relight the gas. After a half dozen reversals the gas burns freely, the furnace begins to pick up heat rapidly, and should be "thrown over" at shorter intervals. After about 24 hours air can be admitted and the reversals made every 20 minutes or half hour.

As the furnace heats up, the roof begins to expand. The longitudinal expansion is largely taken care of by the "slip joints" provided for the purpose, but the horizontal motion must be taken up by loosening the nuts on the tie rods a little at a time as the roof moves. The men go over every nut at intervals, and loosen them up enough so that they move easily, but not enough to loosen the roof and allow bricks to fall out. Here and there a few will slip out of the roof, and these must be replaced with others, held in place with wedges until the expansion is sufficient to hold them securely. When the furnace has reached full heat, the making of bottom begins.

**The Acid Bottom.**—In the acid furnace, the roof, walls and bottom are of silica brick and a lining or bottom of silica sand is set on the bottom brick. It is a saving of sand to bank a good layer of silica brickbats, left from the construction of the furnace, in the angles between sides and bottom. Over these a layer of sand about 2 in. thick is shoveled, and the furnace run up hot enough to partially fuse or sinter this sand into a solid mass. As soon as this layer is firm, another of the same thickness is added, and so on until the bottom is brought up to its full dimensions.

The tap hole can be broken through with bars from the outside after the bottom is made, or an iron pipe the size of the hole desired can be used as a form. In this case the tap hole is shaped with siliceous ganister and closed with coal and sand before bottom making begins.

The sand used for bottom making (and for patching the bottom after each heat) should be either a silica sand with just enough FeO and $Al_2O_3$ to make it "set" (or partially fuse), at the full heat of the furnace, without getting too soft, or preferably a pure silica sand mixed with an impure one containing a larger proportion of FeO and $Al_2O_3$. It is generally much easier to obtain a pure sand and an impure one to mix with it than to get just such a sand as is needed.



When the bottom is finished, a "wash heat" of acid slag may be melted on it; or a light heat of pig iron and scrap melted down, and the slag made bulky with iron ore and sand. In any case, the slag should be thoroughly splashed up on the banks in order to soak the bottom full of it. The furnace is then ready for melting steel.

The tap hole is closed with fine anthracite coal mixed damp with a little sand. The men on the charging side run a rabble or splash hook into the furnace and block the inside of the hole, while two men do the closing from outside. Coal and sand are thrown up into the hole and packed firmly in place with a rammer until it is full. Sand is then banked over the coal on the outside and a few shovels of "seal" (coal ashes and sand in about equal parts) are thrown over the hole on the inside. Great care should always be taken to scrape the hole clean of slag, and especially of metal, before closing, as the penalty for carelessness is a "hard tap."

Needless to say, the tap hole of a tilting furnace is easily closed and not subject to hard taps. Unless it is intended to roll the furnace very far over to keep metal and slag from boiling out the doors, the hole is very lightly plugged.

**The Basic Bottom.**—The bottom bricks of the basic furnace are of magnesite, since acid (silica) bricks would react with the basic bottom material and produce slag. One or two courses next to the steel shell may be of clay, or chromite, bricks. The walls and roof are of silica brick, and to prevent their slagging the magnesite of the bottom bricks at their contact, an action which would be increased by the iron oxide and manganese oxide of the furnace slag which spatters upon the walls, one or two courses of chromite brick are commonly used to separate the bottom and the wall bricks. Chromite brick are sometimes also used to pave the bottom of the gas port. These bricks are made of chromic iron ore, a double oxide of iron and chromium which is almost absolutely neutral, and hence are not slagged by either the silica wall brick or the magnesite bottom.

The bottom of the basic furnace may be made of either calcined dolomite (CaO MgO), or calcined magnesite (MgO), or both.

Magnesite is greatly to be preferred, as it makes a much denser bottom that can be confidently relied upon to stay in place when once set in and soaked full of slag, while dolomite bottoms frequently give trouble by coming up in patches, or cutting through. Whichever is used, it should be mixed with sufficient basic slag (generally from 5 to 15 per cent.) to make it sinter at the full heat of the furnace, and placed a layer at a time as an acid bottom is set. Sometimes a little tar is mixed with the magnesite and slag. Magnesite brickbats can be used to help out in filling up the corners, before any lining is placed.

The patching of the slag line is done with dolomite or magnesite, frequently both, the former predominating. Holes in the bottom that have to be splashed out and patched are best repaired with magnesite. The tap hole is closed with either one, mixed with coal, but magnesite is preferable, as a dolomite hole is very uncertain, frequently taps itself, and nearly always makes the men jump lively in tapping.

**Week-end and General Repairs.**—On Saturdays, the furnace is gone over and minor repairs and patching done for the week. Generally the ends of the furnace are opened, the accumulation of slag chipped out of the gas flues back of the ports, and the slope of the gas port filled up with sand (in acid furnaces) or magnesite (in basic). New doors may be required, or patches in the walls, door jambs and arches, etc., when the brickwork begins to get old. Accumulations of dust in the flues between reversing valves and checkers, or in the stack flue, may have to be removed; and in general things are made ship-shape for the next week. At the same time the ashes are cleaned out of the gas producers and the gas mains and valves burned and scraped free of soot.

When a producer gas furnace of the usual type has been used for some time, and the brickwork has grown thin, the gas often begins to leak through the roof arch of the gas port, generally where it joins the gas uptake, and to mix with the air in the "head." This condition can usually be detected by the flame playing out where the roof and the end wall of the furnace join, and must be attended to immediately or the brickwork will be cut away rapidly and the furnace put out of business. The end wall is partly taken down to get at the trouble, and the holes in the brickwork that are making the trouble are plastered up. The best material for this purpose is chrome ore ground fairly fine and mixed with water and a little fire clay to form a stiff mud. The leaks must be thoroughly stopped,



but of course when a furnace gets to this point it is a question of only a short time until a new top is needed.

When the walls have worn too thin to admit of further patching and the ports have cut back until the furnace no longer heats properly, a short shut-down is necessary. If the roof is fit to outlast another set of walls and ports, it can be left standing, or sometimes part can be repaired. As soon as the furnace is cold enough to work on, often before it has grown black, the walls are knocked out and removed, the brickwork of the ports and ends is dug out as far as necessary, and the bricklayers begin rebuilding as soon as it is humanly possible to do so. At the same time the slag pockets are cleaned out, and the checkers examined. The latter may have to be removed altogether, or part of them taken out, down to good bricks. Checker bricks that are thoroughly glazed are very inefficient and should not be put back in place. A shut-down for this partial repairing keeps the furnace idle altogether about a week. Gas is put on again as soon as possible and operations resumed.

If the roof has fallen in while a heat was molten, as sometimes happens when the furnace is run close to the limit of the top, it is not necessary to get the metal out. The new walls and roof can be put up as if the furnace were empty, and the skull melted out when gas is turned on again. It will, of course, take the furnace a bit longer to become cool enough to approach, under these circumstances.

**Break Outs.**—A break out is a mean thing to contend with, yet if possible it should be fought. An approaching break out can often be foreseen by the violent boiling of the bath over the spot where the bottom is being cut through. Frequently, if at the front of the furnace, the first warning is the reddening of the hearth plates at the threatened spot.

As the bath heats up and grows comparatively quiet, one spot should maintain a steady slight boil—the spot right over the tap hole. If this boiling ceases, a hard tap is to be expected. If it becomes violent, the bath is cutting its way out the tap hole and will soon be running down the spout, "self-tapped." A break out when the heat is about ready, is best fought by tapping the heat and taking chances on analysis, adding silicon and manganese largely on rapid calculations, frequently made in the head of the melter as he hastens to the scene of action. An approaching break out in the flat part of the bottom cannot be fought, and the only remedy is to tap at once before the steel goes into the pit and renders it impossible to approach the tap hole. Small break outs through