# CHAPTER III

## Open-Hearth Process for Making Steel

The open-hearth furnace for converting pig iron into steel is made and used in both the stationary and tilting styles, as shown in Figs. 17 and 18. As the name implies, it has an open hearth on which the metal is placed and where it is exposed to a flame which reduces it to a molten state; or, in other words, it is openly exposed to the action of burning gases.

This furnace must be a regenerative one to get the high temperature that is needed to melt and refine the metal. By this is meant one in which the heat carried away by the chimney flue is used to warm the incoming air and gas before they enter the furnace. This name has been commonly applied to the furnace as shown by the sectional view in Fig. 19, by which both the air and gas are heated before entering the furnace by sending them through passages filled with bricks which are stacked up so as to leave openings between them. Two sets of passages are provided so that one can be used to absorb the heat in the exhaust gases while the other is warming the incoming air and gas. These passages are supplied with reversing valves so that they can be used alternately and thus heat the gas and air to a yellow heat before they unite. This method gives a very intense heat.

From 30 to 75 tons of metal are purified in one of these furnaces in from 6 to 10 hours. It is then "recarburized," or in other words the proper percentage of carbon is added, and the metal poured into ingot molds from which it is taken and rolled or forged into the sizes and shapes desired.

As two of the main considerations in the modern steel mill are output and economy, the size of furnaces has been increasing and Talbot process open-hearth furnaces have been built of 250 tons capacity, while larger ones are to follow. Where blast furnaces and steel mills are located together the pig iron is taken in the molten state to the open-hearth furnaces, and converted into steel as fast as the blast furnaces turn it out. This practice has been an important factor in obtaining large outputs.





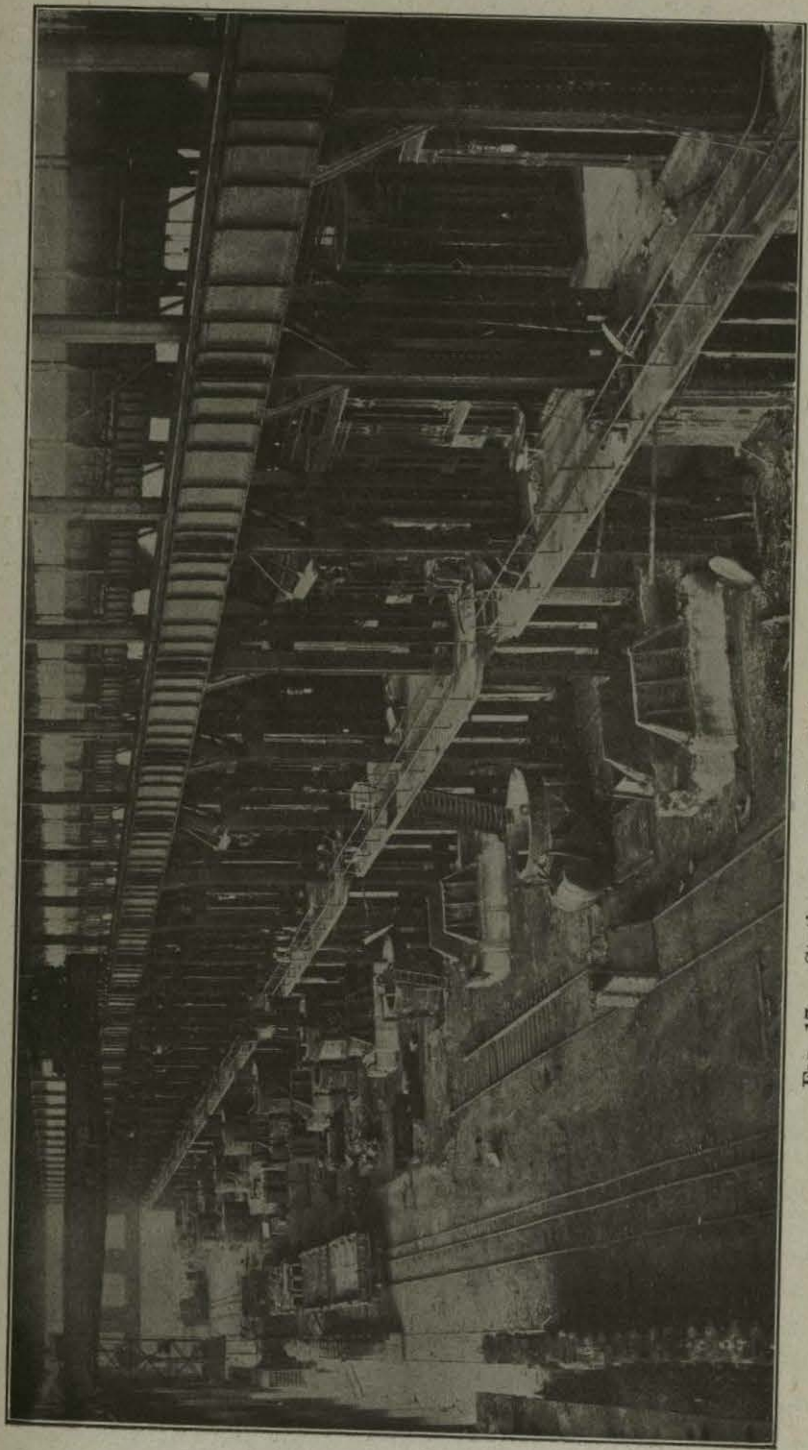

Fig. 17. — Stationary open-hearth furnaces at Bethlehem Steel Co.

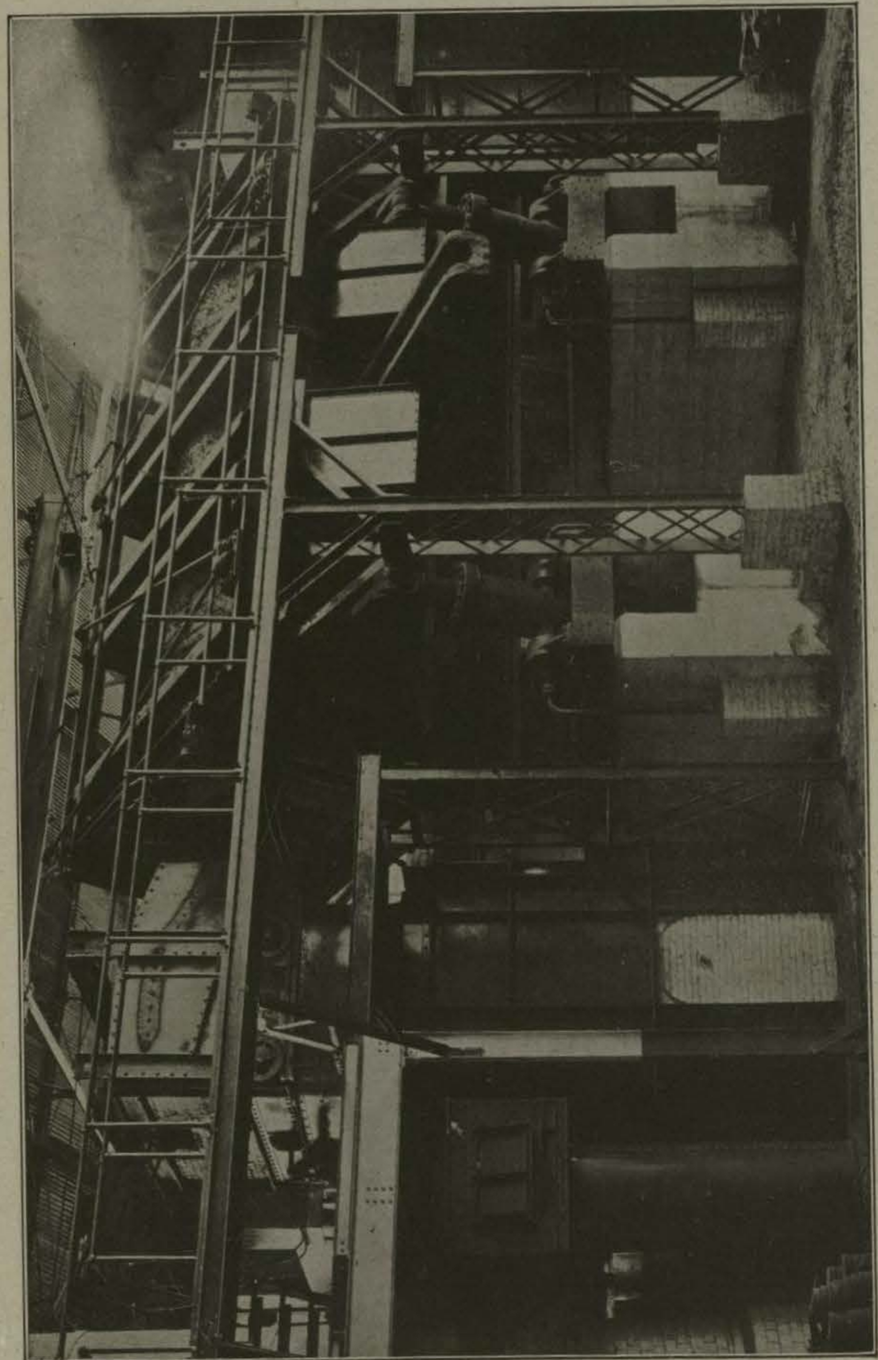

Fig. 18. — Tilting open hearth furnace. Tilted for pouring into ladle.



In the Talbot process the stationary furnace of the original Siemens-Marten process is changed to a tilting form so that the slag which forms, and which limits the rate of charging, can be more easily handled. The charge is worked down to the desired percentage of carbon by means of additions of ore and limestone in the usual manner. The slag is then removed and about one-fourth of the steel poured off and recarburized in the ladle as usual. To the metal remaining in the furnace ore and limestone are now added and through the slag thus formed, is poured a fresh charge of molten pig iron. The removal of the carbon, silicon, etc., under these conditions is rapid, but the reactions are not violent, owing to the

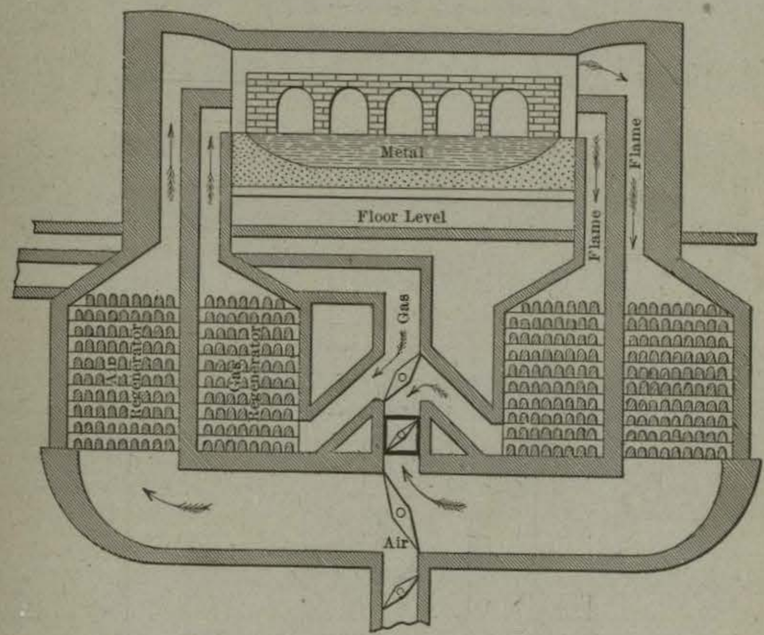


Fig. 19. — Section through regenerative open-hearth furnace.

dilution by the steel remaining in the furnace. The process is continuous and the furnace is completely emptied only once a week.

There are also in use tilting open-hearth furnaces with a double hearth, as shown in Fig. 20, with a stationary top, and in Fig. 21 with a moving top. The tilting serves here not to discharge the furnace, but to carry on different operations simultaneously in the one furnace. The amount of tilt given the hearths governs the amount of metal or slag to be run from one hearth to the other, this amount depending upon the angle of tilt, gradient of hearth, length of hearth, and depth of bath.

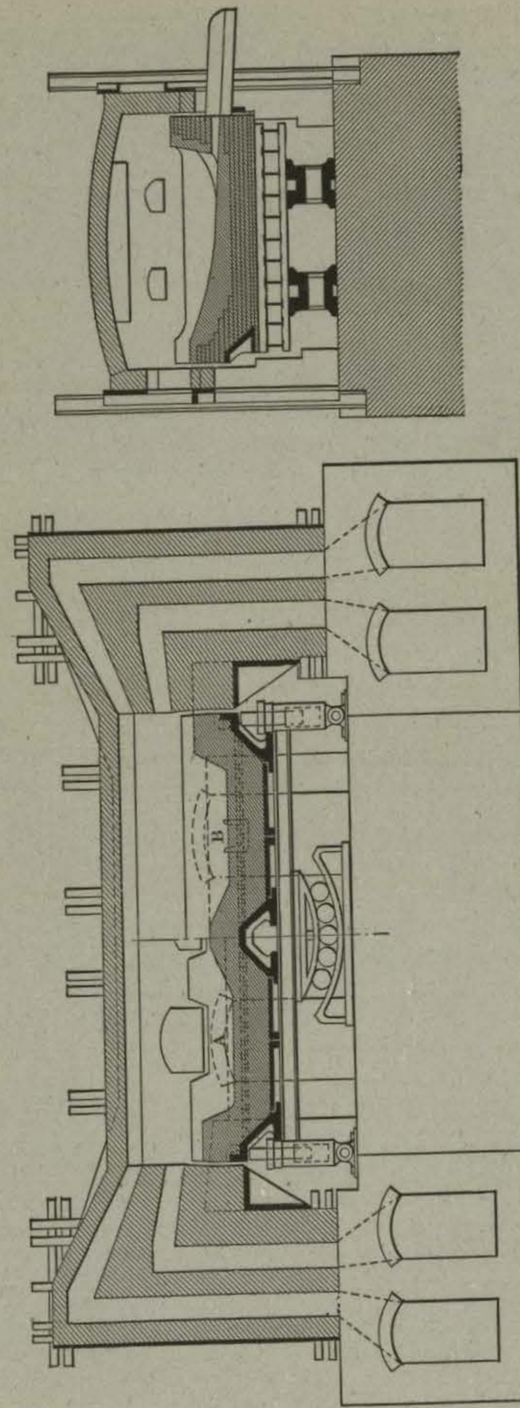

FIG. 20. — Double-hearth furnace with solid top.



The method of operation in the combined pig iron and ore process, which first suggested the furnace, is as follows: A charge is left only sufficiently long in hearth *A* to reduce the iron from the slag, this being already decarbonized. In order to free the charge from the iron-bearing slag and to pave the way for the final refining, the furnace is tilted so the slag flows from hearth *A* to hearth *B*. After the slag has been poured into *B*, molten pig is charged, the contact of the pig and slag sets up an energetic refining action and the iron is taken from the slag. Meanwhile the charge on hearth *A* is finished and tapped. The hearth is repaired as usual and the tap hole left open.

As the operation is a continuous one, the slags which have not been discharged must be poured when sufficiently low in iron. By a slight tilting of the furnace, the slag runs from *B* to *A* and out through the

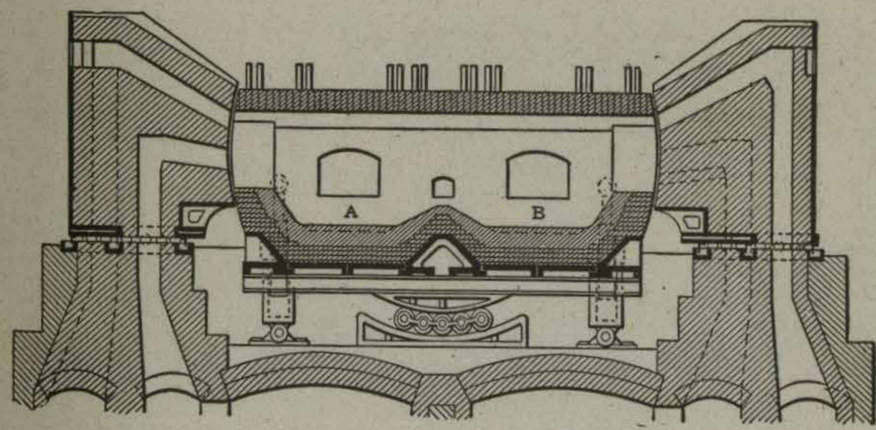


FIG. 21. — Double-hearth furnace with moving top.

open tap hole. Or it may be discharged over the side walls of hearth *B* and the hearth *A* used at the same time for charging fresh material. In hearth *B* the heat generated by the decarbonization of the iron is made use of by the scattering of iron ore over the charge as long as the temperature holds. As all of the iron cannot be reduced from the ore, a certain amount of ore is slagged. The desired slag, heavy with iron, is thus obtained. It will be later poured off into hearth *A* where the operation is steadily going on, molten pig added, and the process continued as before.

Steel is made in two ways in the open-hearth furnace: one is called the acid open-hearth process and the other the basic open-hearth process. About 30% of the pig iron made in this country is converted into steel by the basic process, and 2 or 3% by the acid. For the making of open-hearth steel castings the acid process was used almost exclusively, but it is now giving way to the basic process owing to the fact that ores low in phosphorus and sulphur are becoming higher priced each year, and these elements cannot be reduced in the acid furnace.

The number of charges these furnaces will make into steel before having to be rebuilt is about 300 for the basic furnace, which would cover a period of from 15 to 20 weeks, and about 1000 heats from the acid open-hearth furnace, before doing any more to them than the usual patching at the end of the week's run.

Pig iron and steel scrap are the chief raw materials with the addition of enough iron ore to quicken the operation. In America, on an average,

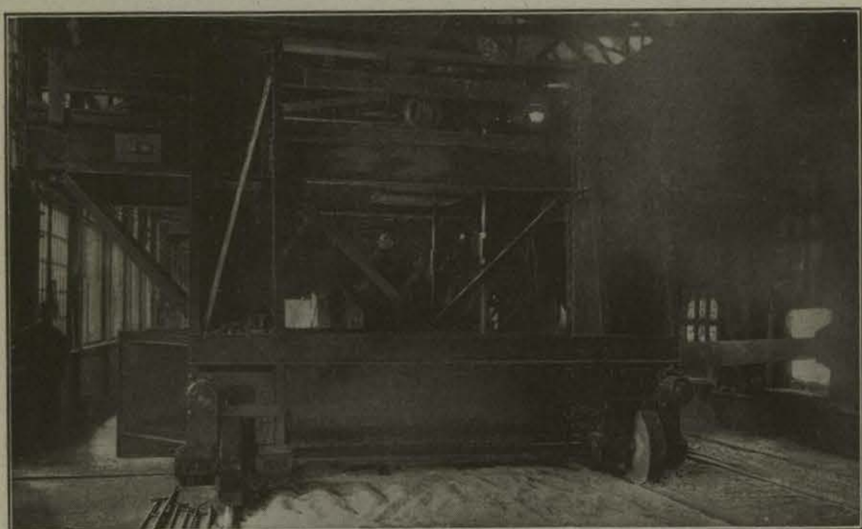

FIG. 22. — Machine for charging open-hearth furnaces.

about one-half the charge is steel scrap but sometimes as high as 90% is used. This latter, however, is but little more than a remelting operation. In most American mills the steel scrap is first placed on the hearth and this then covered with pig iron, as the oxidation of iron is decreased while melting by the impurities in the pig iron. In some American and most of the English mills the pig iron is put on the hearth first and this covered with the steel scrap, with the understanding that the hearth is corroded less with oxide of iron, but unless the scrap is small not much corrosion will take place.

In charging the acid furnace it is best to put the scrap on the hearth and the pig on top of it, while in the basic furnace we may put in a part of the scrap first, the limestone on top of that, then the pig, and cover



the whole with the balance of the scrap, or we may charge the limestone on the hearth, the pig next, and cover the scrap over the top.

The charging machine used is shown in Fig. 22.

### ACID OPEN-HEARTH

In this process the furnace is lined with silicious materials (sand). This lining influences the subsequent operations as the character of the bottom determines the character of the slag that can be carried, which, in turn, determines the chemistry of the process. The metal is heated by radiation from the high temperature flame. The impurities are partially oxidized by an excess of oxygen over that which is necessary to burn the gas in the furnace. This oxidizes the slag which, in turn, oxidizes the impurities in the metal.

The slag is about one-half silica ($SiO_2$) and the other half is composed of oxides of iron and manganese. Nothing is added to form a slag as the combustion of the silicon and manganese with what iron is oxidized and some sand from the lining in the bottom gives the necessary supply.

When the metal is melted iron ore is added, and the oxygen in the ore oxidizes the excess of carbon until the proper percentage is acquired. Recarburization is carried out in the furnace by the addition of a proper amount of ferro-manganese, together with any other materials that may be necessary.

In the acid process the percentage of phosphorus and sulphur depends upon what the stock contains that is put in the furnace, as neither of these are removed; but the amount of carbon in the steel, and therefore its tensile strength, depends entirely on the conduct of the operation. This latter is usually reduced to the right percentage and the charge then tapped out, but it may be reduced below the amount required and enough then added to make up the proper percentage.

The gradual increase in the temperature of the furnace caused by the regeneration of the secondary air first causes the oxidation of the silicon, which occurs mostly on the surface of the metal, by the oxidizing action of the flame. This causes the slag mentioned above to form and cover the surface of the bath, thus protecting the metal from any further contact with the flame from which it might absorb some of the gases, and be injured. After the silicon oxidizes out, the carbon begins to work out as a gas that causes bubbling or boiling throughout the bath. By the addition of iron ore this action can be augmented as occasion requires. When the carbon has been reduced to the percentage desired, the boil is stopped by deoxidizing agents, such as ferro-silicon or ferro-manganese.

The points in favor of the acid open-hearth process of making steel are that the operations are shorter, owing to the fact that the phosphorus cannot be reduced and no fluxes are added, except possibly a little silica at the beginning to prevent the lining from being cut by the iron oxide. The bath being more free from oxygen at the end of the heat, less trouble is encountered from blow-holes.

Most engineers and machinery designers agree that acid open-hearth steel of a given composition is more reliable, less liable to break and more uniform than either Bessemer or basic open-hearth steel, and this is doubtless due to its being more free from the occluded gases, although these are not removed as much in the open-hearth as in the crucible or electric furnace processes.

The principal and possibly the only reason this process is not used more, and especially in this country, is that ores low enough in phosphorus are scarce and consequently expensive. As the prices of these ores are gradually increasing, and have been for some time, the acid open-hearth process is steadily becoming of relatively less importance.

It is usually easy to tell the difference between basic and acid steel, but it is difficult to tell the difference between basic Bessemer and basic open-hearth steel or between acid Bessemer and acid open-hearth steel. Therefore, one has to depend on the honesty of the steelmakers, unless they wish to go into exhaustive tests of each piece of steel received.

### BASIC OPEN-HEARTH

A regenerative open-hearth furnace, similar to that shown in Fig. 19 for the acid process, is used for the basic, but the lining is of a different material. It is composed of some basic material that is usually either magnesite or burned dolomite.

The lining or bottom of the furnace takes little part in the operation, but determines the character of the slag which can be carried. When the bottom is silica (sand) the slag must be silicious and when the bottom is basic the slag must be basic. The charge put in the basic open-hearth furnace is composed of pig iron mixed with steel scrap or similar iron products, the same as in the acid furnace. But in addition to this, lime or limestone is added, in order to make a very basic slag.

This slag will dissolve all the phosphorus that is oxidized, a thing that an acid slag will not do. In the acid open-hearth or Bessemer process the silicious slag rejects the phosphorus which is immediately deoxidized and returns to the iron. Sulphur is also removed to a limited extent, and pig iron with these impurities can be used in the basic open-hearth furnace. When the sulphur is high the slag must be charged with all the lime it will stand without becoming infusible and pasty. The slag can contain as high as 55% of lime (CaO) for this purpose. If the manganese is above 1% it makes the slag more fluid and aids in the removal of sulphur.



If the slag is basic enough not to attack the bottom it will hold the phosphorus, providing the stock does not contain over one half of 1%. With a higher percentage special attention must be given to the phosphorus to prevent its passing back into the steel when a high temperature is combined with violent agitation, as is used when the heat is tapped.

Although the phosphorus and sulphur are lower in the basic steel, the acid steel is considered better, owing to the increased liability of blow-holes and gas bubbles in steel converted by the basic process. Then again the process of recarburizing sometimes produces irregularities. The metal is also more highly charged with oxygen. All of these make a poorer quality of steel than is produced by the acid open-hearth process, but a far better one than is being made in the Bessemer converter.

In the purification of the metal the silicon and manganese are first almost entirely oxidized in the 4 hours or so that it takes the metal to melt, while the phosphorus and carbon are reduced to some extent. After this phosphorus is eliminated, and lastly the carbon is removed. It is necessary that the phosphorus be eliminated before the carbon as the latter protects the iron the most, thus reducing the loss due to melting. The melter controls this by adding pig iron to increase the carbon contents if this is being removed too fast; or he can add ore to produce the necessary reaction to hasten the oxidization of the carbon.

After being purified the metal must be recarburized to get back into it the percentages of the elements that are desired. This must not be done when a basic slag is present, or the manganese, carbon, and silicon in the recarburizer are liable to cause the phosphorus in the slag to pass back into the molten metal. Therefore the recarburizer is added to the molten metal as it is flowing from the furnace into the ladle, and the slag is allowed to float off from the top. As the spiegeleisen cupola cannot be used with the open-hearth furnace, the recarburizer usually consists of a combination of small lumps of coal, charcoal, or coke in paper bags and ferro-manganese.

When soft steel is being made the carbon in the bath is usually reduced to from 0.10% to 0.15%, and enough of the carburizer is then added to bring this up to the percentage desired in the finished steel. When high carbon steels are being made, another method is sometimes used, and that is to bring the carbon in the bath just below the percentage desired, and then recarburize up to it. Thus when a 1% carbon steel is to be made, the carbon in the bath is reduced to from 0.90 to 0.95%, and enough added with the carburizer to raise it to 1%. Many steel makers, however, reduce the carbon in the bath to the same point, namely, 0.10 to 0.15%, when making both high and low carbon steels, and then get the correct percentage by the addition of the proper amount of carburizer.

Among other open-hearth processes might be mentioned the Monell process, in which limestone and a comparatively large amount of iron ore are heated on a basic hearth until they begin to melt, and then the molten pig iron is poured onto it; the duplex process in which an acid Bessemer converter is used to oxidize the silicon manganese and part of the carbon, and the metal then poured into a basic open-hearth furnace to reduce the phosphorus and the balance of the carbon; the Campbell

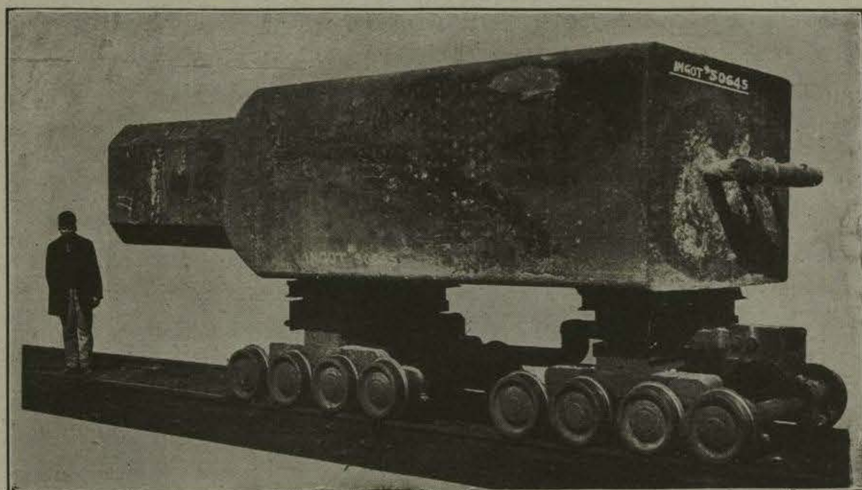


FIG. 23. — One of the largest ingots cast.

No. 1 process, in which a tilting furnace is used with a charge of molten pig iron and ore, the furnace being tipped backward to prevent the bath from frothing out of the door, and the operation continued for two or three hours, and the Campbell No. 2 process, which aims to combine the basic and acid open-hearth processes by working pig iron or pig iron and scrap in the basic furnace at a low temperature until most of the phosphorus and silicon and part of the carbon and sulphur are oxidized out, then transferring the bath to an acid furnace and working it at a high temperature to remove the rest of the carbon. The object is to get a low-phosphorus, low-sulphur steel.

One of the largest ingots that has been cast from the open-hearth furnaces is shown by Fig. 23.

One of the greatest troubles of the steel maker is the pipe that forms



in the top of each ingot and forces him to crop off and remelt a large part of it. Numerous ways have been tried to overcome this and the most successful of these is the fluid compressor of which Fig. 24 is an example.

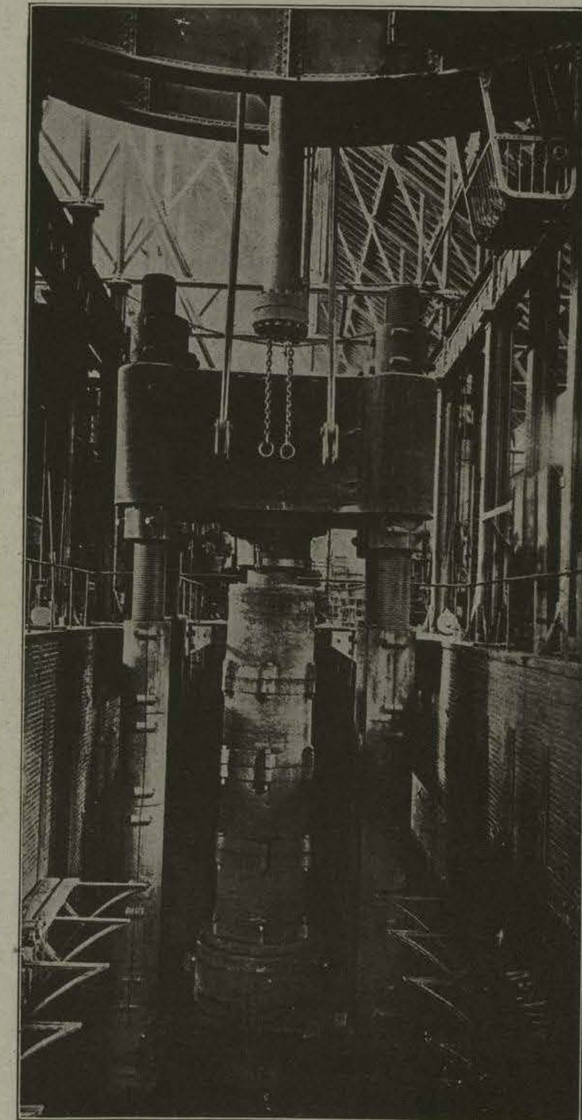

FIG. 24. — Machine for compressing ingots when fluid.

This consists of a large ingot mold, built in sections, into which the molten metal is poured. While the metal is solidifying a ram is pressed down into the mold by means of four screws. This compresses the metal as fast as it shrinks, and thus removes, or at least partly removes, the pipe by not allowing it to form.

# CHAPTER IV

## Crucible Process of Steel Making

In the crucible process a regenerative furnace is sometimes used similar to the one shown in Figs. 25 and 26. In this the heat does not attack the top of the metal as in the open-hearth, but heats crucibles which are covered and the cover sealed on with fire clay, so that the gases from the fuel will not attack the metal. In some places, however, coke furnaces or melting holes containing crucibles are used.

In Europe these crucibles are made of fire-clay by the steel makers, as they are comparatively cheap and no carbon is absorbed by the metal, as is the case with the graphite crucibles used in this country, and consequently this element can be more easily controlled in the finished product. They are usually made to hold 50 pounds of metal, as that is about the limit for the strength of the clay crucible. The molten slag on top of the metal cuts deeply into the clay, and the second charge has to be cut down to about 45 pounds to get below the slag-line, while for a third charge 38 pounds is about the limit, and after this they are thrown away, as it is not economical to use them. One or two steel makers in Europe only use the clay crucibles once, as they claim they can get a better steel, owing to the larger air space causing greater oxidization and the tendency of the metal to absorb and occlude some of the gases.

The graphite crucibles which are used to a large extent in this country are made by concerns that make a specialty of this business, and from a mixture that is about one-half graphite and one-half fire-clay. These generally hold 100 pounds and last for about 6 heats, but as carbon is given up by the crucible and enters the molten metal, it is more difficult to control this than when clay crucibles are used.

The crucible process is used only for the making of high-grade and special alloyed steels, such as high-speed, nickel, or vanadium chrome, etc. It is about three times as expensive as the next cheapest, namely, acid open-hearth, but for such work as cutting tools, armor-piercing projectiles, gears that are subjected to heavy or vibrational strains, high-grade springs and many other uses the crucible steels far excel anything that is made by the other processes. The reason for this superiority is largely due to the fact that it is made in covered pots, which exclude





Fig. 25. — Crucible melting furnace of Columbia Tool Steel Co.

the furnace gases and air. It is therefore freer from oxygen, hydrogen, and nitrogen in the form of occluded gases.

The material used for conversion into steel by the crucible process is usually wrought iron and not pig iron as in the Bessemer and open-hearth processes. The wrought iron, in the form of muck bars, is cut up into

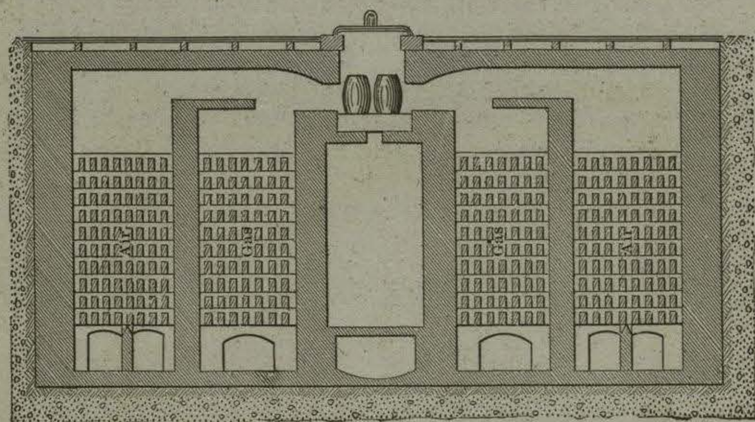

FIG 26. — Regenerative gas furnace for crucibles.

small pieces and placed in the crucible with the desired amount of carbon, which is generally in the form of charcoal, but sometimes is introduced through the medium of pig iron. Some ferro-manganese or spiegeleisen are also added and when alloyed steels are desired such alloying elements as tungsten, chromium, nickel, etc., are added. Sometimes a small

FIG. 27. — The charged crucible.

amount of glass or other similar material is used to give a passive slag, and various physics, such as salt, potassium ferro-cyanide, oxide of manganese, etc., are used by some. The ferro-manganese adds the desired amount of manganese to the steel and it is thought that the salt and oxide of manganese make a more fluid slag, while the ferro-cyanide might



aid the steel in absorbing the carbon. In the pot are also a little air, some slag and oxide of iron, this last being the scale and rust on the surface of each piece of metal, and silica, and alumina from the scorification of the walls of the crucible. Sometimes some cheaper steel scrap is mixed with the wrought iron, but this always lowers the quality of the finished steel. A crucible that has been charged and is ready for melting is shown in Fig. 27.

FIG. 28. — Pouring ingots from crucibles.

Some time is required for the reduction of the silicon from the slag and lining as well as for the various reactions which occur. When this reduction has reached a point where the steel contains from 0.20 to 0.40% of silicon and the metal lies quiet and "dead," that is, the evolution of the gases have stopped so it will pour quietly and cast into solid ingots, the crucible is taken from the furnace and the contents poured into ingot molds, as shown in Fig. 28. After these have cooled they are usually reheated in a furnace and reduced to a size suitable for rolling by hammering under a steam hammer, as shown in Fig. 29. This reduces the grain and makes the metal more dense.

Crucible steel usually contains less than 0.40% manganese, more than 0.20% silicon, less than 0.025% phosphorus, and less than 0.030% sul-

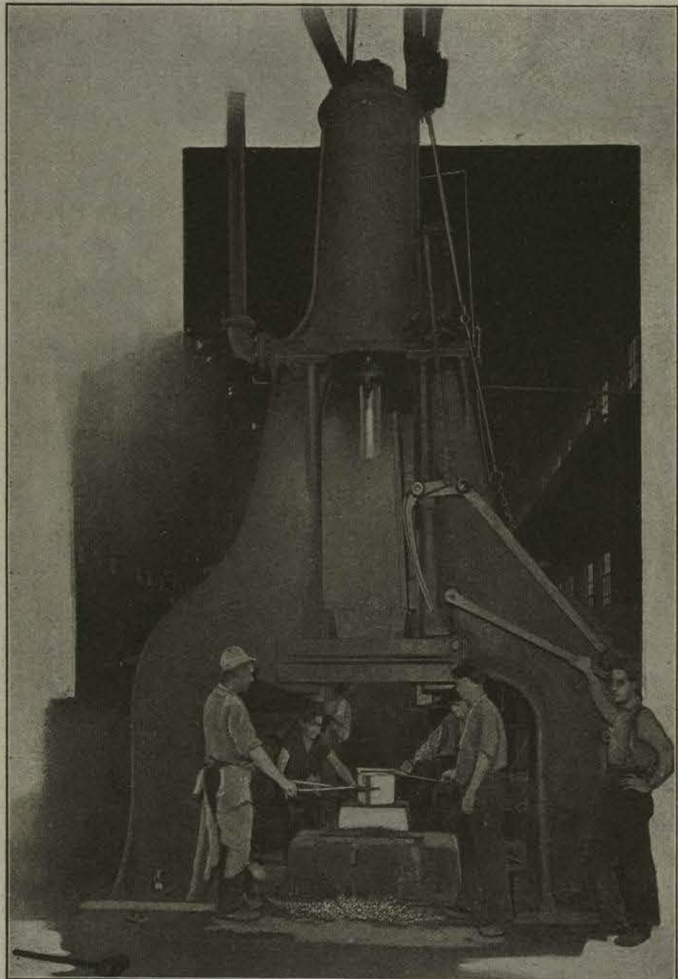

Fig. 29. — Hammering the ingot.

phur, while the carbon content is usually made high, owing to the uses to which crucible steels are put.

The main difficulty with this process is in making large ingots so these ingredients will be combined in a homogeneous mass. As the personal element is a factor in the charging of the crucibles, and these hold only 100 pounds or less, the steel made in each crucible is liable to vary some



in the composition of its ingredients. Thus when a 1000 pound ingot is to be cast it requires 10 or more crucibles to fill it and the metal does not have a chance to mix thoroughly before getting cold, which will result in certain of the ingredients showing a higher percentage in some part of the ingot than in others unless great care is exercised in charging each of the 10 crucibles.

A large part of the crucible steel is hammered into bars, as shown in Fig. 30, and the accuracy and quickness with which a hammersman can turn out these bars is one of the surprising features of the steel business.

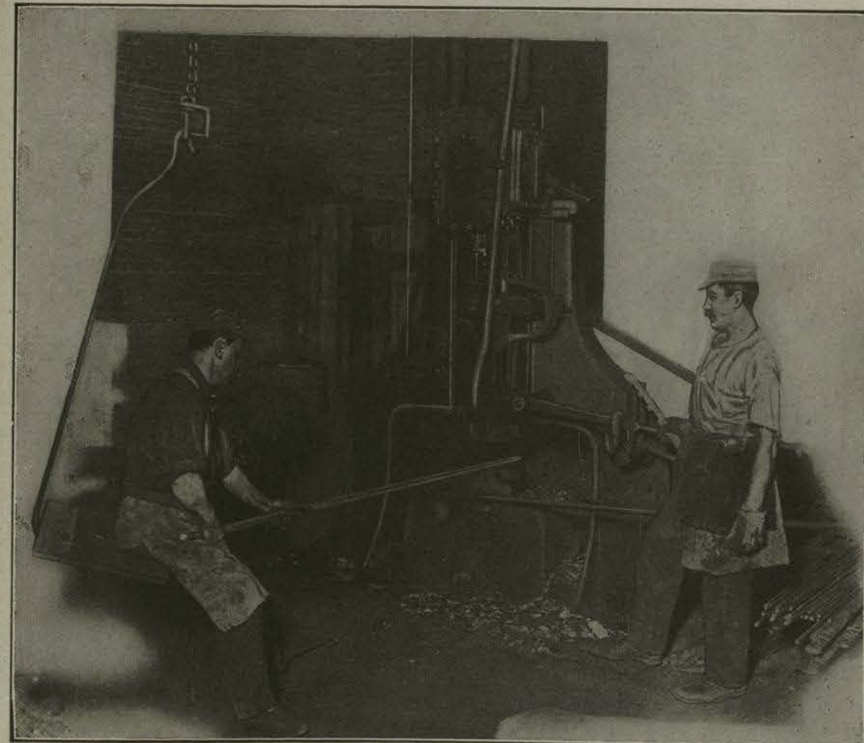

Fig. 30. — Hammering octagon bars.

They usually work by the ton, and it is difficult for the inexperienced man to tell the bars from rolled stock.

This process has changed very little in the last 100 years or more, and its chemistry, which consists principally of eliminating the slag in the wrought iron and adding carbon silicon and manganese to the metal, is very simple. The progress which has been made in crucible steel is due almost entirely to the discovery of new alloying materials that have added strength, toughness, wearing qualities, cutting qualities, etc., to the metal. Thus more different kinds of good steels, and better steels, are being made to-day by this process, which is way above all the other processes for making steel of quality, than at any time previous.

The enormous and wonderful change that has been made in the steel business is due to the perfecting of methods and machinery for making steel quicker, cheaper, and in larger quantities. However, when we want an extra fine grade of steel we have to fall back on the crucible process which is still carried out in practically the same manner as was the case many years ago. The progress that has been made in electricity and the experiments that have been carried on with the electric refining furnace, however, would seem to indicate that in the not very distant future this might do away with the slow, laborious, and costly crucible process; if not entirely, at least to a large extent.

### WROUGHT IRON

The wrought iron used in making crucible steel or for other purposes is also made by the same process and in much the same manner that it was 100 or more years ago. A reverberatory furnace hearth is "fettled" or lined with oxide of iron, that is, either good iron ore, roasted puddle cinder, or roll scale. On this, pig iron is melted, and some of the manganese and silicon being oxidized a slag with a high content of iron oxide is formed by absorbing this constituent from the lining. The impurities are then removed to a greater or less extent through a reaction between the carbon, manganese, silicon, sulphur, and phosphorus in the molten iron and the oxide of iron in the slag. This basic slag carries oxygen to the impurities and is assisted by the excess of oxygen in the furnace gases.

As the iron approaches nearer to purity it thickens, as the purer the iron the higher will be its melting temperature, and the heat in the furnace is not sufficient to keep it molten. When it reaches a pasty state the charge is rolled into balls, called puddle balls, that average about 150 pounds apiece. From the puddle furnace these balls are taken to a rotary squeezer that kneads and squeezes out a large amount of slag or they are taken to a drop hammer where the slag is hammered out. The balls are then rolled into bars, which removes more of the slag, leaving the rolled bars containing from 1 to 2%. These flat bars are then cut up into short lengths and form the muck bar used in making crucible steel.

Sometimes in this country and as a general thing in Europe, the squeezer is not used, in which case the puddle ball is worked under a hammer or "shingled" to remove the slag, and weld the particles of iron in the ball together. Puddling and shingling being extremely hard and hot work, however, efforts are continually being made to devise machines that will do the work. The rotary squeezer does that part of the work



cheaper than it can be done by hand labor, and many different kinds of automatic puddling furnaces have been designed and built. With these latter the finished product has not been turned out as good, as yet, as it can be made by hand labor. The results obtained, however, with the mechanical furnace, have nearly reached those desired, and may yet be made satisfactory.