CHAPTER I

BASIC OPEN-HEARTH FURNACES

Approximately 90 per cent of the steel that is melted and refined in the United States and poured into ingots is made in basic open-hearth furnaces, as shown in Table 1-1. The annual ingot capacity of the steel industry reported January 1, 1950, by the American Iron and Steel Institute\(^*\) was 99,040,160 tons, of which the basic open-hearth process accounted for 85,896,580 tons, 86.7 per cent of the total. The capacity of the individual furnaces varies over a wide range, a large majority falling within limits of 50 to 200 tons (Fig 1-1). Most of the units constructed since 1942 are in the larger size groups, between 175 and 225 tons capacity.

* Superior numbers refer to the References at the end of each Chapter.
Fig 1-2. Cross section of a 175-ton stationary furnace showing bottom construction and general dimensions.

Fig 1-3. Vertical section through length of furnace; centerline of burner at left, center of air uptake at right.
Open-hearth furnaces are either stationary or tilting, the former being the more common. Most of the tilting furnaces are found in plants that employ the duplex process, which combines bessemer and open-hearth practices. The fuel used in open-hearth operation may be one of several types of gas, a liquid fuel such as oil or tar, or a combination of gas and liquid fuel.

**Table 1-1.—Annual Production of Steel Ingots in United States**

<table>
<thead>
<tr>
<th>Year</th>
<th>Basic</th>
<th>Acid</th>
<th>Bessemer</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>1949</td>
<td>69,687,952</td>
<td>408,356</td>
<td>3,946,656</td>
<td>3,687,077</td>
</tr>
<tr>
<td>1948</td>
<td>78,600,059</td>
<td>537,033</td>
<td>4,243,172</td>
<td>4,973,611</td>
</tr>
<tr>
<td>1947</td>
<td>76,142,870</td>
<td>540,007</td>
<td>4,252,543</td>
<td>3,680,515</td>
</tr>
<tr>
<td>1946</td>
<td>60,059,943</td>
<td>468,336</td>
<td>3,327,737</td>
<td>2,479,064</td>
</tr>
<tr>
<td>1945</td>
<td>70,998,819</td>
<td>707,978</td>
<td>4,305,318</td>
<td>3,301,678</td>
</tr>
<tr>
<td>1944</td>
<td>79,072,500</td>
<td>997,855</td>
<td>5,039,023</td>
<td>4,131,703</td>
</tr>
<tr>
<td>1943</td>
<td>77,100,268</td>
<td>1,179,719</td>
<td>5,625,492</td>
<td>4,473,377</td>
</tr>
<tr>
<td>1942</td>
<td>75,086,630</td>
<td>1,060,355</td>
<td>5,553,424</td>
<td>3,843,757</td>
</tr>
<tr>
<td>1941</td>
<td>73,232,959</td>
<td>862,413</td>
<td>5,578,071</td>
<td>2,758,611</td>
</tr>
<tr>
<td>1940</td>
<td>60,821,802</td>
<td>510,433</td>
<td>3,708,573</td>
<td>1,608,032</td>
</tr>
<tr>
<td>1939</td>
<td>47,788,763</td>
<td>437,307</td>
<td>3,358,916</td>
<td>951,522</td>
</tr>
<tr>
<td>1938</td>
<td>28,746,725</td>
<td>218,727</td>
<td>2,106,340</td>
<td>524,843</td>
</tr>
<tr>
<td>1937</td>
<td>51,205,848</td>
<td>373,490</td>
<td>3,863,918</td>
<td>912,027</td>
</tr>
<tr>
<td>1936</td>
<td>48,239,427</td>
<td>311,815</td>
<td>3,873,472</td>
<td>788,718</td>
</tr>
<tr>
<td>1935</td>
<td>33,974,575</td>
<td>278,333</td>
<td>3,175,235</td>
<td>584,436</td>
</tr>
</tbody>
</table>

*Annual Statistical Reports, American Iron and Steel Institute.*

Most furnaces constructed during recent years have been designed to burn liquid fuel.

The design of a modern stationary furnace adapted to burn liquid fuel and with a capacity of 175 tons is shown in Figs 1-2 to 1-4. The cross section of the furnace at the taphole is illustrated in Fig 1-2, which shows the bottom construction, sloping back wall, and the rigid steel binding, all of which are typical of recently built furnaces. The vertical section in Fig 1-3 shows the location of the oil burner, the roof contour, and the air uptake. The location and size of the checker chambers with respect to the furnace proper are shown in Fig 1-4. While both chambers are used to preheat the air for combustion, a furnace of this type...
could readily be converted to burn producer gas by using the small chamber for preheating the gas and the larger for the air. The details of these various parts of the furnace are considered later in the text.

Figs 1-5 and 1-6 show the construction of a typical producer-gas-fired basic open-hearth furnace, indicating the various kinds of refractories that are used. Fig 1-7 is a photograph of the charging side of a modern open-hearth furnace showing the arrangement of structural work.

**Furnace Bottom and Taphole.** The successful operation of an open-hearth furnace depends to a large degree upon the design and quality of the hearth, banks, and bottom, together with the manner in which they are repaired and maintained. The refractories used in the upper portion of the bottom and banks must be capable of holding molten steel at temperatures in the neighborhood of 3000 °F (1650 °C) and also must withstand the chemical action of the slags normally encountered in basic practice.

The various methods for constructing bottoms usually are based on the following sequence:
Fig 1-5. Construction of typical basic open-hearth furnace fired with producer gas. (Courtesy Harbison-Walker Refractories Company.)
1. A layer of 2 to 4 in. of insulating refractory.

2. Firebrick and basic brick courses, which vary in total thickness.

3. A monolithic layer produced either by ramming a prepared refractory in place or by burning in high-magnesia material added in successive layers.
A more detailed discussion of bottom-refractory practice is given in Chapter 3.

The finished taphole is usually about 6 in. in diameter, and in a stationary furnace it is constructed so that the bottom of the hole is tangential to the lowest point in the hearth, which is in the center of the furnace. The hole is inclined in such a manner as to allow a rod to pass through the wicket of the middle door (in the front wall of the furnace) and out the taphole. In order to insure complete drainage of the furnace after tapping, the hole and spout should slope at least one inch per foot; in some cases a slope as great as $1\frac{3}{8}$ in. per foot is preferred. The hole is initially formed, or replaced when necessary, by inserting a steel pipe through a hole in the brickwork and tamping magnesite containing a binder or chrome ore between the outer surface of the pipe and the brickwork.

**Bath Depth.** The bath depth of furnaces varies widely and is not necessarily proportional to the tonnage being tapped. The
maximum bath depth of about 48 in. is found in some large furnaces of 250 to 300 tons capacity or more. There has been a definite trend away from deep baths and now few furnaces exceed 36 in.; the majority of the furnaces ranging in capacity from 100 to 175 tons are operated with a metal depth of 28 to 32 in. and in some of the recently constructed 175 to 225-ton furnaces bath depth does not exceed 28 in. The principal reason for the trend away from deep baths is the more general use of high-iron charges; that is, 55 to 70 per cent or more molten iron in the furnace charge. This practice requires from 100 to 300 lb of ore per ton of steel produced, depending upon such factors as the percentage of hot metal, the silicon content of the iron, and the type of scrap. Since ore, especially fine ore, offers great resistance to heat flow, it is advantageous to use a furnace with a large hearth area, as this allows the ore charge to be spread in a thinner layer, permitting the heat to penetrate to the bottom of the charge with greater rapidity.

The rates of chemical reactions that take place after the charge is molten are closely associated with (1) the ratio of the slag-metal interface area to the volume of metal and (2) the ratio of the metal volume to the surface area of the hearth in contact with the metal; therefore, it is obvious that the bath depth is of considerable consequence to the production rate of the furnace, for a number of reasons. However, insufficient attention has been given to this factor, and only recently has the value of the moderately shallow bath been realized fully by some operators.

**Roof.** The importance of good roof design and of good refractories cannot be overemphasized because roof life normally determines the duration of the furnace campaign. Silica brick is used almost universally for roof construction in America, this refractory having been selected for its light weight and high compressive strength at elevated temperatures. However, the use of silica definitely limits the maximum operating temperature to about 3060 F (1680 C), leaving available only a narrow temperature range in which steelmaking may be successfully accomplished, since about 2820 to 2910 F (1550 to 1600 C) is the minimum desirable tapping temperature for most grades of steel.

Owing to the temperature limitations imposed by the silica roofs, attention is now being directed to the development of basic
roofs, which have been used in European practice. Basic brick has high coefficients of expansion and thermal conductivity and is much heavier than silica brick. These characteristics complicate roof construction, particularly for the large furnaces found in most American integrated plants, and it appears that a suspended arrangement may be necessary for successful application of basic refractories. At the time of this writing, at least two all-basic open-hearth furnaces have been constructed in steel plants in the United States and Canada, and if favorable results are obtained in their operation it seems likely that wider use of basic roofs may be anticipated.

The roof may be constructed as a ring, bonded, or ribbed arch.
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(Fig 1-8), the arch being supported by skewback shapes which are held in the skewback channels attached to the vertical structural members, or buckstays. The buckstays are in turn tied together with a rigid binding, replacing the older system of tie rods. The ribbed roof is said to have the advantage of additional strength as the roof wears thin with service, since a typical 18-in. roof would be reinforced by 22-in. ribs whereas a ring or bonded roof would be uniformly 18 in. thick. The practice of using a thicker roof section above the back wall and near the front wall is frequently advantageous, since these areas usually are subjected to more severe erosion by the furnace gases than is the remainder of the roof.

Back Walls. Originally, furnaces were built with vertical silica back walls but this design has practically been replaced by the sloping back wall. In this latter design, the slope is about the same as the angle of repose for dolomite and grain magnesite, i.e., about 50 to 55 degrees, which allows these granular materials to be used for forming the back wall. This provides a more refractory wall than silica brick and simplifies maintenance (see Fig 1-2). Obviously, the dolomite and magnesite must be supported by neutral or basic brick, which in turn may be held by silica or even fireclay brick since the compressive stresses are relatively low. Chrome ore may be used at the junction of back wall and roof to protect the roof skew brick if severe flame erosion is encountered at this point.

Front Walls and Doors. It is customary for a furnace of 100 tons or more to have five charging doors, the remainder of the front consisting of a series of refractory jambs with brick arches over the doorways skewed to the jambs on either side. This portion, called the front wall, is probably subjected to more severe operating conditions than any other part of the furnace. Until recently, silica brick was used universally in this section; the frequent repairs necessary constituted one of the most disagreeable hot-repair jobs in the open-hearth shop. Now basic refractories are being used widely and, although the original cost is greater, they are claimed in many shops to effect an over-all economy. The design of water-cooled doors and frames has been fairly well standardized, the door being cooled to further the comfort of the furnace men, while the frame protects the re-
fractory jambs from abrasion and shock during charging. The cooling may also have some influence in increasing the refractory life at these points. Archless doorframes are now widely used,

Fig 1-9. Details of construction of a water-cooled brick-lined port for burning gas. The two ports or uptakes for supplying the air are shown in the plan (upper) section. (Courtesy Blaw-Knox Company.)

particularly in shops charging high percentages of scrap. This construction permits faster charging and the front-wall refractories require less hot repairing.

Ports. The design of the ports or openings through which the gas and air are conducted into the furnace is of extreme im-
importance to the furnace operating characteristics. Since the ports are used alternately as burners and as downtakes for carrying away the products of combustion, their construction must be a compromise between the optimum designs of a port for either of these two functions. This fact, together with the high temperature and the erosion to which the ports are subjected, increases the difficulties, since areas and alignments must be maintained within reasonable limits. The most frequently used design consists of two air ports and one gas port, as illustrated in Fig 1-9.

The port areas and alignments determine the velocity and the point of convergence of the gas streams. These factors have an important bearing upon the flame characteristic and heat distribution. The ports are sloped so that the flame plays upon the bath, insuring efficient heat transfer and protecting the roof. From Fig 1-9, it may be seen that a large portion of the air enters above the gas stream, which aids in preventing excessive heating.
of the roof. Water-cooling of the gas port materially increases port life and assures reasonable maintenance of the original port dimensions.

Several types of ports have been developed with facilities for increasing the port area when the ports are used as exits for the products of combustion and for restricting the area when they are used as burners. Probably the two most commonly known variable-area port designs\textsuperscript{16, 17} are the McKune system and the movable Rose port, illustrated in Figs 1-10 to 1-12.

![McKune movable gas port: vertical section. (Courtesy Blaw-Knox Company.)](image)

The McKune system was originally designed to burn coke-oven gas, a high-Btu fuel requiring no preheating. The Rose port was built for a lower Btu fuel consisting of about two parts of blast-furnace gas and one part of coke-oven gas; this mixture requires preheating.

In the McKune system, the two outside ports are closed by
means of water-cooled valves (Figs 1-10 and 1-11), which concentrate the forced draft through the center port, normally used for gas only in other systems, at which point the gas is injected into the lower portion of the air stream. This arrangement produces a sharp "blowpipe" type of flame. When the ports are being used to carry away the burned gases, the valves in the two outside ports are opened, providing a large exit area. The movable-port system utilizes a sliding, water-cooled, refractory-covered port, which is practically withdrawn from the furnace during the periods when the port is carrying off the waste gases.

Therefore, this construction likewise provides reduced port area for the burner and increases the area of the exit ports.

**Oil Burners.** When oil is employed as the fuel, a water-cooled burner of the spray type is generally used, its function being to atomize the oil thoroughly by the action of high-pressure superheated steam or air. The pressure of the atomizing medium at the burner is usually between 60 and 120 psi. The purpose of atomizing is to put the oil in a state that is conducive to intimate
mixing with the air. For this purpose, steam is more commonly used, since it is usually available and less costly than high-pressure air. Theoretically, the use of air should be advantageous from the standpoint of combustion but the efficiency of atomization is not as good as with steam and the cost is higher. Low-viscosity tar is handled in the same manner as oil.

In recent years, a number of oil burners of special design have been developed to permit the introduction of oxygen or primary air adjacent to or surrounding the stream of atomized oil.13

**SLAG POCKETS AND REGENERATORS**

**Slag Pockets.** As the waste gases leave the hearth and enter the downtakes, they carry an appreciable amount of finely divided iron oxides, together with smaller amounts of slag droplets, lime dust, etc. If these materials were allowed to enter the regenerator, they would soon clog the checker system, which would cause a shutdown for cleaning. To prevent such a rapid deposit, slag pockets are built at the bottom of the downtakes where a majority of the solids are deposited before the gases enter the regenerator. Furnaces burning tar or heavy oil carry over considerably more iron oxide than furnaces burning gas, probably because of the agitation created by the high initial velocity of the tar or oil flame. Furnaces with insufficient slag-pocket capacity decrease in operating efficiency as the slag pockets fill up. To help overcome such a situation, auxiliary slag pockets may be used to drain the bulk of the slag from the main pockets; these can be cleaned at intervals during the campaign while the furnace is undergoing hot repairs.

**Regenerators.** In order to obtain sufficient flame temperature and economic fuel consumption, the air supplied to the burner for combustion is always preheated, and when gases of low Btu values, such as producer gas, or blast-furnace gas enriched with coke-oven gas, are used as fuel these are also preheated. This preheating is accomplished by means of a regenerative system. The hot waste gases leaving the furnace are passed through a checkerwork, which takes up a large part of the sensible heat. Upon reversal of the furnace, the heat that has been stored in the checkers is available for raising the temperature of the countercflowing air on its way to the burner. Since a large number
of the furnaces now in operation were designed originally for producer gas, they were built with two regenerator chambers at each end of the furnace, the smaller chamber being used for pre-heating the gas and the larger one for the air (Figs 1-4, 1-5 and 1-6). Most of these furnaces have been converted to burn liquid fuel, using all the chambers for heating the air.

When new furnaces are built for liquid fuel, with no intention of using a gas requiring preheating, they may be designed with only one chamber on each end for the air.

The principal parts of the regenerators are: (1) the chambers enclosing the checkers; (2) the checkers, which alternately absorb and give up heat; and (3) the rider system, which supports the checkers and forms the passage conducting the cooled gases from the checker flues to the exit end of the chamber.

Size of Checkers. There are numerous types of checker construction; one commonly used is the chimney-flue checker constructed from one size of brick, laid on edge, as illustrated in Fig 1-13.

![Chimney-flue checker construction](http://example.com/chimney-flue-checker)

The flue size generally found in this construction ranges anywhere from about 6 by 6 to 11.5 by 11.5 in. The waste gases from oil-burning furnaces, and especially from tar-burning furnaces, carry an appreciable amount of solids, which may rapidly foul the checkers. For this reason, it is common practice to use some-
what larger flues in these than in gas-fired furnaces. In order to facilitate cleaning, many of the newer furnaces fired with liquid fuel have basket-weave checkers, as shown in Figs 1-5 and 1-6. Checkers of this type can be cleaned by blowing air or steam through the side openings in the brickwork as well as through the vertical flues.

A firebrick of dense structure is generally used in the checkerwork, although silica or high-alumina brick is occasionally employed in the upper and hotter zones.

The volume of the air checkers is usually about 1.5 times the volume of the gas checkers. The furnace illustrated in Figs 1-2 to 1-4 has 2723 and 4323 cu ft of checkerwork (one end of the furnace only) in the gas and air chambers, respectively, giving a ratio of 1:1.58.

In regenerator design it is essential that the rider walls that support the checkerwork be of sufficient height to allow unrestricted flow of the gases into or out of the chamber and to provide ample space for the accumulation of solids normally collected at this point during the campaign.

**Draft Equipment.** The draft or flow of air required to support combustion is normally supplied by either natural or forced draft. These two systems are shown diagrammatically in Figs 1-14 and 1-15. With natural draft, the flow of air through the checkers and to the port depends upon the stack effect created in the regenerator and uptake system (see Chapter 20). Forced draft supplementing natural draft is produced by delivering the air under pressure by means of a fan to the checker-chamber intake. In both draft systems, the products of combustion are removed through the opposite ports and carried through the checkers by the stack effect of a relatively tall chimney, which exhausts the waste gases into the atmosphere. In some installations the natural stack effect of a short stack is supplemented by a Venturi arrangement as used in the Isley system and illustrated in Fig 1-16.

The draft systems described are all used with the conventional flue and reversing-valve arrangement as shown in Fig 1-17. The Isley draft system shown in Fig 1-16 is a combination of forced
and induced draft arranged in such a manner as to simplify the flue and reversing mechanism.

**Control Equipment.** While equipment is available for full automatic control of the open-hearth furnace, it has not yet been fully adopted by the industry. The various automatic controls in the order of frequency of their occurrence are: (1) furnace-pressure control, also called draft control, (2) automatic reversal of furnace, (3) roof-temperature control, and (4) control of fuel-air ratio.
Fig 1-16. Venturi arrangement in the Isley system.

Fig 1-17. Conventional flue and reversing system used with gas-fired furnaces. (Courtesy Blaw-Knox Company.)
It is usually found advantageous to operate a furnace under a pressure of about 0.05 to 0.10 in. of water, measured at the highest point in the furnace. This pressure normally is maintained by means of the damper in the stack and may readily be controlled automatically. Automatic reversal of the furnace is based either on a time cycle or checker temperature, or both. Manual reversal is frequently guided by a checker-temperature indicator and recorder. While full automatic roof-temperature control, which is obtained by automatic regulation of the fuel flow with respect to the roof temperature, is occasionally used, a roof-temperature recorder is more commonly employed as an aid to the furnaceman. Automatic control of the fuel-air ratio to maintain the proper combustion mixture may be used, but in many installations flowmeters indicate and record the volume of fuel and air being used, the adjustments being made manually. When heavy liquid fuels are burned that require preheating to obtain the proper fluidity, the fuel temperature and the steam pressure used for atomizing are generally indicated and frequently recorded. Details of furnace instrumentation and control are discussed in Chapter 4.

Fuel Consumption. A survey of a large number of steel plants showed that the best modern furnaces using hot-metal practice consumed from 2,850,000 to 3,380,000 Btu per net ton of steel produced. These furnaces were of approximately 200 tons capacity with bath depths of 28 to 30 in., except for one furnace of 38-in. bath depth. The less efficient furnaces were found to use as much as 4,800,000 Btu per net ton.

Maintenance. After each heat has been tapped, the back wall and bottom of the hearth are repaired with dolomite. The dolomite may be either shoveled into place or added by means of a dolomite machine. If large holes are found on the flat area of the bottom, the molten pool of metal must be removed by means of rabbles before these holes are filled with double-burnt dolomite or some of the refractories specially prepared for this purpose. During the early stage of the heat, the section of the front walls (jambs) just above the banks may be repaired with chrome ore, which is placed in the desired location by means of a spoon. With basic front-wall construction, it is now frequently possible to run
through a campaign with only one front-wall replacement; more repairs are required if silica is used.

The roof life may be from 150 to 400 heats; it is frequently extended by hot repairs. The extent to which the roof repairs may be justified depends largely on the condition of the other parts of the furnace.

Leaks in any water-cooled part of the furnace, such as doors and frames, must be avoided, since water causes severe damage to refractories.

Tight-fitting doors are desirable to prevent the infiltration of air. However, if the furnace is operated under pressure, infiltration is not a problem.

Doors must frequently be removed for relining, but replacement of doors is readily handled by the mechanical equipment available on the furnace floor. The doorframes also are easily replaced when necessary and without interference with production.

To prevent serious port failures, especially in furnaces fired with producer gas, it is essential that the ports be protected by an adequate supply of cooling water. Liquid-fuel burners do not present such a serious problem, since they may be readily replaced.

The accumulation of excessive deposits on the checkers and the resultant decrease in furnace efficiency are largely overcome by cleaning the checkers at regular intervals with steam lances. Openings are provided in the side or end walls of the checker chambers for this cleaning operation, which blows the accumulation off the checkers and deposits it in the bottom of the chamber, from where it is subsequently blown out the stacks by means of steam blowers located in the flues of the checker chambers.

Too much stress cannot be placed upon the proper maintenance of the open-hearth furnace if a minimum of delays, economical operating costs, and a long campaign are to be obtained. The maintenance of furnace refractories is dealt with in Chapter 3.

MISCELLANEOUS AND AUXILIARY EQUIPMENT

In addition to fuel and air for combustion, an open hearth requires various other utilities. A surprisingly large quantity of water is needed for cooling the doors, frames, and burners, a
150-ton furnace requiring approximately 2,800,000 gal of cooling water per 24 hr. A separate hydraulic system or electric motors are used for raising and lowering the doors. Other services required are: (1) electric power for the fans used in the draft system and for the control instruments, (2) steam for atomizing and heating liquid fuels as previously explained, and (3) oxygen piped to each furnace, where it is commonly used in a lance for opening the taphole. In recent years heavier oxygen lines have been installed in many shops for metallurgical uses such as direct oxidation by lances or jets or air enrichment at the burner.

Auxiliary Equipment. The operation of a modern open-hearth shop requires a considerable amount of auxiliary equipment for the handling of raw materials and the steel from the furnace. Hot-metal mixers are needed for the storage of molten pig iron, together with ladles and crane facilities for transferring the iron to the furnaces. Narrow or standard-gage rail buggies handled by small steam, electric, or diesel locomotives are used to convey the boxes of scrap and other essentials of the charge from the stockyard to the front of the furnaces, where charging machines empty the contents of these boxes into the furnace. Open-hearth shops constructed during recent years have standard-gage tracks throughout. Ladles and ladle cranes of sufficient capacity to hold the contents of a heat are required for handling the steel during tapping and teeming of the ingots. Ingot molds, stools, and mold buggies, together with stripping cranes for removing the ingots from the molds, complete the major auxiliary items of equipment.

Mixers and Mixer Ladles. The purpose of the mixer, which may range in capacity from 200 to 1700 tons, is to serve as a storage place for the molten pig iron received from the blast furnace until it is required by the open-hearth furnace. The mixer also aids in reducing fluctuations in the chemical composition of the molten iron as it comes from the blast furnace. However, to be effective it is necessary for the mixer to have a capacity of 800 tons or more and to have the receiving hoppers and outgoing spouts properly located. Shops frequently are equipped with two mixers—a smaller one of from 400 to 600 tons capacity, and a second one capable of holding 1000 tons or more of iron. Two medium-size mixers are preferable to one large unit in
serving a group of furnaces because holding capacity is available during relining and off-quality hot metal may be segregated for most efficient metallurgical control.

Mixers are refractory-lined steel shells, usually cylindrical in shape with spherical heads, and are supported by two or more rockers attached to the shell. These rockers are mounted on a train of roller bearings; this arrangement allows the vessel to be tilted so that metal may be drawn off through a spout when desired. The receiving hoppers through which the iron is charged into the mixer are on the side opposite the pouring spout and should be covered, when not in use, with refractory-lined lids to conserve the heat. While practically all mixers are equipped with a burner, its use is not required under normal operating conditions. A wide variety of refractory linings is used in mixers, the commonest being silica brick, a hard-burnt bosh brick, or stone of high silica content. The thickness of the lining in the lower portion may be as much as 30 in., while the arch over the top is usually one course of 9-in. brick.

Molten iron is transported from the blast furnaces to the open hearth either in open-top ladles of 25 to 65 tons capacity or in larger mixer-type ladle cars ranging from 60 to 200 tons in capacity. While many open-top ladles are still in use, they are gradually being replaced by the larger mixer type. The latter are lined with either brick or sandstone, which varies in thickness from 15 to 18 in. in the bottom to about 9 in. in the top. The larger mixer-type ladles are capable of holding metal in a molten state as long as 24 to 36 hr with only a slight skull formation. While most of the hot metal used is put through a mixer, there are a few plants not equipped with mixers, and there the iron is poured directly into small transfer ladles from a mixer-type car.

**Charging Equipment.** More recognition than in the past is now being given to the importance of rapid charging in order to obtain maximum productive capacity. To facilitate this, charging machines of 10 to 15 tons capacity, capable of handling charging boxes with a capacity up to 50 cu ft, are being used. However, the size of the charging boxes is frequently limited by the size of the furnace doors, doorframes, and the height of the furnace roof.

**Steel Ladles.** Ladles used for receiving the steel from the open
hearth, and subsequently for teeming the ingots, are of sufficient size to hold the contents of one heat. Ladle shells are fabricated from steel plates in the form of a thimble to which trunnions are attached for lifting. The cross section usually is circular but oval sections sometimes are used in shops where the size of the heats has been increased. By resorting to the oval section, greater ladle capacity can be obtained without costly changes in the spreaders used for handling the ladles, as the distance between the trunnions need not be changed. The reduction of the ferrostatic head to a minimum is another advantage cited for this type of ladle. Formerly, ladles were fabricated by riveting but this has largely given way to all-welded construction, with a considerable saving in weight. The lining of a 150-ton ladle may consist of two courses of ladle brick with \( \frac{1}{2} \) in. of clay mud or insulating cement between the shell and the brick, totaling about 6 in. in thickness. A pad, or heavier section, frequently is used in the side subjected to the force of the stream during tapping. The bottom is made up of approximately 15 in. of brick, the upper two or three courses being laid on their rowlock (narrow face). While small ladles are equipped with only one pouring-nozzle and stopper-rod mechanism, ladles of 125 to 200 tons capacity are sometimes equipped with two in order to decrease the teeming time and minimize the temperature drop during the pouring of the heat. The double-stopper arrangement also prevents excessive erosion and changes in the dimensions of the nozzle orifice. However, the two-stopper design is practical only in shops using very few mold sizes, since the varying distance between different sizes of molds precludes such an arrangement.

For teeming large heats, a clay nozzle with a 2-in. orifice is popular; some shops use nozzles 2.5 in. in diameter and occasionally larger for teeming large slab ingots of low-carbon steel. The stopper head may be either clay or graphite, preferably the latter; the stopper rod is protected by clay sleeves. The nozzle, stopper head, and sleeves are replaced after each heat. The nozzle and stopper-rod assembly are illustrated in Figs 10-10 and 10-11, pages 417 and 419.

Open-hearth Pit. In the pit, directly behind the spout of each furnace, permanent stands are constructed for holding the ladle prior to and during tapping. Slag thimbles are located at the
side of each ladle to collect the excess slag delivered from the overflow spout on the ladle. Ladle cranes of sufficient capacity for handling the combined weight of the ladle and heat are provided for moving the ladle from the stands to the pouring position over the molds. A number of pouring platforms at about the elevation of the top of the molds extend the length of the shop at the far side of the pit; these are used by the pouring crew during the teeming of the heat. The molds to be used are placed on a track running parallel to this platform. In addition to the track for handling the mold buggies, a second track for handling standard-gage railway cars should extend the length of the pit. This facilitates the removal of pit scrap and debris and is necessary for handling supplies during furnace rebuilds.

Molds, Stools, and Mold Buggies. The molds in which ingots are cast and the stools used for supporting the molds are iron castings produced from either direct blast-furnace iron or cupola iron. Molds may be roughly classified into two main groups; i.e., big-end-down and big-end-up. The cross section of these molds may be square, rectangular, or round, and they may have plain or corrugated inner surfaces. The dimensions and capacities of molds vary within wide limits depending upon the product to be produced from the ingot. The mold buggies used for transporting the stools and molds may be either narrow or standard railway-gage buggies. The wider buggies are desirable, however, if double-stoppered ladles are used, since they allow a greater variation in mold arrangement.

Mold Preparation. In modern plants, mold preparation is carried out in a separate building. This building is equipped with a number of parallel tracks on which the strings of mold buggies are placed. To facilitate cleaning, inspection, and so forth, working platforms of about the height of the molds are built parallel to the tracks. Crane service is provided for handling the molds and stools. After cleaning, molds may be coated by dipping or spraying; among the materials commonly used for this purpose are tar, pitch, graphite, and salt. If hot tops are required, they are then placed on the molds. After preparation is completed, the molds may be held in the building for protection from the weather until needed in the open-hearth shop. By using the proper number of strings of molds, the interval between their use
Fig 1-18. General layout of a modern six-furnace open-hearth plant.
Fig 1-19. Section through open-hearth building, pouring pit, mold yard, and stockyard of the plant shown in Fig 1-18.
may be so regulated that they can be returned to the open hearth at the desired temperature. Proper mold temperature just prior to teeming is essential to assure reasonable mold life and good ingot surface.

An extended discussion of mold design and preparation may be found in Chapter 10.

**Stripping Ingots.** After the ingots have solidified sufficiently to be moved, the string of mold buggies is taken from the pouring pit to the stripping yard or building. Specially designed stripping cranes remove the molds from the ingots, leaving the ingots on the stools. The ingots are then moved to the soaking pits, where they are heated for rolling. If the ingots are cast in big-end-up molds with refractory hot tops, the stripping crane is used to loosen them in the molds and they are removed from the molds by the soaking-pit charging crane. It is desirable to remove as much of the hot-top refractory as practicable before charging, since this material is detrimental to the bottoms of the pits.

![Diagram](image_url)
Shops producing large tonnages of big-end-up ingots frequently employ permanent refractory-lined hot tops and are equipped with cranes specially designed for ingot stripping.

**Plant Layout.** In order to obtain the maximum production from a number of furnaces in an open-hearth shop, the plant must be laid out and equipped to minimize delays in the flow of raw materials to the furnace and in handling the heats after they are finished in the furnace. This problem is more complex than it might appear at first thought. Of prime importance in the construction of new shops or the modification of old plants is the provision of ample floor space at the front, ends, and rear of the furnaces, to facilitate mechanization of materials handling. One of the major factors complicating the operation of an open-hearth shop that must be taken into consideration in the plant layout is that open-hearth furnaces cannot be operated on a definite time cycle. While all shops work on a predetermined schedule aimed at preventing too many furnaces from being ready for charging or tapping at one time, the schedule cannot be maintained rigidly. Arrangements must also be made to allow for furnace rebuilds with a minimum of interference with the operation of the remainder of the shop. The general layout of a modern plant with six open hearths of the type illustrated in Figs 1-2 to 1-4 is shown in Fig 1-18. Sectional views of this plant are shown in Figs 1-19 and 1-20.

**SUGGESTED READING**

2. AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS: *Open Hearth Proc.*, AIME, 1935 to date. Published annually.


