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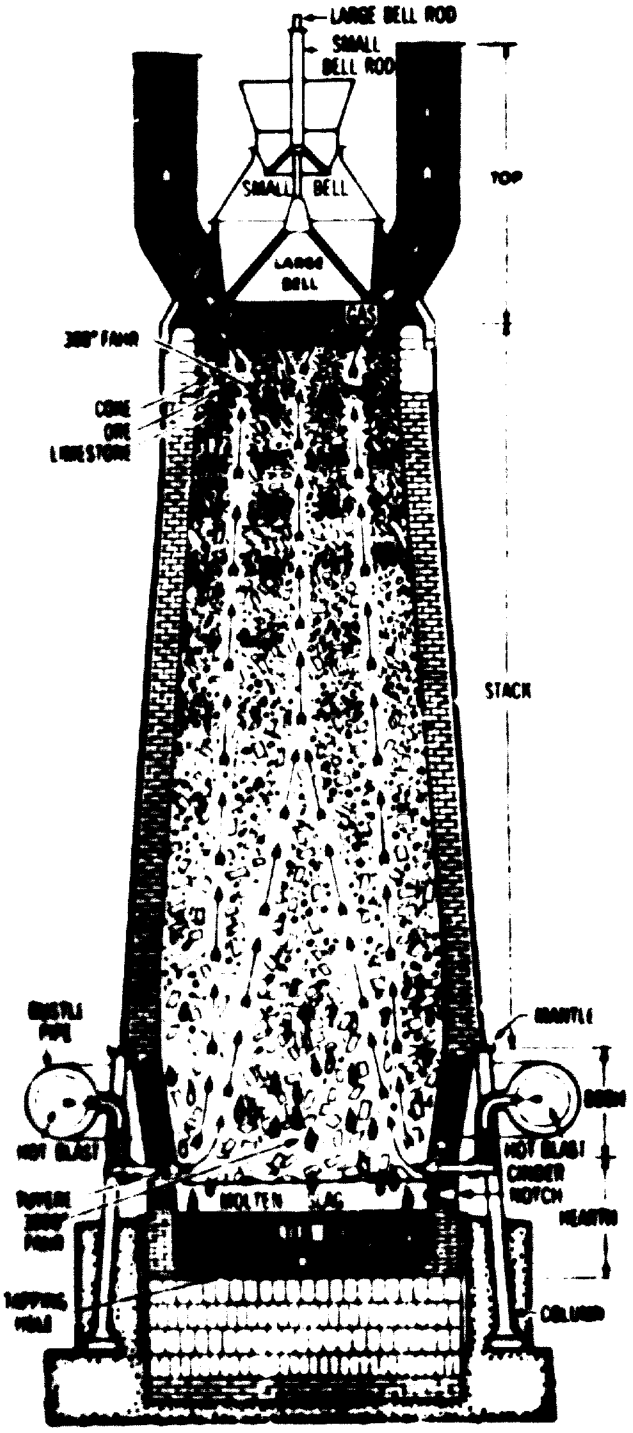
In many cases the bells revolve in order to allow a better distribution of the materials in the furnaces. In each successive charge, the entire operation is repeated in a similar manner.

At the same time that these raw materials are being charged into the furnace stack, a large quantities of preheated air (1800° F.) are being blown into the lower part of the furnace through a number of inlets called tuyeres. The resultant heat at the bottom of the furnace begins to burn the coke which in turn generates additional amounts of heat and gas. The heat and gas tend to rise up through the furnace stack and as they do they come into contact with additional quantities of coke, ore and limestone which is then reduced into a spongy mass of iron. As the material at the bottom of the furnace reaches a temperature of about 3500° F., the iron which is then in a molten state begins to drop into the furnace hearth. Slag, which is a product of the interaction of limestone, coke ash and material other than pure pig iron, is also formed in the process. This matter is considerably lighter than the iron and will float at the top of the molten material from which point it can be separated from the pig iron. Firgure 2 illustrates the process.

The pig iron and slag are tapped from the furnace hearth by means of the tap hole for iron and the cinder notch for slag. The cinder notches, there are usually two, are higher than the tap hole because the slag floats on the top of the iron.

Figure 2



Blast Furnace Process

The modern blast furnace itself is usually in excess of 100 feet tall. The general design of the furnace can be divided into four parts: the furnace top, the stack, the bosh and the hearth. The tap has already been described.

The stack is that part of the furnace which rises from the mantle to the furnace top. It is a steel jacket, cylindrical in shape and lined with refractory brick in order to protect it from rapid wear due to the intense heat and pressure and friction of the burden as it moves downward. The lines of the stack on most modern furnaces are tapered from bottom to top to give added strength and durability to the structure. Further, this design allows the furnace burden to move downward toward the hearth with minimum danger of burden separation which can cause dangerous "blow outs." The mantle which is the widest part of the furnace is surrounded by a bustle pipe through which the heated air is forced and from the bustle the hot air is fed into the tuyeres and then into the furnace. The number of tuyeres per furnace differs to some extent, but in general the number will be between 18 and 24 depending on particular furnace requirements and designs.

Below the mantle and the bustle pipe is the bosh, which is tapered from top to bottom on the inverse of the stack design. However, the bosh is much shorter in length than the stack, i.e., only about 15 feet on the modern furnace. The angle of the bosh is usually about 79 to 83 degrees, and is so constructed in order to allow an easy downward movement of the furnace burden. It is in the bosh that the final reduction of the furnace burden is completed. It is also here that the gases begin to ascend to the furnace stack and begin the combustion processes for the remainder of the furnace burden.

The lowest part of the blast furnace is the hearth area and it is here that the molten pig iron and slag are collected prior to their periodic removal. The hearth dimensions of a blast furnace will differ considerably from one furnace to another, but in general the size of the hearth and the volumetric capacity of the furnace stack will determine the capacity of the blast furnace. The hearth is lined with layers of refractory brick and is reinforced with a metalic jacket for added strength. Most blast furnace hearths are equipped with three tapping holes, one which is at the bottom of the hearth and is for the molten iron and the two remaining ones which are near or at the top of the hearth for the removal of slag.

Once in operation the blast furnace is a continuous process which runs for 24 hours a day. The hot air which provides the initial heat required to begin the combustion process is provided by hot blast stoves of which there are usually three or four per blast furnace. A device called a turbo-blower creates the cold air blast which in turn is fed into the hot blast stoves. At the same time cleaned hot gas from the blast furnace itself is fed into the hot blast stove combustion chamber and is passed through the checker brick. The hot blast furnace gas provides the heat which keeps the temperature of the checkers high enough to heat the cold air which is passed through this checker area, the result of which is a blast of air heated to 1000° F. The hot air is then passed into the bustle pipe, through the tuyeres and into the furnace stack.

The manner in which blast furnace gas is taken from the furnace, cleaned and re-used in the hot blast stoves is basic to an efficient blast furnace operation. At the furnace top there are two to four gas uptakes into which the ascending gases rise after passing through the furnace burden. These gases are then directed into a gas downcomer which carries the hot gas into a primary gas cleaner or dust catcher. This process is continuous due to the constant pressure of gases rising from the furnace burden. In the primary gas cleaner, the larger particles of flue dust and coke ash are removed from the gas. The gas is then directed into a secondary cleaner or gas washer in which high power water sprays are applied to the gas in order to complete the gas cleaning operation. On the more modern blast furnaces, an electro-static precipitator is used to insure an even cleaner final product. The cleaned gas is then transmitted to the hot blast stoves in order to be used in generating the hot blast. It should be noted that while the raw material input of coke, ore and flux are significant, the air requirement per ton of pig iron is often in excess of four tons.

The overall raw material requirements per ton of pig iron produced on a modern blast furnace will differ to some extent, but in general these inputs can be said to approximate the following.

Iron Ore	1.6 tons
Coke	.65 tons
Limestone	.2 tons
Air	4 to 4 1/2 tons

Further, in addition to the production of one ton of pig iron, the furnace will yield about 700 pounds of slag and 6 tons of gas per ton of pig iron.

The productivity or output per unit of input on a given blast furnace can be increased in several ways. The most commonly used method is the pre-treatment or beneficiation of ore. In particular, the use of sinter and or pellets can increase the production of a typical blast furnace by a considerable amount. Increasing the physical size of the furnace and the use of hotter blast temperatures can also result in increased blast furnace productivity. It is largely through the proper application of these principles that many modern blast furnaces are able to produce in excess of 3,000 net tons of pig iron per day.

The Open Hearth Furnace

At the present, and over the past 50 years, the open hearth furnace has supplied the greater part of the world's steel. The open hearth furnace, which gets its name from the design of the furnace, was first conceived by Sir William Seimens after the middle of the 19th century. Since that time the furnace and its operation have been subjected to many changes and improvements, all of which have resulted in a more efficient and dependable operation. Actually there are two types of open hearth furnaces, the basic open hearth and the acid open hearth, a distinction which is determined by the type of refractory used in the furnace. Since the acid open hearth is almost extinct today and, in fact, never represented large tonnages, the following discussion will be confined to the basic open hearth.

The Open Hearth Furnace Plant

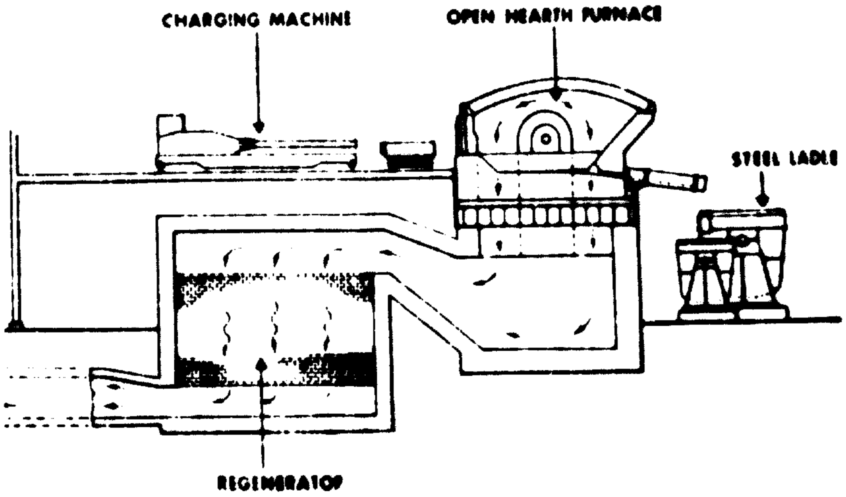
An open hearth shop usually consists of a number of individual furnaces constructed side by side in a row. This is the center line of the overall open hearth plant. The section of the open hearth plant which is located directly in front of and adjacent to the furnace doors is called the charging side or charging floor. This area is usually constructed some 20 feet above the actual ground level of the plant. On the back side of the furnaces, and at ground level, the pit side or pouring side is located. Here, the open hearth furnace is tapped and the molten steel is teemed.

into the ingot molds. Figure 3 represents a cross section of a typical open hearth plant, together with a closeup of the furnace section. Figure represents a cross section of the furnace.

On the charging side of the furnace, there are two sets of parallel rail tracks. The first of these, which is often of narrow gauge and is closest to the furnace doors is designed to carry charging boxes which load scrap and other items into the furnace. The second and wider gauge is designed to carry the charging machine. The charging machine is used to charge solid materials such as scrap, iron ore and limestone into the furnace. These are loaded into the charging boxes in the scrap yard. The boxes are then place on small rail cars called charge buggies and moved into position in front of the furnace doors by means of a locomotive. The size and capacity of charge boxes will differ in accordance with the size of the open hearth furnaces. When the charge boxes are in position in front of the furnace which is about to be charged, the electrically operated charging machine is moved into position behind them. The arm of the charging machine is then extended and picks up the charging boxes one at a time. The box is thrust through the opened furnace door and its contents dumped into the furnace. The machine then replaces the charging box on the buggie and picks up and charges other boxes until the furnace is full. The number of scrap boxes which are put into a furnace may vary considerably and is dependent on the size of the furnace as well as the charging practice of the particular plant.

Figure 3

Furnace Section



Open Hearth Plant

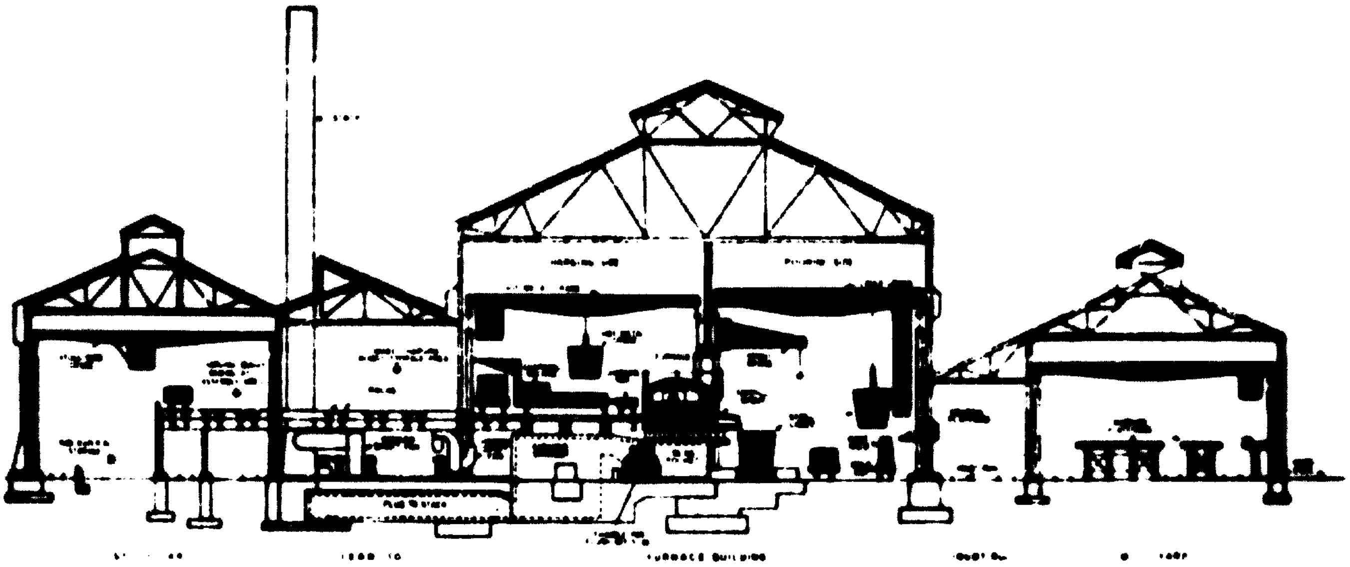
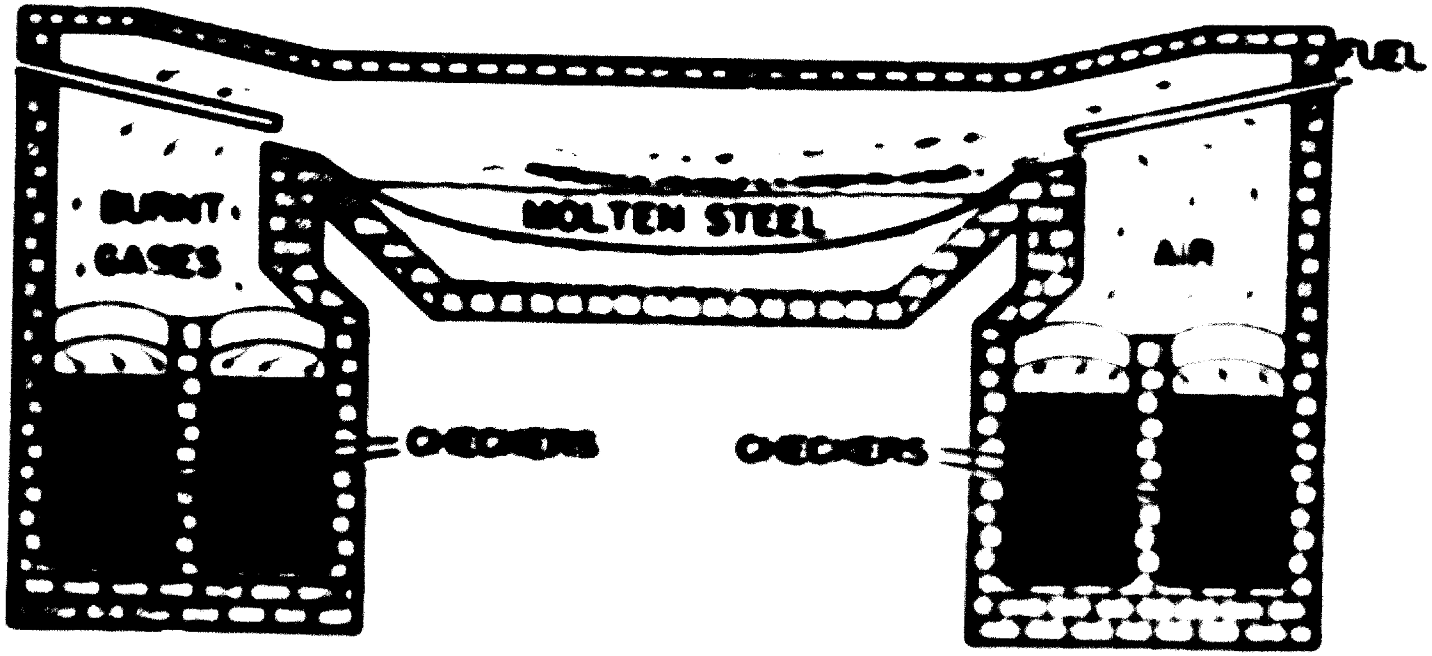


Figure 4



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REPORT ON THE IRON AND STEEL INDUSTRY

The empty charge boxes are then removed to the scrap yard to be reloaded for the next charging operation. The number of charging machines depends on the number of furnaces in the shop.

In most instances the charging side of the open hearth shop will also be equipped with one or more hot metal mixers. These hot metal mixers vary in size up to about 1500 tons capacity. Generally, the molten pig iron from the blast furnace will be poured into the mixers to await charging into the open hearth furnace. Hot metal mixers serve two purposes. First, they provide a ready supply of molten pig iron which can be readily charged into the furnace and, secondly, they allow the mixing of successive lots of molten pig iron which insures a more uniform iron. These hot metal mixers are usually located at the end of the open hearth plant and are constructed in such a way as to allow the easy transfer of the molten iron into ladles which are carried to the furnace by overhead cranes and poured into the furnace after the scrap has been charged. Factors determining the size of hot metal mixers would include the size of open hearths, time requirements of steelmaking, and the frequency and size of blast furnace casts.

The pit side or pouring side of the open hearth shop is usually the same length as the charging side, but is usually somewhat wider in actual working space. Here, large steel ladles are put into position below the open hearth tap hole and when the "heat" is finished, molten steel flows from the furnace into the waiting ladle. The lighter slag which floats on top of the steel is permitted to flow over the rim of the ladle into a slag thimble. Once all the steel has been emptied into the ladle, a large overhead electric crane moves the ladle into position over a row of ingot molds on the pouring platforms at the rear of the pit side. The ladle used in this operation is of the bottom pour type as opposed to the lip pour ladle used to charge the molten pig iron into the furnace. Once in position over the ingot molds, the steel is poured or teemed into these molds at which point the solidification of the steel ingot begins.

The stock yard in which scrap and other solid materials are kept is usually located near the charging floor. This area should be located to allow easy loading and shipment of scrap to the furnace area. For this reason, it is important that the inter-plant transportation system be constructed to conform to this objective. The scrap yard should also be of sufficient size to permit the accumulation of sizeable amounts of scrap which may be required during periods of peak operation.

The Open Hearth Process of Steelmaking

The actual process of manufacturing steel begins when the materials are charged into the furnace. Aside from molten pig iron and scrap, amounts of sinter or ore as well as limited amounts of flux may be charged into the furnace. The composition of the open hearth charge may differ substantially from time to time and place to place, ranging from a steel scrap charge of 90 to 100 percent with some cold pig iron to make up the balance to a charge of 80 percent molten pig iron and 20 percent scrap. One of the primary factors which will influence the amount of scrap used compared with the amount of pig iron are the relative costs of each material. When the price of scrap is low, increasing amounts of it will be used and, for this reason, scrap must be recognized as an important raw material in the steelmaking process. Fortunately, a steel mill generates a certain amount of scrap from its own operations. Ingot, bloom, slab and billet croppings, and side trimmings of plates and strip, as well as broken ingot molds are all important sources of scrap which can be re-melted in the open hearth furnace.

The melting process usually begins with the reduction of the scrap charge which is put into the furnace first. This part of the charge should be melted as quickly as possible to prevent the waste of fuel and loss of oxygan from the hearth area. The scrap must be heated to a temperature equal to or greater than the temperature of the hot metal charge in order to prevent a loss of heat from within the hot metal. The use of roof oxygen lances has been a major factor in bringing about a sizeable reduction in the time required to bring the scrap charge to the proper temperature and degree of oxidation. The time required to melt the scrap charge may vary from one to two hours depending on furnace conditions and whether or not oxygen is used.

Once the scrap is sufficiently melted, the molten pig iron is charged into the open hearth. At this time, a series of chemical reactions begins that first reduce the silicon and manganese which eventually form part of the open hearth slag. The oxidation of carbon begins as these former materials are removed from the "steel," and gradually the phosphorous is oxidized. The removal of phosphorous was one of the major factors which brought about the gradual replacement of Bessemer converters with the open hearth, for the Bessemer process was unable to reduce high phosphorous iron sufficiently. Gradually, the carbon content of the "steel" is reduced, and as this occurs the temperature of the heat rises. The final refining brings about a more complete reduction of carbon, sulphus and phosphorous, and the heat is considered finished when the carbon content and other elements are in accord with desired specifications. Through the use of modern specialized open hearth instruments, the operator can readily tell when the required specifications have been reached.

The time required to complete a heat of steel in an open hearth furnace may differ substantially from one furnace to another depending upon the general condition of the furnace, the percent of scrap in the charge, the size of the heat, the desired composition and, most important, whether or not oxygen is used as a supplementary fuel. A typical furnace without oxygen would require about nine to ten hours to complete the process, while a similar furnace with oxygen would require only about six and a half to seven hours to finish the operation. Thus the use of oxygen in the open hearth has been one of the most significant factors in bringing about increased open hearth productivity within the past decade.

When the steel in the open hearth reaches the desired temperature, composition and grade; the tapping hole at the back side is opened. Since this hole is at the bottom of the hearth, steel which is heavier than slag will flow out before the slag which will tend to remain at the top of the molten mass. As the molten steel flows into the waiting ladle, alloying or other materials may be added in accordance with the desired end product. When the open hearth is emptied, the ladle holding the steel is lifted into position over the rows of ingot molds.

In producing steel, the open hearth furnace uses the principles of reverberation and regeneration in order to develop and maintain the necessary temperatures within the furnace. As the charge rests in the hearth area, a flame is passed over it, and heats both the charge and the furnace roof which is relatively close to the hearth. Part of the heat required to reduce the charge is provided by radiation from the heated roof. Thus the furnace roof must be constructed of sturdy refractory brick in order to withstand the intensity of the heat. Further, when an oxygen lance is used, the roof is also subjected to splashing of hot metal which causes added and more rapid wear of the roof area. Because of these circumstances, basic brick is often used for the open hearth roof refractory if excessive shutdowns for maintenance and rebuilding are to be avoided

The process employs a regenerative principle when the hot gases from fuel combustion are put through the regenerative chambers at either end of the furnace. These regenerative chambers contain checker bricks which are arranged in such a way that the gases pass through them so that a part of their heat will be absorbed by the checker brick. The cold air needed for the continuation of the combustion process is admitted into these regenerative chambers and will be heated to sufficient temperature by contact with the checkers and the hot gas. By reversing the direction of the gas flow periodically (about every 15 minutes) the temperture of the flame can be maintained or increased. The checker arrangement and the flow of air and gases in the open hearth are shown in the furnace cross section in Figure 4.

Open hearth steelmaking has been at the heart of the steel industry for the past 50 years. The process is proven, it is dependable and it is efficient. However, with the advent of the basic oxygen process, the open hearth is beginning to lose favor among the world steel producers. It appears likely that the open hearth will be gradually replaced by the newer and more productive oxygen converters.

The Bessemer Steelmaking Process

The first broad scale commercial method of steel manufacture was the Bessemer process which gets its name from one of its inventors, Henry Bessemer, an Englishman. The process, which was almost the exclusive method of steel manufacture prior to the turn of the century, has very limited commercial use today. In general, the process consists in blowing atmospheric air which in some cases is slightly enriched with pure oxygen, through a charge of molten pig iron and small amounts of scrap. The process generates sufficient heat to reduce the foreign elements in the charge, for when the air is blown through the molten pig iron which is already at 2300 degrees F, the oxygen in the air combines with the carbon, silicon and manganese in the charge and this generates temperatures 300 to 500 degrees F in excess of the molten pig iron temperature.

A typical Bessemer plant is usually constructed close enough to a blast furnace so that the molten pig iron may be easily transferred to a hot metal mixer by a rail transfer car. The molten pig iron is stored in the hot metal mixer prior to its being charged into the converter. The iron is poured from the mixer into a ladle and then charged directly into the converter. The converter is equipped with a wide mouth at the top, and is constructed in such a way that it may be tilted to allow the molten pig iron to be easily charged into the vessel. Once the molten pig iron has been charged into the converter, it is returned to an upright position and the air blast is turned on and the operation begins.

Figure 4a depicts a typical Bessemer plant and Figure 5 illustrates the Bessemer converter.

When the process is completed, some additions to the molten steel may be made as the metal is being poured from the converter into a ladle for transfer to the ingot pouring area. At this pouring area, an overhead crane lifts the ladle from the transfer car and the contents are poured into the waiting ingot molds.

The Bessemer converter itself is a pear shaped steel vessel which is lined with clay and refractory brick. The converter is constructed so that there is an air chamber below the surface on which the molten metal rests. The top of the air chamber has a number of tuyeres or air holes through which the air is blown into the charge of pig iron. The converter is supported by two trunions which allow the vessel to tilt. One of these trunions is usually hollow and is connected to the blowing engines in such a way that the air blast may be blown through this hollow pipe into the wind box and ultimately into the charge of pig iron.

Typical Bessemer converters range in size from 50 to 30 tons per heat. On a 15 ton converter, air is blown in at a pressure of 15 pounds per square inch and at a rate of 25,000 to 35,000 cubic feet per minute.[1]

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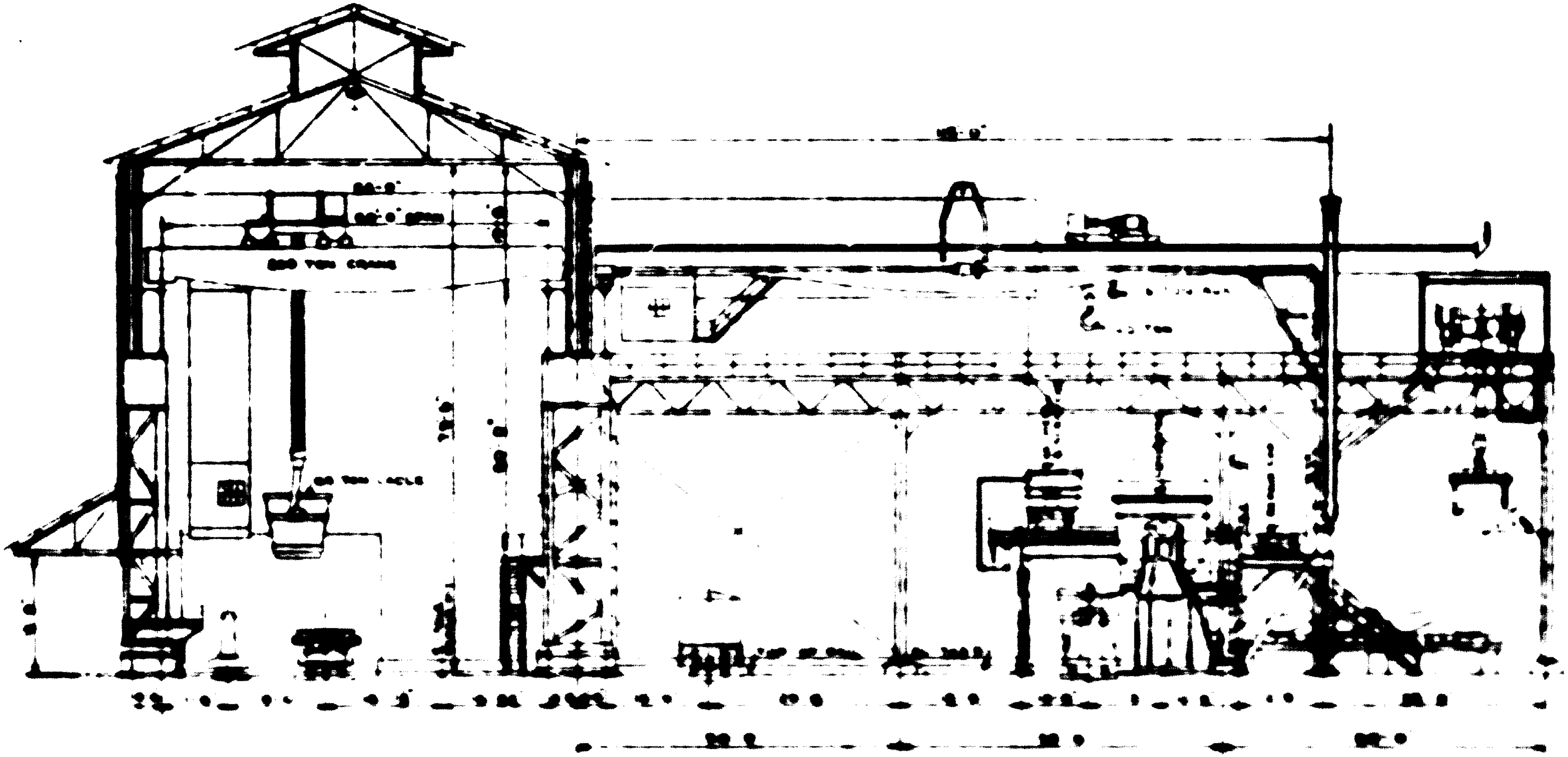
[1] American Iron and Steel Institute, The Making of Steel, New York, 1964, p. 47.

Figure 4a



Section Through Ladle Repair and Bessemer Converter Bays

Figure 9

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This combination of pressure and heat causes rapid wear of the furnace bottom and, consequently, the bottom must be replaced about every 20 heats.

The actual steelmaking operation begins after the pig iron has been charged and the air blast has been turned on. At this point the reduction of silicon and manganese begins, a result of the manner in which these elements combine with the oxygen in the air. As these elements burn off, the temperature of the heat rises and the reduction of carbon begins. As the various elements burn off, bright flames and sparks burst from the open mouth of the vessel. From the color and intensity of the flames, the operator can tell what stage the process has reached and when the flames subside the operator shuts off the air blast and the heat is completed. The time period during which the air blast is on may vary from 10 to 15 minutes depending to a large extent on whether oxygen enriched air is used.

When the air blast is shut off, additions may be made to the heat either while the metal is in the vessel or while it is being poured into the transfer ladle. Some form of manganese is often added to reduce any remaining iron oxide, and other additions may be made in accordance with the desired grade and composition of the steel. When the steel has been poured into the transfer ladle, the slag is then removed from the vessel and the process is repeated.

The Bessemer converter suffers from several marked disadvantages. Foremost among these is its inability to remove relatively large amounts of phosphorous and sulphur from the pig iron charge. Thus, when Bessemer steelmaking facilities are used, the ore and coke used to manufacture pig iron must have a low phosphorous and sulphur content, a condition which is not always easy to meet. Another disadvantage of the process is the fact that it cannot be as readily controlled as can the open hearth and other steelmaking processes. This factor becomes especially acute when specialty steels are made. The fact that the Bessemer converter uses only about a 10 percent scrap charge may also be a disadvantage in many instances, for it will require additional blast furnace capacity. However, in periods of scrap shortages and high scrap prices this may become an advantage.

Perhaps the greatest disadvantage of the Bessemer converter stems from the use of air as a fuel. Air contains about 80 percent nitrogen and a certain amount of this is left in the steel causing it to become brittle under cold working conditions. This was the pricnipal reason why the Bessemer rail was replaced by the open hearth rail, for in the winter Bessemer rails had a tendency to break and crack when fast, heavy trains passed over them.

Perhaps the single most important advantage of the Bessemer process when compared with other steelmaking facilities is its relatively low investment cost. Further, the speed with which steel can be manufactured

May also be considered an advantage, but when the advantages are weighed against the disadvantages, the process does have notable net deficiencies which have limited its application to steel production relative to other steelmaking processes.

The Basic Oxygen Steelmaking Process

Although the basic oxygen steelmaking process is a relatively new type of steelmaking, it has gained rapid acceptance by the world steel industry as an economical and highly efficient manner of steel production. The Iron and Steel Engineer[1] reports that the world-wide productive capacity of oxygen converters is presently just short of 70,000,000 net tons with an additional 53,000,000 tons of capacity planned in the near future. Basic oxygen steelmaking plants are now in operation in 26 countries, including virtually every steel producing country of any consequence in the world.

Although there are a number of somewhat different basic oxygan processes, the most generally used is the L-D type which is essentially a modification of the Bessemer converter. The L-D (taken from Linz-Donawitz, the locations in Austria where the process was developed) and Bessemer processes both produce steel by pneumatic conversion and use vessels similar in shape and design, but while the Bessemer process produces steel by blowing atmospheric air through the bottom of the vessel, the L-D converter introduces high purity oxygen into the bath by means of an oxygen lance which is inserted in an opening atop the vessel. The lance is water cooled and its size is determined by the size of the converter and the desired heat time. The oxygen is blown downward on the surface

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[1] Iron and Steel Engineer, November 1964.

of the molten pig iron contained in the vessel, producing a violent reaction between the oxygen and the bath at the spot where the oxygen stream impinges on the bath surface. An area of central reaction is created and unwanted elements oxidize and are carried off in the form of gas or slag. Because the metallurgical reaction originates at this one spot, the L-D process differs fundamentally from all other steelmaking processes in which the metallurgical reactions take place in the bath proper or are spread over large areas. In the L-D process, the metallurgical reactions are circulated to and from the point of central reaction by the kinetic energy of the oxygen stream and by the reaction gases which are produced.[1] A typical basic oxygen vessel is illustrated in Figure 6.

Types of Basic Oxygen Processes

In the discussion that follows of basic oxygen process and the equipment used, major emphasis will be placed on the L-D type basic oxygen method of steelmaking since, as has been noted, this is the most widely used basic oxygen process in the United States. The use of high purity oxygen, however, has given rise to the development of several new steelmaking processes which are in part variations of the L-D method. These are used to some extent on an industrial scale in a number of the steel producing nations. They include:

1. Top-blown oxygen-converter processes, including the L-D process and its modifications, which employ technically

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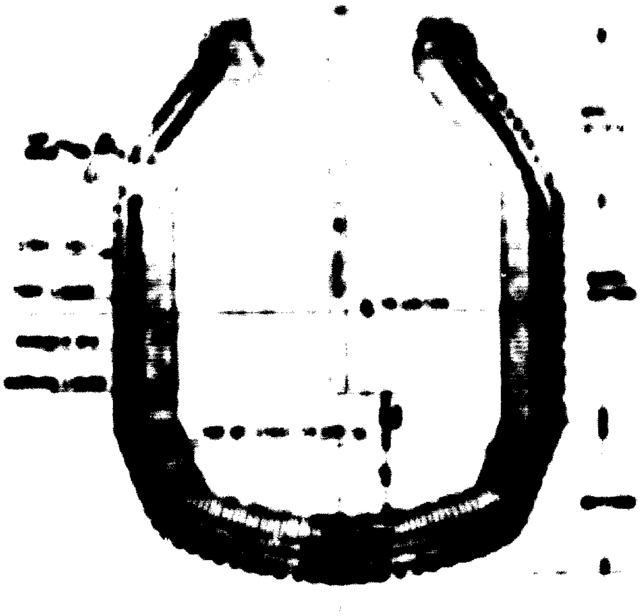
[1] SUESS, "Production of Steel by the Oxygen-Impingement Processes," Iron and Steel Engineer, 1950, pp. 149-150.

Figure 6



Basic Oxygen Vessel

pure oxygen in a vessel which is held stationary during the blow. The L-D process was initially used for low phosphorous iron (up to 0.3 percent or 0.4 percent phosphorous content) and for common-grade carbon steels, but modifications of the process have made it suitable for the conversion of high-phosphorous as well as low-phosphorous iron and have increased its application to include a greater number of product grades including alloy steel.

Two modifications of the L-D process have made possible the conversion of high phosphorous iron, namely, the L-D - A-C and L-D - Pompey processes. The latter, which was the first to be developed, introduced lumpy lime to the bath during blowing. In the L-D - A-C the bath is blown not with pure oxygen but with an oxygen stream containing powdered lime. Where powdered lime is utilized the cost is only slightly more than entailed with the L-D - Pompey process which requires facilities for crushing, screening and transporting the lime in lump form. However, the use of powdered lime makes it possible to control the physical and chemical composition of the steel more closely. These two modifications of the L-D basic oxygen process have been introduced to some degree in Belgium, France, Luxembourg and Western Germany.

The L-D - A.C which usually requires a double flush of slag has been the most widely applied of the two modifications. In the United States the straight L-D process has offered the most economical means of basic oxygen steelmaking given the grades of iron ore used by the industry.

2. The Kaldo process which uses technically pure oxygen and takes place in a rotating vessel inclined at 15 degrees to 17 degrees to a horizontal line. An opening at one end of the vessel is used for charging raw materials, blowing, slagging off and tapping the molten steel. The process is suited either to high-phosphorous or low phosphorous iron with an addition of scrap or iron ore. In contrast to the basic Bessemer and L-D converters, the oxygen in the Kaldo process operates essentially through the medium of the slag which enriches the metal with oxygen upon contact. The chemical conditions required for dephosphorization are locally combined, and the necessary interaction between the hot metal and the slag is maintained by mechanical agitation produced through furnace rotation.

The speed of rotation can be varied, normally up to 30 rpm, in order to control the course of the refining operation. A high rate of rotation sweeps the slag along the furnace walls thereby exposing some part of the metal surface to the direct action of the oxygen stream. This increases decarburization of the bath relative to dephosphorization. On the other hand, a slow rotational speed does not uncover the bath so that the slag takes on oxygen and, consequently, oxidizes more iron and eliminates phosphorous. In short, a high rotational speed is best suited to decarburization, whereas a slow rotational speed is conducive to dephosphorization. The course of the refining operation can also be regulated by changing either the oxygen input or the position of the oxygen lance. At a given lance position an increased oxygen input increases decarburization relative to dephosphorization, whereas a reduced oxygen input is conducive to dephosphorization. Similar results are possible by changing the lance position while holding oxygen input constant. A closer lance favors decarburization, whereas a farther lance favors dephosphorization .

The Rotor process wherein a vessel which is open at both ends is rotated either on a horizontal plane or inclined at 7 degrees. The speed of rotation which is much lower than that of the Kaldo process was originally established at 0. 5 rpm and, subsequently, increased to 5 rpm. The process uses two streams of oxygen in comparision to one stream in the L-D and Kaldo furnaces. One lance introduces high purity oxygen beneath the bath surface to oxidize impurities in the charge and a second lance directs lower purity oxygen upon the bath surface to assist in its oxidation and to burn the carbon monoxide contained in escaping gases. Like the Kaldo process, either high-phosphorous or low-phosphorous iron can be used together with scrap and iron ore to produce steel.

Basic Oxygen Plant and Equipment

As in the case with other steelmaking processes, the principal determinant of plant design and layout for the basic oxygen shop is the need to move raw materials to the melting furnace and molten steel away from the furnace in the most efficient manner possible within the space available for plant construction. In the basic oxygen shop this is accomplished by means of three major operating areas which are generally designated the charging aisle, the furnace aisle and the teeming aisle. Figure 7 depicts the layout of a basic oxygen shop, showing these three major operating sections.

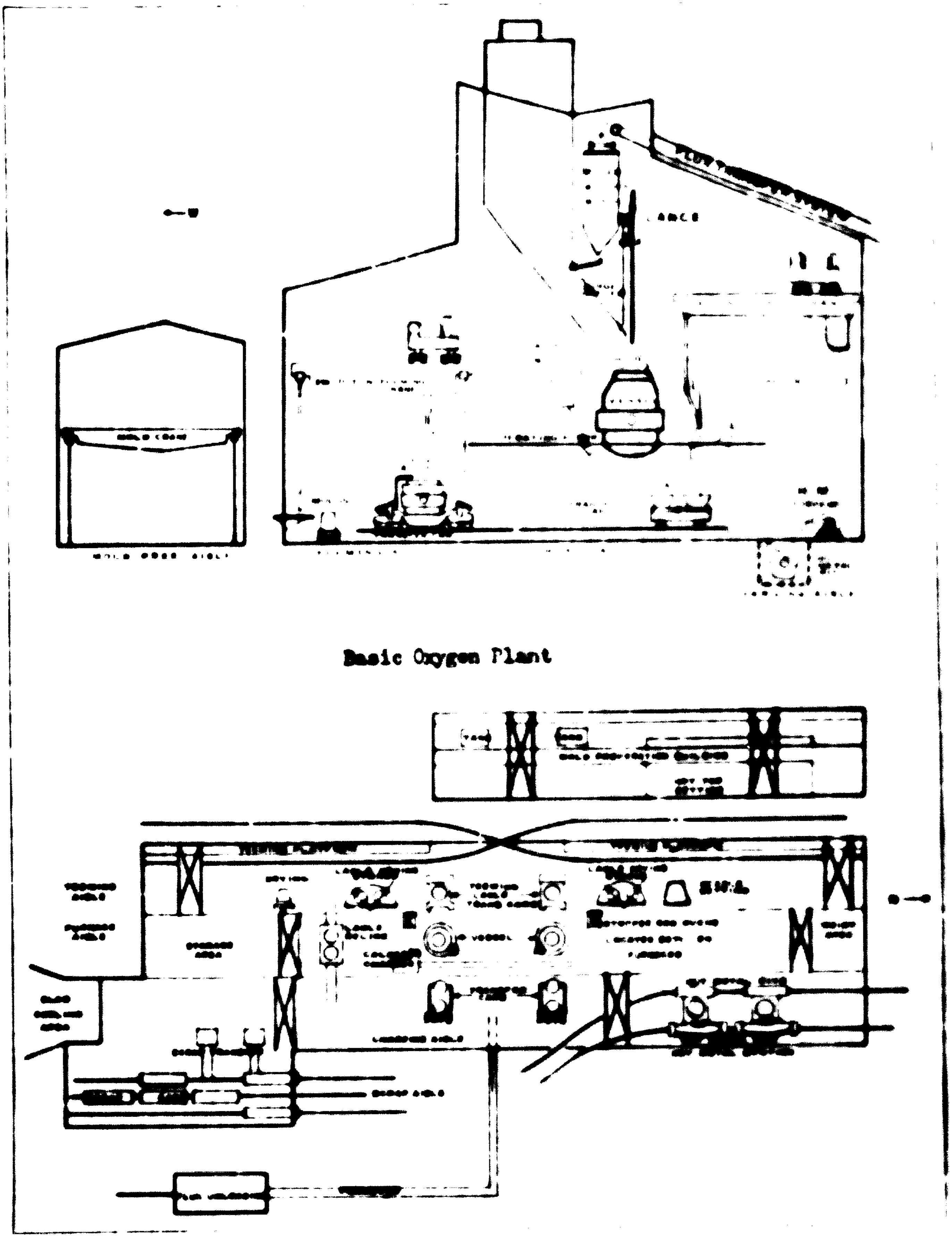
Charging Aisle

Situated usually at opposite ends of the charging aisle at ground level are the scrap yard and the hot metal transfer station. Flux storage bins, weigh hoppers and material conveyors are generally located above the charging crane runway. Located on the charging floor which is above ground level are the control pulpits, shop offices and the scrap charging car, scrap scales and tracks.

SECTION I

IRON AND STEELMAKING FACILITIES

Figure 7



Basic Oxygen Plant

The scrap yard and scrap preparation area, although they are situated at one end of the charging aisle, in most cases run adjacent to it and, consequently, are often referred to as the "scrap aisle" and are often considered apart from the charging aisle as a fourth major operating area within the basic oxygen plant. In the scrap yard, gondola cars are loaded with scrap by means of a scrap-yard crane, and are moved into the plant structure on railroad tracks. Usually more than one track line is used so that a sufficient number of gondola cars can be spotted under the scrap cranes to fill approximately one day's scrap requirement. In some plants scales have been installed at ground level to weigh the incoming scrap.

In the larger oxygen furnace shops the prepared scrap is transferred, usually by magnet, from the gondola cars to a self-propelled scrap charging car located on the charging floor. In an alternative procedure the scrap is loaded into boxes at ground level and the loaded boxes are lifted by crane to the charging floor and then charged into the converter by crane.

The scrap charging car, or charging machine as it is also called, holds a number of scrap boxes, usually two, each of which when loaded constitutes a single-box scrap charge. In charging the boxes are tilted individually toward the furnace mouth by means of a hydraulic tilting mechanism. When the charging car is loaded it is positioned on the scrap scales and the weight of each box is recorded. The charging car is then moved in front of the furnace, which is tilted toward the car to accept the charge and the number of scrap boxes which are in accordance with the thermal requirements of the heat are charged into the furnace. The charging car moves so that the box to be charged is aligned with the furnace mouth. Once the scrap is charged, the furnace is tilted away from the charging car to distribute the scrap over the furnace bottom and when this is accomplished, it is returned to the charging position so that the hot metal charge can next be added. The charging cars are used on the larger converters. In smaller shops, i.e., which have converters with about 100 ton capacity, the scrap is charged into the furnace from a charging box that is carried and tilted by an overhead crane.

The hot metal transfer station is located at ground level often at the opposite end of the charging aisle from the scrap area. The hot metal enters the plant in self-dumping, submarine-type ladles, which are emptied into hot metal transfer ladles. Two hot metal or reladling pits are provided for this purpose. While being filled, the transfer ladles rest on track scales located in each pit and the hot-metal weight is recorded. The charging crane lifts the ladle and moves it into position in front of the furnace. In some plants hot metal mixers are used to hold the metal until it is poured into the ladles to be charged into the converter.

Fluxing materials which enter the plant in bottom-dump hopper cars or trucks are conveyed to bins located above the furnace. A belt conveyer system is often used to move the fluxes to the bin floor. Bins for storing lime, ore and fluorspar are located near the top of the furnaces, and a tripper discharges the materials into their proper bins. Materials are weighed and fed automatically from these bins into batch hoppers which in turn feed them into surge hoppers. The material is then reweighed for a control check. Fluxes are released from the surge hoppers and charged by gravity into the vessels.

Furnace Aisle

Equipment in the furnace aisle consists of the basic oxygen furnaces, the oxygen lance hoists, control pulpits, gas cleaning facilities and a system of transfer tracks beneath the furnaces at ground level to accomodate the steel ladles and slag pots. The furnaces are single-piece, open-top vessels of all-welded construction and rotate freely on trunnions to facilitate charging and tapping. The working linings of the furnace consist of tar bonded dolomite brick, while the permanent linings, which rarely need replacement, consist of burnt magnesite brick. The most common basic oxygen shops house two furnaces so that one is producing while the other furnace is being relined or standing by.

The oxygen lances are copper tipped and water-cooled, and it is common to have each furnace serviced by a dual lance hoist so that a lance which becomes defective during a heat cycle can be withdrawn and replaced immediately with the stand-by lance. Additional lances are stored adjacent to the lance hoists with the result that lance replacement merely entails detaching the oxygen and water hoses and connecting the new lance. When lowered into the oxygen vessel, the lance enters the furnace hood through a funnel-shaped opening, and once it reaches the proper vertical height in relation to the bath, it is secured by lance changes which would occur during the blowing period.

Lance operation and the vertical heights of the lance are regulated from the control pulpit by means of lance position indicators and multiple step controls. The latter makes it possible to use high speeds during the initial stages of the lance's descent and low speeds for exact positioning.

Most of the operating functions connected with basic oxygen steelmaking are regulated from the control pulpits located next to each furnace. Indicating, recording and controlling facilities within the pulpit collect data on oxygen flow and pressure, lance height, and the temperatures of cooling water, exhaust gases and the bath. In many instances, the pulpit operator acts on instructions received by hand signal from the operating floor, and additional instructions are received by public address system from plant areas not within sight.

Steel ladles and slag pots on transfer tracks are positioned under each furnace. The steel is poured first and then the slag which remains in the converter is poured into the slag pot. Both the ladle and the slag pot are then moved into the charging aisle to be carried away by the charging crane.

Exhaust gases from the furnaces are usually cleaned by electrostatic precipitators or by wet washing.

Teeming Aisle

The teeming aisle of the basic oxygen plant houses all of the normal pouring and ladle repair operations found in the open hearth shop. Once the steel is tapped into ladles in the adjacent furnace aisle, the ladles are moved by transfer car into the teeming aisle. Here a teeming platform usually large enough to accommodate two drays of ingot molds is located together with a system of teeming cranes. Here the steel is poured into ingot molds. A locomotive moves the mold cars away from the teeming platform and a spur track is provided to handle pots which received ladle slag.

At the opposite end of the aisle from the teeming platform, the stopper-rod oven and ladle repair station are located.

Raw Materials Used in Basic Oxygen Steelmaking

As in the open hearth furnace, the principal materials in the furnace charge for a basic oxygen furnace are molten pig iron and steel scrap. However, the proportion of steel scrap remelted in the open hearth furnace can range from 20 to 80 percent in the basic oxygen furnace. In this respect, the open hearth is more flexible than the oxygan converter.

To place this relationship into proper perspective, it should be noted that the average range for scrap utilisation in the open hearth in actual practice is from 40 to 45 percent. An offsetting advantage in favor of the oxygen converter is that it does not require the addition of iron ore to the charge as an oxidising agent. The basic oxygen process is also more efficient from the point of view of energy consumption since unlike the open hearth and electric furnace processes, the internal chemical enery which is produced during the conversion of liquid iron and scrap into steel is sufficient to provide for the total heat energy requirement. The following table lists the pounds of raw materials required to produce one net ton of ingots using the basic oxygen process.

TABLE

Pounds of Material Required Per Net Ton of Ingots in Basic Oxygen Steelmaking

Furnace Charge	Pounds	Per Cent of Charge
Hot Metal	1585.2	72.36
Steel Scrap	583.4	26.68
Scale	21.0	.96
Total Furnace Charge	2189.6	100.00
Alloys		
Ferro-manganese	11.4	
All Other Alloys	.7	
Fluxes		
Lime	143.0	
Spar	5.5	
Fuel Consumption		
Oxygen	1,502 Cubic Feet per ton	

Source: Operating statistics for the basic oxygen plant at the Aliquippa Works of Jones & Laughlin Steel Corporation which has a design capacity of 63,000 net tons of ingot per month. Statistics relate to one month's experience. From D. R. Loughrey, The Basic Oxygen Process Jones & Laughlin Steel Corporation, p. 14.

The actual steelmaking process begins when the scrap charge has been dumped into the furnace. The scrap content of the charge usually averages from 26 percent to 32 percent of the gross metallic charge. Once the scrap has been charged into the furnace, the hot metal is poured in immediately thereafter. During this phase of the operation, the typical basic oxygen furnace is tilted on its side in much the same manner in which Bessemer converters are tilted in order to facilitate charging operations. Once the charge has been completed, the furnace is again tilted upward to a vertical position and the oxygen lance is lowered into the furnace and turned on. When the oxygen lance has been lowered to the desired position relative to the bath, it is clamped into position. At this point, additions of flux and other materials may be made according to specifications, after which the process continues until the charge reaches the desired grade and composition. The molten steel is then tapped from the furnace and the furnace is prepared for the next charge.

It is generally agreed that the basic oxygen process will gradually replace the open hearth as the major method of steel manufacture throughout the world. The process is more economical in terms of output per unit of time, investment cost and can be easily adapted to the efficient manufacture of most grades of steel.

The Electric Arc Furnace

The electric arc steelmaking furnace uses the heat generated by electric current to melt and refine steel. The process is especially suited to the production of alloy and other specialty grades of steel, since it can be more rigidly controlled than the open hearth or other steelmaking furnaces. Its application, however, is not limited to the specialty steels since in recent years larger electric furnaces (up to 200 ton capacity per heat) have been introduced for the production of a wide range of steels, including the basic grades of carbon steel.

In the electric furnace steelmaking process, electricity is used solely to generate the necessary heat. The electric arc furnace is capable of generating temperatures up to 3500 degrees F in a relatively short time period, a condition that allows added furnace control. The heat is transmitted through the metallic charge in two ways: first, by the proximity of the arc to the charge and, secondly, by the electrical resistance of the metallic charge. Because oxygen is not needed to bring about combustion in the electric furnace, the amount of oxygen entering the furnace can be readily controlled and the expensive alloying materials can be added to the charge without the danger of loss through oxidation.

There have been a sizeable number of steelmaking furnaces developed which utilize the heat generated by electric current, but only two have gained commercial acceptance as practical tools for steel manufacture. These two types are the direct arc electric furnace and the high frequency coreless induction furnace. These furnaces are essentially different because the heating methods differ substantially. The direct arc furnace, as the name implies, uses arc heating while the high frequency coreless induction furnace uses the principle of induction to generate the required amounts of heat. The two types of furnaces are shown in Figures 8 and 9.

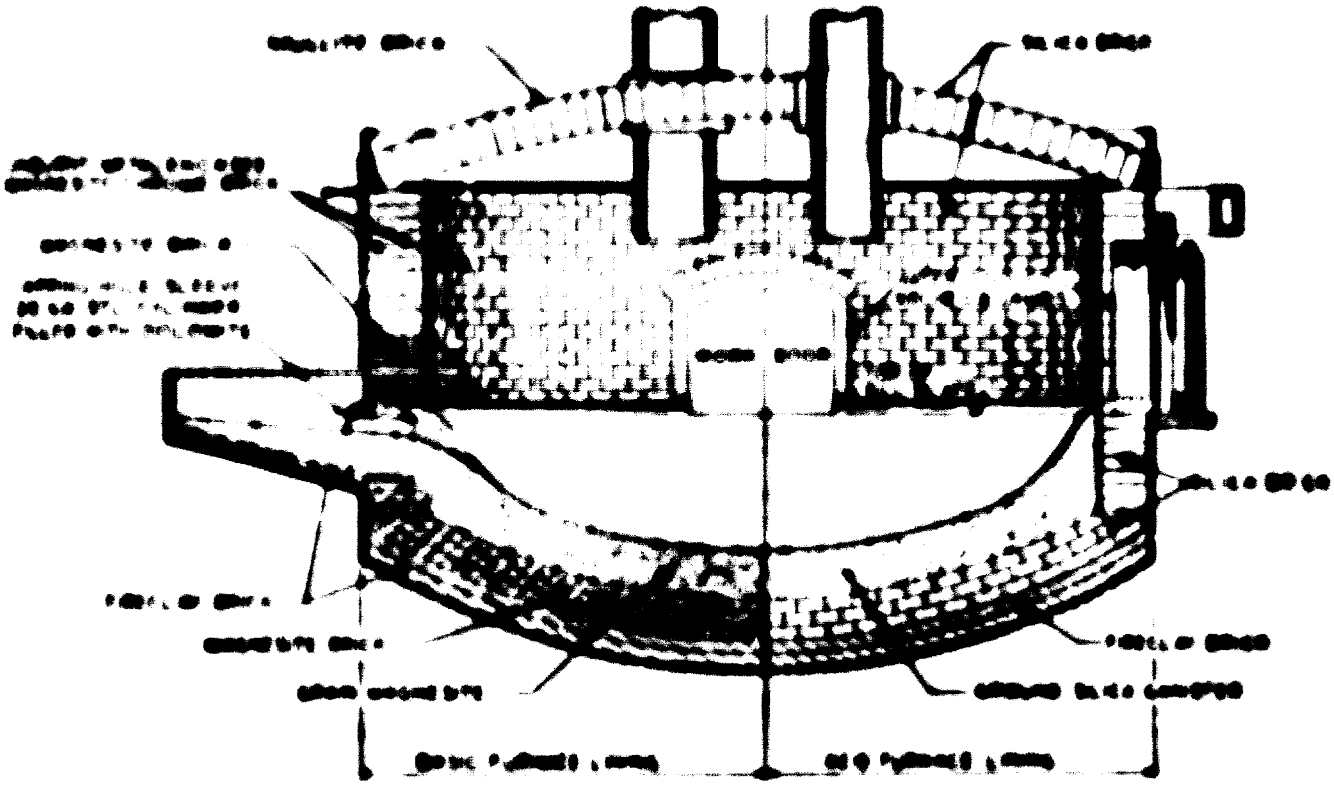
In the direct arc furnace, electric arcs are made between a series of graphite or carbon electrodes and the steel bath itself. This is in contrast to indirect arc heating wherein the arcs are made between the electrodes supported above the bath, so that the metal is heated solely by the radiation from the arc. Direct arc heating uses not only the heat generated from the arcs, but also the heat generated by the electrical resistance of the metal to the current which is made to flow through the bath.

The high frequency coreless induction furnace consists of a refractory lined vessel surrounded by a copper coil which is hollow and water-cooled, and which carries electrical current alternating at approximately 1000 cycles per second, amounting to some 400 amps at 200 to 3000 volts. This creates induced current which passes through the charge and melts it by resistance heating. Commercial use of the high frequency

This work on the iron and steel industry consists of three parts: First, a description of the basic iron and steelmaking facilities and the basic primary rolling mill facilities; second, a statistical section on world production of iron and steel ingredients, as well as the iron and steel export-import statistics for most of the countries of the world; the third section is an analysis of the present status of the world steel industry, the goals set by a number of countries and the possibility of their achievement.

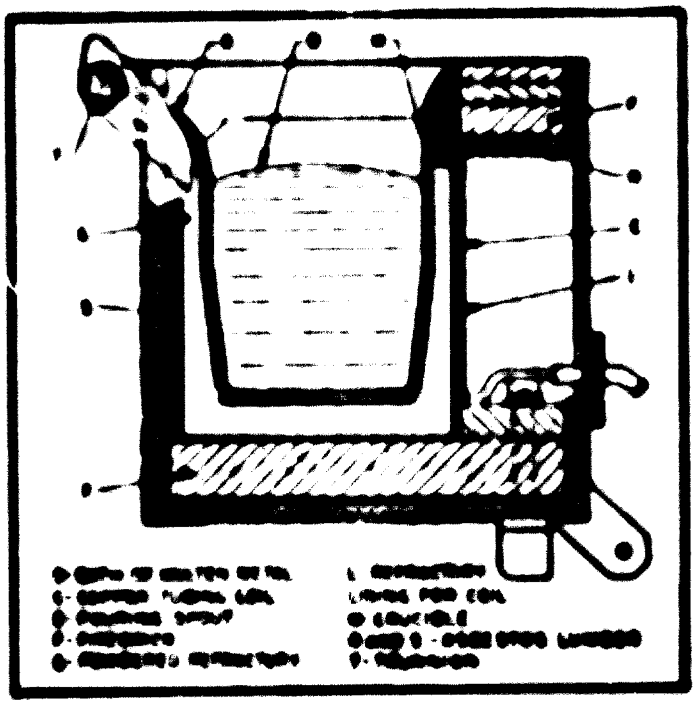
Figure [illegible]

Electrodes



Direct Arc Furnace

Figure 9



Induction Furnace

furnace is somewhat limited, since its economical operation is generally restricted to the highest quality alloy steels.

The Electric Arc Furnace Plant

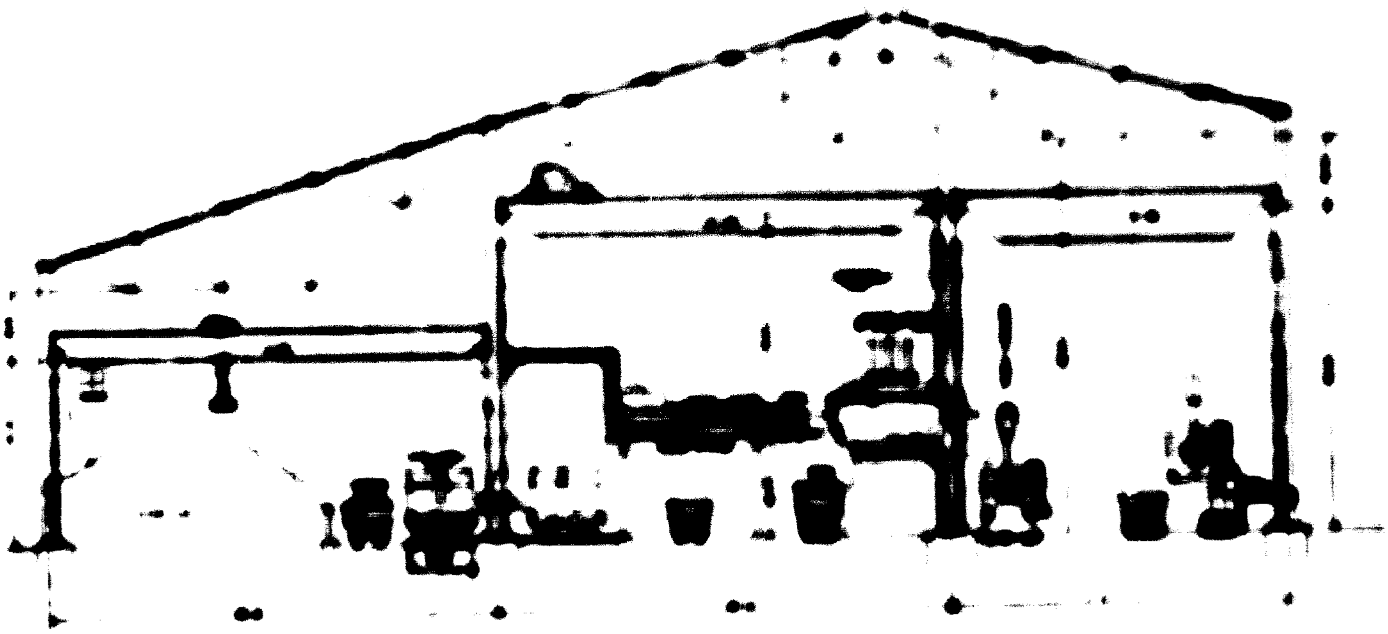
The electric arc furnace plant consists of three major sections or areas which house the charging facilities, the melting furnace and the facilities for pouring the hot metal. In this respect it is similar to the open hearth and the basic oxygen plants and shares the common requirement that the three major operating sections be planned and laid out in a manner which eliminates the possibility of delays It is essential that the flow of materials must be smooth and orderly in order to insure efficient operation. Figure 10 represents a typical electric arc furnace plant with its three operating areas.

Charging Aisle

The charging section of the electric furnace plant should be especially geared to efficient scrap handling since the major part of the material used in the electric furnace is scrap. The capacity of the scrap handling facilities must be related to the charging bucket capacity and to the size of the melting furnace. Rail tracks for charging cars and incoming supplies such as limestone, ore and brick are an important factor in the layout of the charging section. In plants designed to use hot metal, a 75 to 100 ton, four girder, two trolley crane is required to handle the hot metal ladles. This crane can also be used as a utility crane for general charging floor operations. In plants where hot metal

Figure 10

[illegible]



is not used, the charging bay must include one or two 25 ton cranes with 10 ton auxiliary hoists. The use of top charge furnaces requries that cranes be of sufficient capacity to handle loaded charge buckets of the size required by particular furnace operations.

The charging section must also contain equipment for drying additions to the furnace charge in order to prevent explosions in the furnace and reduce the possibility of hydrogen being absorbed by the steel due to excessive moisture in the charge. A number of drying procedures can be employed, some plants use a gas pipe which is brought into direct contact with the materials, while others use gas jets and, still others use some form of preheating furnaces. The most widely used method is a small rotary kiln which insures uniform drying and does not require a great amount of space.

Furnace Aisle

Many electric arc furnaces are designed to tilt in two directions, one for tapping the steel and the other for the removal of slag. The furnace rests on toothed rockers and is tilted by a motor driven rock and pinion mechanism, a screw type mechanism or a motor driven mechanism.

The capacity of the furnace is determined by the inside diameter of the furnace shell. The modern furnace is top-charged with an automatic roof removing device to allow easy charging. The shell is usually cylindrical in shape and has either a curved or flat bottom which can be lined with several layers of clay, magnesite or silica brick as required. The usual roof moving mechanism is either the gantry lift type or the swing type. The gantry lift type has the electrode mast and roof raising equipment built into a gantry crane which travels on tracks along the charging floor. When the furnace is to be charged, the electrodes are raised to clear the shell and the roof is removed by the gantry crane. The swing type unit uses motor driven or hydraulic equipment to lift the furnace roof and supporting structure for the electrode masts and swing them to one side, thereby uncovering the furnace shell.

The type of electrode used depends upon the size of the furnace and the types of steel which are to be produced. Graphite electrodes are required for large electric furnaces, particularly for those which manufacture high-grade alloy steels, whereas carbon electrodes can be used in smaller units. As an electrode is consumed in operation, a threaded graphite or carbon nipple is inserted on the top so that a new electrode section can be attached. Graphite and carbon electrodes vary widely in physical shape, dimensions and properties and, consequently, must be carefully selected depending on usage.

Teeming Aisle

In the pouring side of the furnace shop, provision must be made for mold preparation for at least two heats of steel, since a large portion of electric furnace production is alloy steel which requires hot-topped ingots. This is best done in an adjacent building since substantial space is required and since the preparation of the moulds may interfere with crane service needed for other operations. Where hot-topped ingots are used, some plants provide a stationary stripper located in the pouring aisle in order to loosen the ingots. The pouring side may also include pre-heating facilities for ladles, stoppers and hot tops.

The Steelmaking Process in an Electric Arc Furnace

The actual electric furnace steelmaking process begins with charging scrap through the furnace roof. In most cases, the electric furnace charge is comprised of upwards of 80 percent scrap, and due to difficulty in oxidizing some ferro alloys and virgin alloys these materials may be charged into the furnace prior to the bulk of the charge. If the metallic charge is low in carbon content, proportionate amounts of coke may be added. Conversely, ore may be added in order to lower the carbon content of the charge. It is through the careful use of these practices along with a careful separation of scrap that the speciality steels may be more easily produced within the electric furnace.

When the charge has been completed, the electrodes are lowered and melt their way through the scrap to the bottom of the furnace. By the time the electrodes have reached the bottom of the charge, a small pool of molten metal has formed and the remainder of the charge is then melted by a combination of the heat of the electrodes and that from the radiation caused by the pool at the bottom of the charge. Once the entire charge is in its molten state, the process may be momentarily stopped and a part of the slag run off, or in some instances and depending on the required specifications, the process may continue right through to the end.

As has been indicated, electric furnace steelmaking can be geared to either highly specialized grades of steel or to common grades of steel. Depending upon which type of steel is being produced, single or double slag run offs may be used. For common grades of steel, a single slag run off operation is sufficient in much the same manner as is used in open hearth steelmaking. However, when high-grade specialty steels are being produced, a double slag period may be used to insure better quality. In such instances, a part of the slag is removed when the charge is brought to a molten state and is only partially refined. The process is then continued until the metal reaches the desired specifications at which time the furnace is topped and the remaining slag removed.

Electric furnace steelmaking is presently more widely used than at any other time. The process offers several advantages both from the point of view of cost and economical operation, and with respect to the types of steels which it can produce. Further, since it is capable of operating on a 100 percent scrap charge, the electric furnace is especially well suited to semi-integrated steel mills.

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The Blast Furnace

The first operation in the transformation of the basic raw materials into finished steel products is the manufacture of pig iron which usually takes place in a blast furnace. In general, the blast furnace process is carried out by blowing vast amounts of preheated air into and through the furnace stack which is filled with a calculated mixture of iron ore, coke and limestone. The purpose of the operation is to reduce the iron ore to molten pig iron. This is accomplished by:

1. Driving off all moisture from the charged materials.
2. Reducing oxides in the iron
3. Calcining the flux.
4. Melting the slag and iron.
5. Reducing the oxides of manganese, silicon and phosphorous.
6. Removing the sulphur from the molten iron[1]

The blast furnace plant is equipped with large stock yards in which quantities of raw materials are stored (See Figure 1). These stock yards are usually located close to the furnace itself in order to permit ready transfer of materials to the furnace. In general, the stock yards should provide:

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[1] American Iron and Steel Institute, The Making of Steel, 2nd Edition, 1964, New York, p. 27.

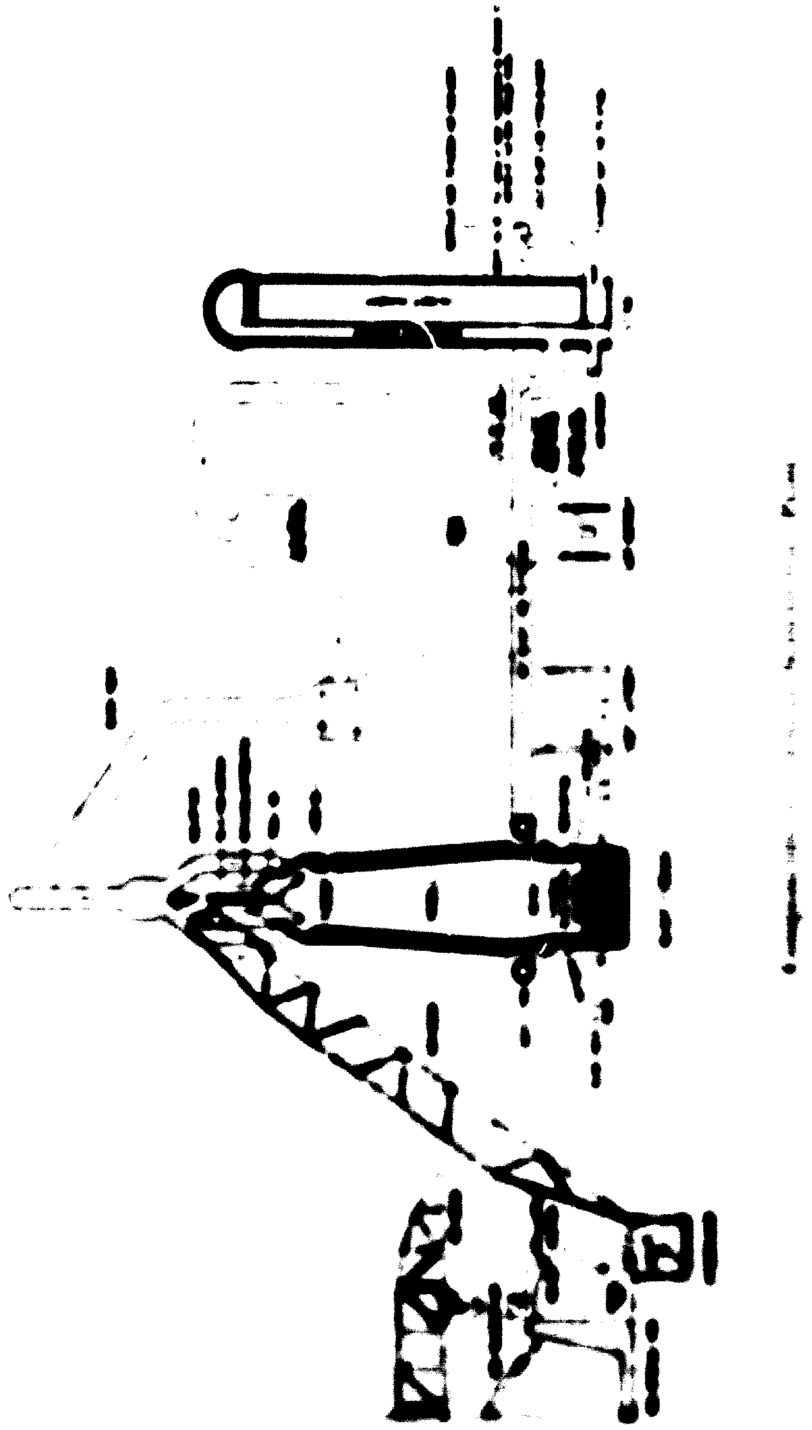

Figure 1

1. Sufficient size to allow the accumulation of large stores of raw materials and thus guard against seasonal and temporary shortages in raw material supply.
2. Easy accessibility by whatever method of transportation is used in the particular plant.
3. Construction in such a way as to allow the easy transfer of materials to the furnace skip hoist.
4. Provision for several different piles of ore in the event that shipments of ore might differ in composition.

The materials may be moved from the stock yards to storage bins whence they are transferred into larry cars or brought by conveyors, or a combination of both to the skip hoist. A scale or transfer car is used to transfer the ore while in most cases the coke is transferred from the bins to the skip hoist by means of a conveyor belt. Generally the skip bins are located directly above the bottom of the skip incline in such a way that alternate loads of coke, ore and stone may be dropped into the skip cars and ultimately charged into the furnace

The skip hoist is, by far, the most widely used method of blast furnace charging. This apparatus consists of a mechanically driven skip car which runs up an incline from below the skip bins to the furnace top at which point it dumps the raw materials into the furnace stack. The size and volumetric capacity of the skip cars will differ according to the frequency of the charge and the size of the furnace. However, since it is advantageous to keep the furnace stack as near full as possible, the size of the skip and the frequency of the charge should be geared to this objective. For this reason, most blast furnaces are equipped with two skip cars.

The skips are charged into the furnace in such a way that successive layers of coke, ore and flux are placed on top of each other as each additional charge follows a predetermined order. This procedure will allow for a more rapid and complete reduction of the burden into high quality basic pig iron.

The raw material burden which is dumped into the furnace top is received by a cylindrical shaped vessel at the furnace top called a distributor. At the bottom of this distributor is the first of and the smaller of the two bells which will ultimately allow the raw material charge to be emptied into the furnace itself. Once the raw material charge is resting on the small bell, the bell is lowered or opened to allow the material to slide on to the large bell which is located directly below the smaller bell. The small bell is then closed to prevent the loss of valuable gases and heat. Once the small bell is closed, the large one is opened and the raw materials drop on to the furnace burden. Upon completion of this the big bell is closed.

2 OF 2

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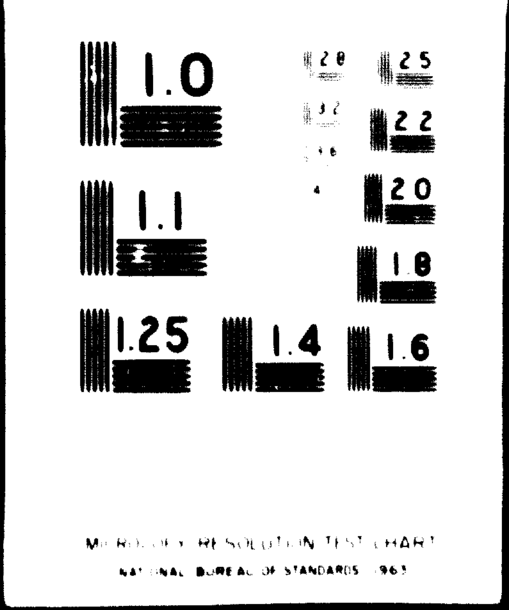
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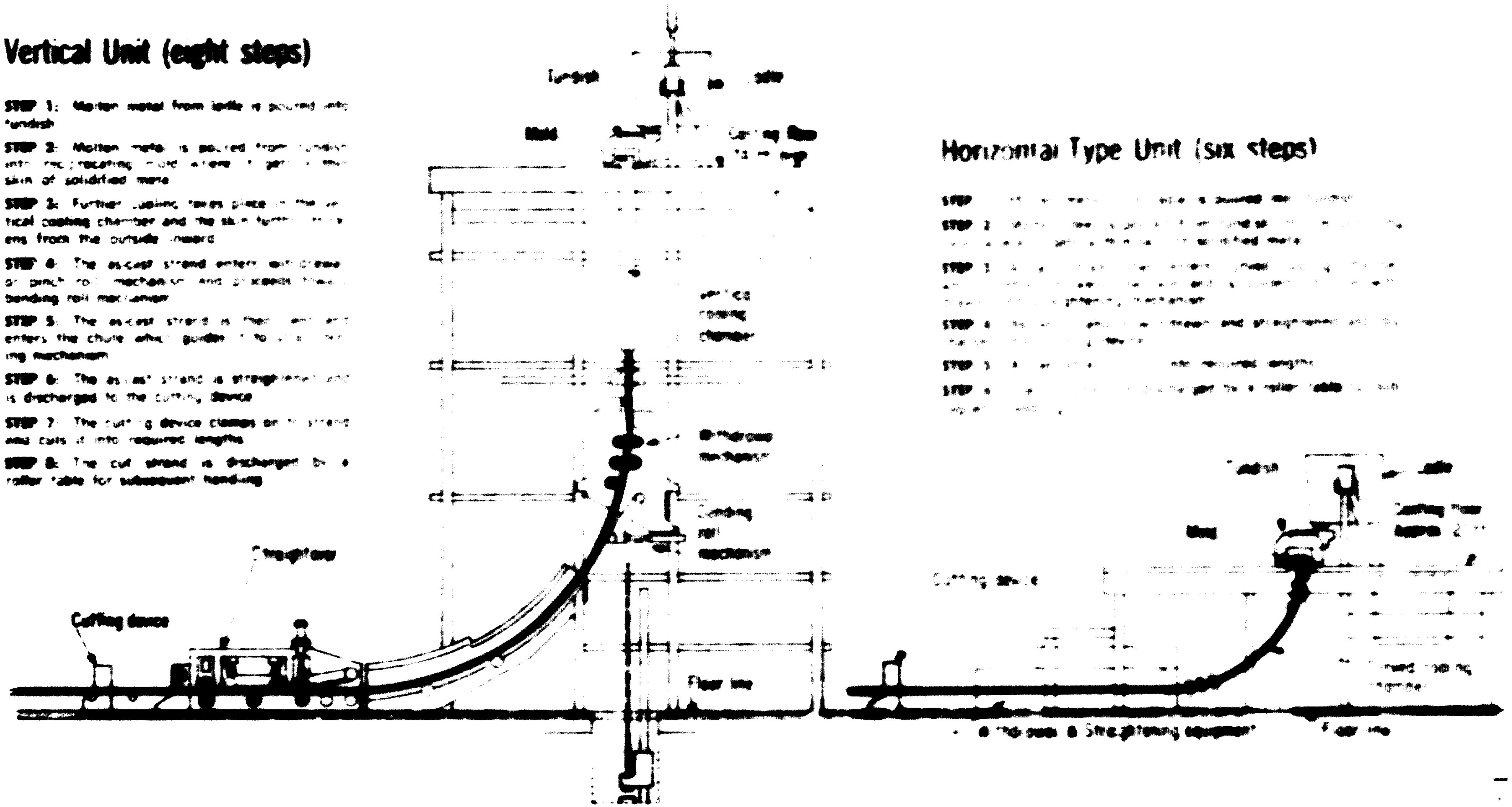
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963

FIGURE 11

CONTINUOUS CASTING PRACTICE



Vertical Unit (eight steps)

STEP 1: Molten metal from ladle is poured into tundish

STEP 2: Molten metal is poured from tundish into reciprocating mold where it gets a thin skin of solidified metal

STEP 3: Further cooling takes place in the vertical cooling chamber and the skin further thickens from the outside inward

STEP 4: The as-cast strand enters withdrawal or pinch roll mechanism and proceeds through bending roll mechanism

STEP 5: The as-cast strand is then bent and enters the chute which guides it to straightening mechanism

STEP 6: The as-cast strand is straightened and is discharged to the cutting device

STEP 7: The cutting device clamps on the strand and cuts it into required lengths

STEP 8: The cut strand is discharged by a roller table for subsequent handling

Horizontal Type Unit (six steps)

STEP [illegible] is poured into tundish

STEP 2 [illegible] solidified metal

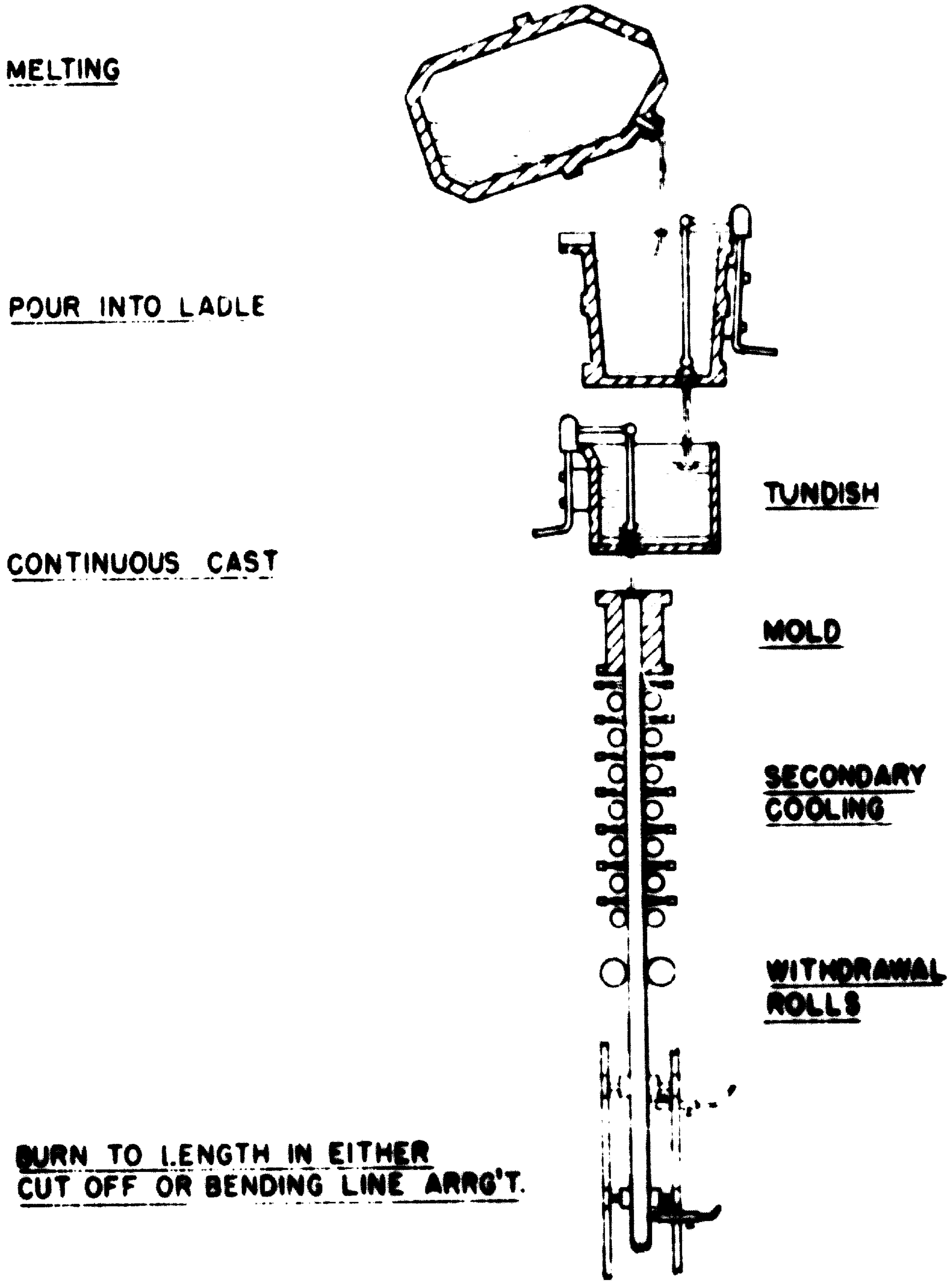
STEP 3 [illegible] straightening mechanism

STEP 4 [illegible] drawn and straightened [illegible]

STEP 5 [illegible] into required lengths

STEP 6 [illegible] discharged by a roller table [illegible]

Figure 12



TYPICAL CONTINUOUS CASTING PRACTICE

in operation or under construction throughout the world as of June 1, 1964. There are 71 plants currently operating and 49 under construction making a total of 120 units. The preference for mold reciprocation is indicated by the fact that of the 92 units on which information about the type of mold is available, some 74 units use or plan to use reciprocating molds. On the other hand, only 4 make use of fixed or non-reciprocating molds and no such machines are planned for the future. Of the 74 units with reciprocating molds, 18 utilize dht new curved mold design; one of these is currently in operation at the Von Moos Steelworks, Lucerne, Switzerland, and a second, capable of casting slabs up to 60 inches x 10 inches, has recently been installed at Dilligan, West Germany, while another has been installed at Atlas Steels, Ltd., in Tracy, Quebec, Canada.

Advantages and Disadvantages of Continuous Casting

The principal advantages claimed for continuous casting as compared with the conventional ingot method of production are as follows:

1. Continuous casting elminates the production phases associated with conventional ingot casting and, consequently, reduces overall production costs. Teeming operations and costs, including ingot mold and hot top costs are eliminated, as are the costs of stripping facilities. The need for soaking pits is eliminated and primary rolling costs are eliminated or significantly reduced. In general, overall operating costs are said

to be reduced by 7 percent as compared with the conventional ingot method of casting. Seaway Steel in the United States saw the possibility of a $20 per ton savings, and Concast, Inc., one of the leading manufacturers of continuous casting units, places the figure at $8 to $10 per ton.

2. Yields are significantly improved by the use of continuous casting, averaging about 96 percent as compared with 85 percent for ingot casting. Yields on the Babcock and Wilcox installation at Roanoke Electric Steel and at Conners Steel have been reported as high as 98 percent. The improvement in yields leads directly to reductions in scrap recycling and fuel consumption.

3. Increased product uniformity in some grades of steel is a further advantage in view of the strict demands of steel consumers for steels of exact composition. The slight variations in composition from ingot to ingot which exist even where strict control is observed are eliminated.

4. The capital investment required to install a continuous casting facility is relatively low when compared with a conventional facility capable of the same output. Dillinger, which is operating continuous casting machines in Western Germany, estimates the investment savings to be $10

million on a 2 million metric ton facility. A significant part of the savings is attributable to the compactness of the unit which permits concentration of operations in a small area.

5. Many claim that due to the uniformity and quality of the steel when it is continuously cast, the process often reduces the need for surface conditioning to a substantial degree. This is said to be especially true for certain grades of killed and semi-killed steel.

6. Since the process can be automated easily there is a substantial potential in labor savings.

7. Where provision is made for direct transfer of the cast product from the casting machine to a rolling mill or forge, reheating prior to hotworking can be reduced.

8. The process is well suited to the installation of new steelmaking capacity, both on an integrated and semi-integrated basis. The low investment requirement and present state of technology make it especially well suited for the installation of additional capacity in the semi-integrated sector of the industry. This added capacity can be expected to come from three sources: First, mills which were formerly limited to finishing operations are now in position to produce steel on an economical basis through the use

of an electric furnace and continuous casting facilities. An instance of this situation is found in the case of Seaway Steel which is now operating a Kappers continuous casting unit. Second, the process and its relative cost can be expected to reduce significantly the difficulty of entry into the industry for the semi-integrated producer. Third, many semi-integrated producers will now be able to expand present capacity economically through continuous casting. The principal reasons why such activity can be expected include the relatively low investment cost of the facility and the fact that continuous casting is especially well suited to the types and sizes of steel which many of the smaller semi-integrated firms produce. Further, semi-integrated plants are usually supplied with steel by electric furnaces which are especially well suited to continuous casting operations.

9. The continuous casting process can produce longer slabs than the conventional process wherein slab size is limited by ingot size and to a great extent by slabbing mill capabilities. This is of particular advantage in producing sheets for the automotive market where orders have been received for large weld free coils. Coils of 1,000 lbs. per inch of width can be rolled from the longer continuously cast slabs.

The principal disadvantages of continuous casting as compared with the conventional ingot process of casting are as follows:

1. The process must remain continuous throughout the cast and cannot be temporarily interrupted should trouble such as nozzle freeze-up or cutting failure develop. The hot metal remaining in the ladle must either be recharged into a melting furnace, scrapped, or poured into ingot molds.

2. Rimmed steel of good quality has not been consistently cast in commercially suitable quantities. This is true of the experience in most of the installations in the world, for although some producers have claimed success in continuously casting rimmed steel slabs, test slabs ordered from abroad by producers in this country were found to be of inferior grade and when rolled into sheet and strip showed poor surface quality. This is a serious drawback to the acceptance of continuous casting since rimmed steels comprise a high percentage of the sheet, strip and tinplate tonnages currently produced. Rimmed steel with its low carbon content (less than 0.15 per cent c) offers the advantages of sound surface conditions, cleanliness, ductility and corrosion resistance in galvanized, tinned and enameled products and, in general, is used extensively where the

surface of the product is important. However, it is not suited to continuous casting since the process has not been modified as yet to handle the brisk evolution of gas which occurs when the hot metal begins to solidify with the mold. It does not seem likely that boiling and degassing in the continuous casting machine mold will ever be eliminated, so that if rimmed steel is to be continuously cast some means must be developed to control the rimming action and prevent gases from being trapped as the casting solidifies. As yet, this has not been done, and efforts now are being directed toward development of a steel which will serve the functions of rimmed steel and still be suited to continuous casting. Vacuum degassing, a process by which some of the gases are removed from the steel while it is still in the ladle is another possible means offered for the solution of this problem.

3. One of the problems which continues to plague further advances in continuous casting relates to the temperature and speeds of the cast which is necessary to insure high quality steel sections. Temperature control, a vital concern in any continuous casting process, is not really an acute problem until the metal reaches the secondary cooling chamber. Here the rate of solidification which is a function of the time and the cross section of the metal

can be a problem of significance. This is especially true with respect to the casting of large sections os steel. When casting a larger section, there is a core of molten metal with a shell of solidified metal which must be fully solidified before the section reaches the pinch rolls. Consequently, either the length of the cooling chamber must be extended or the speed of the cast must be slowed down. Either of these colutions are possible, but both can result in loss of economies as well as possible surface damage to the metal.

4. Continuous casting is slower than conventional slabbing mill operations. For instance, a continuous casting unit casting a slab 7 inches thick and 60 inches wide at a rate of 35 inches per minute would cast about 120 tons an hour. This rate is far too slow to keep pace with the large basic oxygen furnaces now being installed. The use of multistrand machines reduces the difficulty somewhat, but the problem of casting large single strand sections is one which is yet to b^ solved satisfactorily.

TABLE 1

Summary of Continuous Casting Lines in Operation and Under Construction as of June 1, 1964

Country	Number Operating	Number Under Construction	Total
Argentina	-	1	1
Australia	1	-	1
Austria	5	-	5
Belgium	1	3	4
Brazil	1	-	1
Canada	4	3	7
Red China	2	-	2
Czechoslovakia	2	-	2
Finland	-	2	2
France	5	-	5
East Germany	1	-	1
West Germany	6	3	9
Greece	-	1	1
Hungary	-	1	1
India	1	1	2
Italy	1	2	3
Japan	4	4	8
Mexico	1	2	3
Norway	1	-	1
Peru	1	-	1
Poland	2	4	6
Spain	1	2	3
Sweden	2	2	4
Switzerland	2	-	2
Tunisia	-	1	1
Turkey	-	1	1
United Kingdom	8	1	9
United States	5	10	15
Republic of South Africa	1	-	1
USSR	13	4	17
Venezuela	-	1	1
Total World	71	49	120

Development of Continuous Casting for Steel

Traditionally, the major technological advances in steelmaking have involved the replacement of "batch" type processes with "continuous" processes, as for example in the development of continuous rolling and reduction, continuous normalizing and heat treatment, and continuous annealing. Currently, attention is being forucsed on the application of the continuous casting process to steel and its potential for increased efficiency as compared with conventional steel ingot production methods.

The continuous casting process was largely European in origian, although development work on the process in the United States dates back to 1940. Almost all of the pilot plants which were installed, principally after World War II, were located in countries other than the United States. Since 1960, development work and pilot plant experience has been conolidated and emphasis has been placed on the installation of production plants throughout the world.

The principal pilot plants for the continuous casting of steel had many features and methods in common basicially because they all sought the solution of the same problems. The requirements and procedures that were established for hot metal handling, control of pouring rates, heat transfer, etc. were largely similar and fundamental differences were for the most part related to plant scale, the size and shape of the section cast and objectives with regard to casting speeds.

The Direct Reduction Processes

The term direct reduction as it is normally used in the steel industry applies to the making of iron in some other manner than the use of a blast furnace. A number of processes have been used and the product is some type of iron. Very often it is called "sponge iron" which, like pig iron, will be subsequently reduced into steel.

The present state of the art is such that none of these processes is able to compete with the proven and highly efficient modern blast furnace. However, there are conditions and situations peculiar to some areas and countries which can make direct reduction processes an economical alternate method of iron manufacture. For instance, in areas where large deposits of high grade iron ore and natural gas are available and where coking coal is in short supply, direct reduction could prove to be an adequate substitute for the traditional ironmaking processes.

Direct reduction processes are many in number, but they can be divided into four principal types:1)

1. Those that utilise the kiln for ore reduction.
2. Those that use retorts in a batch process.
3. Those that use fluidised-bed techniques.
4. Electric pig-iron furnaces.

In each of these general classifications there are a number of processes, however for purposes of illustration only one process of each type will be described.

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1) D.L. McBride and P.W. Chase - Present and Future of Direct Reduction Processes in Latin America. Paper presented at General Assembly of I.L.A.F.A., July 1963.

The Stelco-Lurgi or S.L. process is one of the more recently developed direct reduction processes which uses the kiln. The S.L. process makes high speciality sponge iron in a rotary kiln. The kiln is equipped with 10 natural gas burners along its length through which natural gas is introduced to the charge which is composed of high quality iron ore or pelletized concentrates some carbonaceous reducing agent, and limestone or dolomite. At one end of the kiln a bucket elevator and rotary feed valve serve as the charging machanism. The raw materials and the air blast are put into this end of the furnace in such a way as to maintain an even flow of each into the kiln.

The rotation of the kiln and the pressure of material being charged into the end of the kiln provide the necessary force to move the charge slowly through the kiln. Further, the rotation of the kiln provides a more complete and uniform reduction of the charged material. When the material reaches the end of the kiln, it is discharged, passed through a cooling device and then is placed in a magnetic concentrating system in order to recover the iron.

The principal advantages and limitations of this process are:1)

Advantages

1. The equipment and technology are simple.
2. Metallic recovery is good, over 90%.
3. The reduced product is non-pyrophoric.

Limitations

1. The reduced product is friable, and fragments severely in storage and transportation.
2. Low volatile anthracite coal or charcoal are used as the reducing agent.
3. The process does not remove any gangue from low grade ore.

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1) D.L. McBride and P.W. Chase

The retort reduction process, the most widely known variation of which is the HyL process, has been commercially operated at the Hajalata y Lamina Steel Company in Monterrey, Mexico. Commerical operations at Monterrey include a small 200 tons per day plant and a larger 500 tons per day plant installed in 1957 and 1960 respectively. The investment cost of such an iron producing plant which has been placed at $6 million for 500 tons a day plant. The figure is significantly lower than the investment cost of the blast furnace. The lower cost is especially attractive to developing countries and probably accounts for the interest shown in the process by other developing countries. Further, production rates on such a process can be economically geared to lower amounts of iron, a fact which is also of importance to developing nations whose iron needs are limited.

In general, this process involves the batch reduction of high grades of ore or pellets in retorts using natural gas to provide the heat requirement. This natural gas is purified and preheated from 1600 to 1800°F before it is passed into the retorts and brought into contact with the ore. The reduction process begins when one of the several retorts are charged with a fresh batch of ore. Following charging, a three step operation is required to complete the reduction process. The first of these is the secondary or initial reduction stage in which the preheated gas passes through the charge and the charge is subject to this heating for about 2 hours. The gas used in the initial reduction stage has previously been used in the final reduction of another batch. Thus, after the batch has been subjected to the initial reduction, the direction of gas streams are reversed and a stream of newly heated gas is projected through the charge. This action begins the final reduction which continues for an additional 2 hours. Upon completion of this, the charge is emptied and cooled. The empty retort is then recharged and the operation is started again. With 3 or 4 retorts the operation can be arranged in such a way so as to operate the process in a continuous manner.

The advantages and limitations of this are as follows:

1. The quantity of sulphur in the ore is diminished by about [illegible]
2. Small production plants can be operated efficiently.
3. More than [illegible] conversion of the reducing gas is achieved during its passage through the reduction stage.
4. The reduction can be carried almost to completion if desirable, either by increasing the period of cycle time, or by increasing the rate of reducing gas flow through the retorts.

Limitations

1. Only lump ore or lump material can be processed. Agglomerating facilities ahead of the retort furnaces are necessary if fines are to be successfully processed.
2. The reduced product, although suitable for immediate use in steelmaking furnaces, is probably not able to withstand the rigours of storage, loading and transportation to remote steelmaking plants.

The third major type of direct reduction processes is the fluidized bed process, one variation of which has been developed by Bethlehem Steel and Hydrocarbon Research Incorporated in the United States. This process, called the H-Iron Process uses four fluidized beds which are arranged in series so that when natural gas is passed through the lowest bed, it rises and continues through each of the three remaining beds. These beds are arranged so that the lowest bed contains the most fully reduced ore and after passing the gas through it the reduction process is completed. The contents of the bed are then discharged

1 McBride and Chase

and the contents of each other bed are allowed to pass into a successively lower bed. The gas which is preheated to 1000°F is then passed into the lowest bed again at a pressure of 500 pounds per square inch. The gas, after passing through all four beds, goes into a gas offtake and is recompressed for eventual re-use.

Ironmaking plants of this nature have been operated in the United States by Bethlehem Steel on a pilot plant basis and by Alan Wood Steel Co. on a small scale commercial basis.

The advantage of the H-Iron Process are:1)

1. It can process fine ores to a highly reduced product.
2. No solid carbon is required.
3. It can use natural gas, oil or gasified coal as the source of heat for the process.
4. Relatively low temperature requirement avoids some problems of sticking and defluidization.
5. Construction materials are not as limited due to lower temperature requirement.
6. The reduced sponge iron can be compacted into a dense, strong briquette which can withstand storage and transporatation without sever fragmentation.

The limitations are:

1. The freshly reduced product is strongly pyrophoric.
2. Gas conversion is low.
3. High purity hydrogen is required.
4. An estensive system is required for purification and recycling of off-gas

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1) McBride and Chase.

from the reactors.

5. It requires an oxygen plant as part of the system for manufacturing hydrogen.

Electric smelting or ironmaking processes are the most widely used of the direct reduction processes. In some areas, where good quality ore is available, the electric ironmaking furnace can prove a more economical method of iron manufacture because of its significantly low investment cost.

In principle, the furnace operates in a manner very similar to the electric steelmaking furnace. The ore, coke and limestone are charged through the roof and three or more electrodes are lowered into the hearth area at the furnace bottom as is done in the electric steel furnaces. Ore reduction takes place in the hearth area on a continuous basis for iron and slag are periodically tapped from the furnace in much the same manner that they are removed from a blast furnace. In the electric furnace, the heat requirement is provided by the heat energy generated by the electrodes,and thus the cost of electric power compared with the cost of coke will be an important determining factor in comparisons of these furnaces with blast furnaces.

In general, the advantages of the electric iron making furnace are:

1. It can be operated intermittently without difficulty.
2. Extremely high hearth temperatures can be attained, a factor particularly important in reducing ferro alloys.
3. It can smelt titaniferous ore.
4. The practice can be adopted for selective smelting of manganiferous, nickleferous, lateritic and other complex iron ore.

The limitations and disadvantages are:

1. Due to the large requiement for electricity, its economic use depends

upon the availability of low cost electric power.

2. Carbon is required as the reducing agent, either as anthracite or low volatile coke.

3. It must use lump ores or agglomerates.[1]

A general evaluation of the direct reduction process is difficult because it economical use when compared with blast furnaces is closely related to local conditions rather than general circumstances. Investment cost for direct reduction plants can generally be expected to be lower both in absolute amounts and in dollars per ton of output than for the blast furnace. However, even this may not always be the case, especially when increasingly larger production units are considered. Operating costs will vary because in most instances they are closely related to the availability of local power or natural gas. However, in areas where the proper combination of raw materials is available at competitive cost, the direct reduction process can be operated at a comparable or lower cost than blast furnaces of similar sizes in those areas. Thus, while it is difficult to generalize, it can be said that in certain places the direct reduction processes can offer economic advantages over the blast furnace.

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1) McBride and Chase

Rolling Mills

In the most traditional steel rolling operations, the large steel ingot must first be rolled into a semi-finished shape, either a slab, bloom or billet. This is done by use of a primary rolling mill which may be one of three possible types according to the dimensions of the section desired. When a continuous casting unit is used, the semi-finished shape may be directly cast in this machine, thus eliminating the need for primary rolling mill operations. Once the steel section has been rolled into a semi-finished shaped, it is subjected to a number of additional rolling operations, the number and variety of which will depend upon the final product to be produced. Aside from these rolling operations, there may be additional treatments such as annealing, pickling, and plating, depending on the desired end product.

Primary rolling mills are generally divided into three groups: the blooming mill, slabbing mill and billet mill. Each type of mill gets its name from the size and dimensions of the products which it produces. These sections are usually distinguished along the following lines:

1. Slab - a steel section 2 to 10 inches thick and at least 24 inches in width. These sections are always rectangular in opposition to the square cross-section of the billet or bloom.
2. Bloom - a section of steel which is usually square with dimensions ranging from 6" x 6" to 12" x 12".
3. Billet - a square section of steel which is less than 6" x 6".

The steel ingot, which has been heated to a uniform temperature in the soaking pits, is transferred to the primary mill by means of an ingot buggie or transfer car. The ingot is then placed upon the mill's roll tables and the processes of shaping the ingot into one of the above mentioned shapes begins. Primary rolling mills and operations do not differ significantly except in reference to the shape of the product, and for this reason it will be sufficient to discuss the operation of the blooming mill. Where significant differences in operations are necessary, they will be pointed out, but in general this discussion will be limited to blooming mills with the understanding that these others are basically similar.

The most widely used blooming mill is the two high electrically driven reversing mill. Such mills are referred to as "two high" because they consist of two large grooved rolls which are located directly above each other and through which the ingot passes back and forth. The number of passes depends on the required specifications of the finished bloom. At proper intervals, the ingot must be turned upon its side in order to effect equal rolling on each side and thus eliminate the possibility of the ingot being rolled flat. This is done by means of manipulators, which are also designed in such a way as to allow the ingot to be moved from side to side on the roll table in order that it may enter the proper grooves. The manipulator functions by means of fingers which are raised from below the roll table and come into contact with the edges of the ingot. The "fingers" continue to operate until the ingot is sufficiently raised so that the pull of gravity will cause it to fall on its side. The side guards, which are standard equipment on these mills, then move the ingot into proper position with respect to the roll grooves, and the ingot is then passed through the rolls. The operation is continued until a bloom or proper dimensions has been shaped. The time required for such a rolling operation will differ according to the size of the ingot, the power of the rolls, and the desired size of the semi-finished shape. However, in general, to roll down an ingot 25" x 27" into a bloom 9" square will require about 5 minutes or 16 passes through the rolls.

One important variation in blooming mill design is the three high mill, which although fairly common, is not as widely used as the 2 high reversing mill. These mills are constructed with 3 large rolls which are directly above each other, however, in such mills the ingot is first passed through the 2 bottom rolls and upon reaching the roll tables on the opposite side is raised by these tables and passes back through the second and third rolls. The process continues in this manner until the ingot has been satisfactorily rolled to the proper dimentions.

As one would expect,the power requirements for such mills are great. On the newer type mills, the electrically driven motors are capable of developing upwards of   horsepower. In order to generate this amount of power, two separate motors are often used, one on each roll. The motors used to drive the rolls are housed in a separate motor room which must be kept clean and carefully ventilated in order to ensure efficient operation of these large but delicate machines.

Once the steel ingot has been rolled into the desired shape, in this instance a bloom, the shape is carried from the rear mill table to the shear table which is located about 100 ft. in back of the blooming mill itself. The blooming mill shear may be of several varieties, however, the most common is designed in such a way that the lower blade, which is made of very hard steel, is stationary, while the upper blade is activated. The bloom is still red hot when brought into shearing position, and when the cut is made, the cropped end drops off into a pit and is eventually brought back to the open hearth shop to be used as scrap.

Many blooming mills are actually capable of rolling both slabs and blooms, and some may even roll billets. However, in making billets, the ingot is generally rolled into a bloom and then transferred to a billet mill for further reduction.

All of the pilot facilities incorporated the following features and modes of operation: 1.) a facility for transporting molten steel to the casting floor located at the uppermost level on the machine; 2.) a means of pouring the molten steel into the top of the vertical water-cooled mold; 3.) a means for extracting a partially solidified section from the bottom of the mold in a continuous strand; at this stage of the process an outer crust of solidifed steel, cast in the shape of the mold, surrounds a core of molten steel; 4.) a water spray battery down into which the partially solidifed section passes to be cooled and completely solidifed; 5.) an assembly of pinch or withdrawal rolls through which the solidified section passes once it has emerged from the water spray battery; 6) a cutting chamber into which the pinch rolls direct the cast section in a continuous strand to be cut to required lengths; 7.) a means for discharging the finished cast sections from the machine.

Although all of the pilot plants for the continuous casting of steel followed the basic procedures just outlined, they differed in the design and operation of the specific methods employed. Both lip-pour and bottom-pour ladles were used in pouring and various means were devised to control the pouring rate and to maintain required temperatures. Bottom-pour ladles were found more suited to handling heavy heats, but presented a problem with regard to temperature control. Lip-pour ladles, covered with lids into which heaters were built, Moreover, because of the width requirements of many of the sheet and flat rolled products, a separate slabbing mill will usually be required to roll slabs to specifications. In some instances, where billets are the principal semi-finished product of a given plant, billet size ingots may be poured from the steel furnace but this is generally a costly operation and is now difficult to justify due to the successful operation of multi-strand continuous casting units for billet size sections..

Generally, when a bloom is to be rolled into a billet size section, another full rolling operation is required, namely the billet mill. Such mills may be either 2 high reversing mills as were the blooming and slabbing mill, or they may be continuous mills. Continuous billet mills may consist of up to 10 stands, 6 of which are in a row in much the same manner as the finishing train of a continuous hot strip mill. Each of the stands of a continuous mill must be designed in such a way that the rolling speed of that stand is proportionally faster than the speed of the preceding stand. This is necessary to compensate for the gradual elongation which occures with each stand. On the newer and more advanced mills, each of the individual sets of rolls is separately driven which improves operating conditions as well as quality and dimension control. Once the steel section has passed through the 6 stands of the mill, its dimensions will usually be approximately 4 inches square. The billets are then cropped to the proper length by means of flying shears which are designed to cut the section as it is moving along the shear table. Such shears must be carefully maintained in order to assure the maintenance of a speed equal to the velocity of the billet as it emerges from the rolls. After shearing, the billets may be put through an additional 4 stand mill for further reduction, or prepared for further rolling by means of surface conditioning and/or reheating.

This semi-finished products of the three types of primary mills are actually the first instance of a diversely shaped steel product. From these three principal shapes, the numerous other steel products are made. Each type of semi-finished steel is especially suited to the production of certain product groups, and thus for each there must be added secondary rolling facilities.

Slabs are used in the manufacture of thin plates, sheets, strip and tin plate. Blooms are rolled into structural shapes, rails, and tube rounds and thick sections of plate and sheet. Billets are rolled into pipe and tube rounds, bars, rails, merchant bar and wire products.

Prior to any secondary rolling operations, certain preliminary operations must be performed on the steel sections. First, any surface defects in the semi-finished slab must be removed. Such defects may be the result of a number of causes, which include defects in ingots, or improper primary rolling. The semi-finished sections are "scarfed", and then carefully inspected to ensure surface quality. The steel is then reheated in a furnace to bring it to the proper temperature for further rolling. This is usually about 2200°F.

There are a number of mills which can be used to roll slabs into flat rolled products and would include the following:1)

1. The two high mill for rolling sheets in a pack.
2. The two high mill for rolling sheared plates.
3. The universal mill for rolling plates.
4. The three high mill for rolling plate.
5. The continuous or tandem hot strip mill for rolling sheets, strip, and hot rolled breadkowns for cold reduction in coils.
6. The cold reduction mills for sheets and strip.
7. The continuous sheared plate mill.

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1) The United States Steel Corp. - "The Making, Shaping, and Treating of Steel", Pittsburgh, Pa., 1951.

One of these will be described as an example.

Perhaps the most efficient method of rolling sheets and strip is the continuous hot strip mill. Such mills are large in size, often half a mile long and produce a fine quality of product. Some of the newer continuous hot strip mills have an annual capacity in excess of 5,000,000 net tons, and can be fully operated by a system of computers. In general such mills consist of 4 roughing stands and 5 to 7 finishing stands, as well as additional facilities for scale breaking, cleaning and coiling.

The semi-finished steel slabs are mechanically pushed from the continuous reheating furnaces and come to rest on the beginning of the long series of roll tables over which they move to the mill proper. The first two operations characteristic of a continuous hot strip mill are usually a vertical edging mill and a horizontal scale breaker. The function of these mills is to condition the surface of the slab and to loosen the scale and other surface impurities. As the slab comes out of the rolls of the horizontal scale breaker, it is subjected to high pressure water sprays which remove the scale from the slab surface. Although the water sprays do result in minor temperature losses, the heat within the slab is more than sufficient to offset these losses and thus keeps the temperature at a suitable level for the high speed rolling operations.

The horizontal scale breaker is usually a two high mill, but in some instances may be a 4 high installation. The rolls for this mill are driven by one of a set of electric motors which provide the requisite amounts of power for the mill. Each mill stand in the complex is driven by its own individual motor in order to ensure maximum power availability at any time. These motors are located in a motor room which in constructed parallel and adjacent to the hot strip mill itself. The horsepower requirements of these motors are not as large as are those of the blooming mill, however, they are often as great as horsepower, for the broadside and roughing mills. The hot strip motor room, like the blooming mill motor room, must be carefully ventilated to allow maximum efficiency of these motors.

Prior to passing through the first roughing mill, which is called a broadside mill, the slab passes over a turntable or slab turner which sometimes turns the slab a full 90 degrees and allows it to pass broadside through the first stand of rolls. If this is done another turntable on the other side of the rolls straightens the slab again. This process widens the slab. Generally, the broadside mill is a 4 high mill, in which the two center rolls are considerably smaller than the remaining two. These smaller rolls, or "work rolls" are the middle rolls, and it is these which actually come in contact with the steel and reduce its thickness. Above and below the working rolls are the two additional rolls which are considerably larger in diameter called back-up rolls, and whose function it is to exert pressure on the working rolls in order to keep the smaller rolls in uniform physical condition, and to provide some additional rolling strength. One additional set of rolls, the vertical edging rolls are often included and these are placed in such a position that they square off the slab edge before it passes through the horizontal rolls.

After passing through the broadside mill, the elongated slab then moves through a mechanical slab squeezer. This is designed to squeeze the slab to its proper width specification, and also to square off the cross section in order to allow for a more uniform final product. Once the slab has passed through the slab squeezer, it moves to the succeeding roughing mills. These remaining roughing mills are basically similar to the broadside mill. They have four rolls and reduce the slab in thickness and increase it in length. Thus, the rolling speed of each mill must be proportionally incrased with respect to the length and thickness of the slab.

In place of the 3 or 4 roughing mills mentioned in the preceeding discussion, some hot strip mills are a reversing mill, similar in design to the primary reversing mill. This type of installation is cheaper with respect to investment cost, but will usually limit the capacity of the mill to a level of production somewhat less than the hot mill with four roughing stands.

Prior to entering the finishing train of the continuous hot strip mill, the elongated slab is cropped and is passed through a second scale breaker and a set of high pressure water sprays. The function of these operations is to remove scale and thus help to provide for a better surface.

The slab is then passed into the finishing train or finishing mill which may consist of from 5 to 7 finishing stands each with 4 rolls. These stands are set very close together so that the strip is in all of them at one time. Each of these stands roll the section of steel thinnner and it becomes longer, thus, each rolls at an accelerated speed when compared with the preceeding stand. When the steel sheet emerges from the last stand of the finishing train it will be traveling at a speed of from 2200 to 2500 feet per minute. High pressure water sprays are then used to cool the steel as it travels over the roll out table. Two or three coilers rapidly coil the steel into large coils easily suited to interplant transportation and additional rolling and finishing operations.

Steel Plants

[illegible] integrated mills, [illegible] semi-integrated mills and [illegible] non-integrated or finishing mills.

The integrated [illegible] produces [illegible] either pig iron [illegible] furnace [illegible] The steel is then rolled into finished products. In the large mills these may [illegible] the small mills they may be [illegible]

The semi-integrated steel mill [illegible] of steel in either electric furnaces or old open hearth furnaces. This latter [illegible] an open hearth furnace [illegible] The steel is then rolled into finished products.

The non-integrated plant is usually a finishing mill [illegible] steel in some form [illegible] finished products.

Within each of the above three categories there are also wide differences in respect of size, variety of product and investment. This is particularly true in the first two categories, namely, integrated and semi-integrated plants.

Integrated plants can range in size from 250,000 tons of steelmaking capacity such as the Iligan plant planned for the Philippines to 4 or 5 million tons of capacity as found in the Sparrows Point Plant of Bethlehem Steel and the Gary Steel Works in the United States.

Semi-integrated mills can range in size and type of product from a small electric furnace, which may produce 10,000 tons of steel a year and a bar mill to roll this steel into concrete reinforcing bars to a 5 or 600,000 ton plant with a number of large electric furnaces and a variety of finishing facilities such as the one planned for Pakistan.

The non-integrated mill category embraces a great variety of steel rolling operations and would include any type of mill which imports steel for further processing.

The details of an integrated and non-integrated mill are given below and it will be noted that each represents a planned facility in a developing economy.

Integrated Plant

The integrated steel mill described here represents the first stage of the proposed Bokaro mill in India. Although this mill is still in the planning stage, and the information contained is subject to change, the description will provide an example of the manner in which steelmaking and rolling facilities are combined to form a fully integrated mill.

The mill, in its first stage, is designed to produce the following product mix:

a.	Hot Rolled Sheet, Strip and Skelp	300,000 metric tons
b.	Cold Rolled Sheet, Strip and Skelp	250,000 metric tons
c.	Galvanized Sheet	130,000 metric tons
d.	Plate	360,000 metric tons
	Total Finished Products	1,040,000 metric tons

The ingot production necessary to produce this 1,040,000 tons of finished products is estimated at 1,400,000 and thus the blast furnace and steelmaking operations must be geared to this level. Considerable excess rolling capacity is allowed in order to process the additional steel to be produced in stages 2 and 3. Estimate costs per unit of production of ingots and finished products are as follows: cost per ton of ingots, 650 U.S.A. dollars, cost per ton of finished products, 880 U.S.A dollars. In addition to the cost of the steel plant itself, it is also estimated that additional costs for such items as water canals, dams, extension of power, rail and road systems, the townsite and other associated items will total in excess of 133 million U.S.A. dollars. The facilities which will be constructed to form this mill consist of the following:

Coke Facilities: The mill will have 2 batteries of coke ovens, each containing 174 ovens, the aggregate capacity of which are about 1.27 million tons per year. Other coke plant facilities will includ coke crushing and screening equipment, as well as coke transportation facilities.

Steelmaking Furnaces: Steel is to be manufactured in four 75 ton electric arc furnaces which will be of the swing roof top charge variety. Two 70 ton main hoist cranes with 15-ton auxiliary hoists are also provided. Each furnace is equipped with an 18,750 K.V.A. power transformer and two 15,000 K.V.A. synchronous condensers are also included. The teeming aisle is equipped with 75 ton teeming ladles, a 110 ton overhead crane and the necessary ingot pouring facilities.

Continuous Casting Equipment: The continuous casting unit to be installed in this mill is a 4-strand curved mold machine. The machine will be capable of producing blooms 6" x 6" or larger or billets 4 inches square. Because of the steel furnace heat size, the casting of billets in somewhat restricted due to the reduced metal requirement of smaller sections. Continuous casting will not be used to cast slabs because of the technical difficulties associated with the processes.

Ingot Preperation and Treatment: In the production of flat rolled products, the conventional ingot casting methods must be used and this requires the use of soaking pits, stripper cranes and a slabbing mill. The soaking pit facilities consist of two, three hole batteries. Each hole is 8 feet by 24 feet and 13 feet deep. Temperature requirements are approximately 2200 degrees.

Slabbing and Roughing Mill: Rolling facilities needed to reduce ingots into more workable shops consist of a 36 inch by 66 inch 2 high reversing slabbing roughing mill. The horizontal rolls of this mill are driven by a 5000 horsepower electric motor while the vertical edging mills are driven by a 2000 H. P. motor. The mill is equipped with a hot shear capable of cutting sections up to 6 inches thick and 50 inches wide. The steel ingot is first rolled to a thickness of about 6 inches and then it may be further rolled to a thickness of about 5/8 inch to 1 1/2 inches.

Hot Strip Mill: The hot strip mill is a single stand 4 high reversing mill, 26 1/2 inches and 49 inches by 56 inches. Each unit is driven by a 6000 horsepower electric motor. Such a mill is capable of rolling the strip to a minimum thickness of 0. 075 inches or plates with a thickness range of 1/4 inch to 1 inch. Maximum roll speed is about 1850 feet per minute. This mill is also equipped with 2200 pound per square inch descaling water sprays.

Rail and Structural Mills: The rolling equipment for these products is a 26 inch mill with a capacity of about 30 ton per hour. Such a mill produces rails up to 100 pounds per yard, structural shapes 6 to 12 inches, equal leg angles from 6 inches by 6 inches and billets down to a minimum of 2 inches by 2 inches. This mill consists of 3 stands which are side made it easier to obtain higher temperatures and to maintain a given temperature level during casting, but the hot metal when lip-poured was drawn off from beneath the slag at the top of the ladle and so contained a greater amount of slag inclusions. In the cooling section, pilot machines differed in the design of water-spray jets and supporting equipment. In the cutting section a number of methods were used including oxyacetylene torches which moved downward at the same speed as the casting, hydraulic shears and sliding hears. In the case of the discharge arrangement the various machines utilized such means as roller conveyors, tilter baskets, inclined elevators and bending devices.

The development of a suitable mold has been one of the most important factors governing the rate of growth of continuous casting. The pilot plants under discussion all employed vertically-supported, water-cooled molds, but a number of different features of mold operations were used and it is mainly through these differences that the various casting processes are distinguished.

The earliest continuous casting processes employed rigidly mounted or fixed molds together with uniform rates for pouring the hot metal and the withdrawal of the finished section. Efficient mold lubrication was essential to prevent surface fractures in the section cast and only low casting speeds were attainable. The earliest development program in the United States for the continuous casting of steel was based on the

Blast Furnaces: In its first stage, the mill will consist of 2 blast furnaces, each with a capacity of 1.25 million tons per year. The approximate hearth size of the furnaces will be 30' 6". Auxiliary facilities include three 30" diameter and 135' high hot blast stoves per furnace, 3 turbo blowers, gas washing and cleaning facilities and other related blast furnace equipment.

Steelmaking Facilities: Basic oxygen steelmaking furnaces have been selected as the method of steel manufacture. The mills first construction phase will call for two 170 ton per heat B. O. F's, and the necessary oxygen. The aggregate annual steelmaking capacity of this steel shop is about 1.4 million tons.

Soaking Pits: Soaking pit facilities will include 6 rows of 24 pits, each pit having a capacity of 150 to 200 tons of ingots.

Primary Rolling Mill: A universal slabbing mill with an annual capacity of about 4 million tons will serve as the method of rolling ingots into semi-finished slabs. The general features of this mill are as follows:

One 46" x 90" two high horizontal roll stand

One 38" x 84" vertical mill stand

One two-side scrafing machine

One 2700 ton hydraulic slab sheer.

Hot Strip Mill: The continuous hot strip mill will have a rated annual capacity of approximately 3.5 million tons. The mill will consist of a broadside mill, 4 roughing stands and a 6-stand finishing train as well as the necessary auxiliary facilities. The general features of these mills are as follows:

One 46" x 80" two high roughing mill

Four 46" x 60" x 80" four high roughing stands.

Four 33" vertical edgers

One 25" x 80" two high finishing scale breaker

Six 28 1/2" x 80" four high finishing stands

Three 30" x 80" hot strip coilers.

Strip Processing: A single 74" continuous pickle line will be used to prepare the coils for further reduction.

Cold Reduction: The cold reduction mill planned for the first stage of this mill has a 1 million ton annual capacity. This mill will consist of four 23" x 60" x 80" four high roll stands.

Annealing: Box type annealing will be used for the coils in this mill. Six 4 stack annealing furnaces and six 1 stack furnaces are planned to re-heat the cold rolled sheet and strip.

Temper Mill: A single 26" x 60" x 80" four high single stand temper mill is also planned for further sheet and coil treatment.

Additional facilities will include a shear and slitting line, a leveling andshearing unit and a galvanizing line.

Semi-Integrated

In many ways semi-integrated plants offer the best possibilities for a developing economy when the country is establishing its domestic industry. This assumes that scrap is available through imports and/or some domestic supply. Such a semi-integrated mill is currently being planned for Pakistan. This particular plant is designed to have an initial capacity of 375,000 tons of finished products of which half will be flat rolled products and half bars and rails and accessories. The plant will serve as a model of a semi-integrated mill with the following facilities:

> Dock Facilities: The dock facilities of a medium size semi-integrated plant should provide equipment for the efficient unloading and transfer of the necessary amount of scrap. Further, if steel products are to be shipped by water it should also include facilities designed to handle the particular types of products to be shipped. In light of scrap requirements, magnetic unloaders, clamshell buckets and rail cars and tracks are needed. The capacity and location of these facilities with respect to each other is determined principally by the amount and volume of ship traffic. Obviously a plant located inland would not require dock facilities but would need material handling equipment.

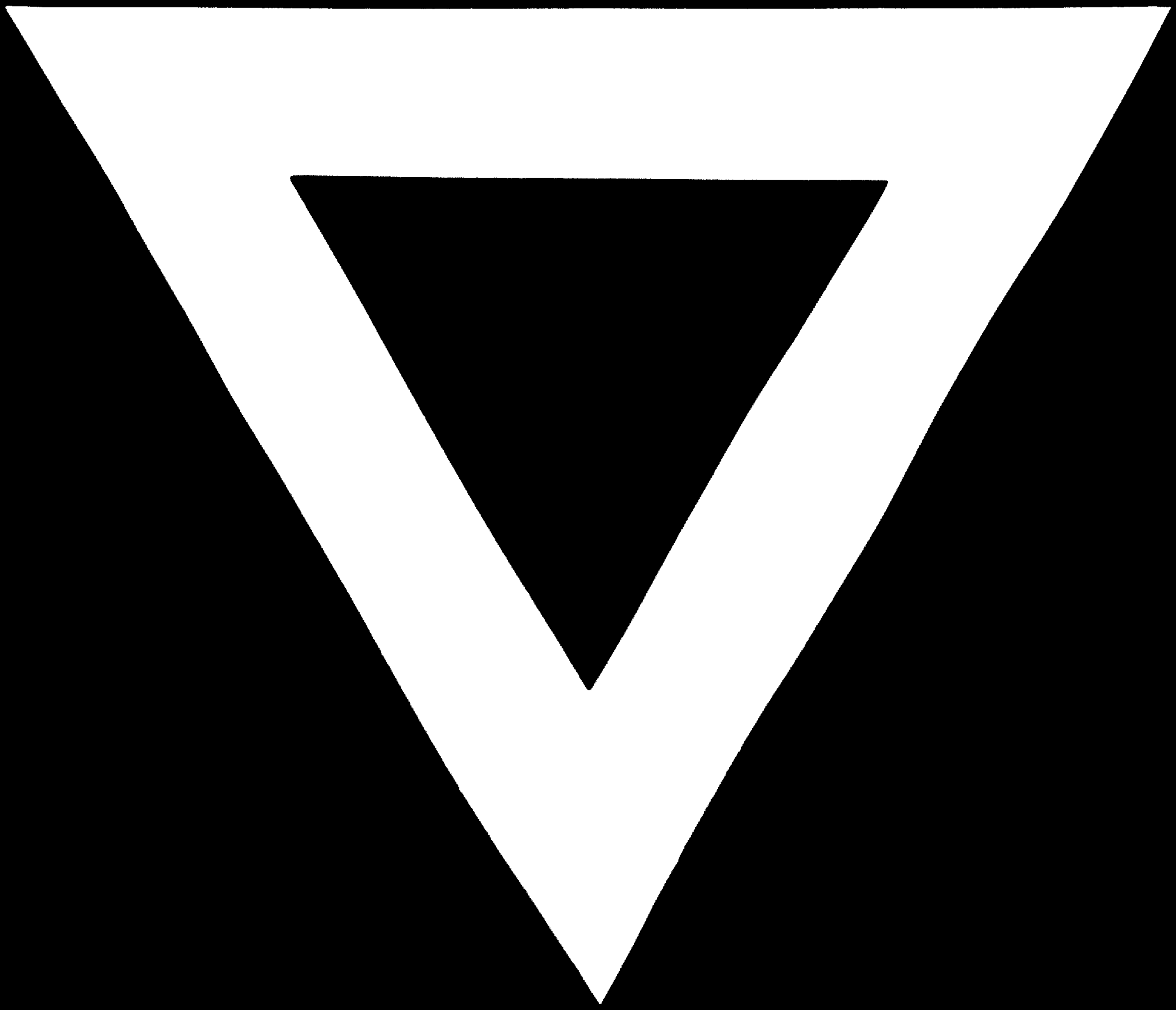
by side, 2 of which are 3 high and the last which is a 2 high mill. Electric motors which deliver 2000 horsepower drive these mills.

Continuous Pickle Line: Coils from 24 to 50 inches wide can be pickled on this line. The thickness of the metal is limited to a maximum of 0.125 inches. The entry speed on this continuous pickle line is about 465 feet per minute.

Cold Reduction Mill: The cold reduction mill to be used in this mill is a single stand 4-high reversing mill. The work rolls on this mill are driven by 3500 horsepower motors which provide a maximum rolling speed of about 2000 feet per minute.

Electrostatic Cleaning Facilities: The electrostatic cleaning line which is designed to clean strip up to 48 inches wide and from 0.0625 inches in thickness to .008 has an operating capacity of about 30 tons per hour.

Finishing Facilities: This proposed plant will also be equipped with 7 single stack annealing furnaces that are designed to hold a stack of coils with a maximum outer diameter of 60 inches and of maximum height of 162 inches. The temper mill will be a single stand 4 high mill with a capacity to roll strip and sheet at a maximum speed of 2500 feet per minute. The work rolls on this mill are driven by 700 horsepower motors. An electrolytic tinning line and a hot dip galvanizing line are also to be provided for the coating of sheet and strip.



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fixed mold concept. It was inaugurated in 1941-1942 by Republic Steel Corporation and after 1944 was carried on as a joint venture between Republic and the Babcock and Wilcox Tube Company. By mid-1949 good casts were produced on a pilot facility at Beaver Falls, Pennsylvania, but serious problems were encountered in cooling the stationary mold wall and casting rates were low by current standards (60 inches per minute with oval shapes).

Babcock and Wilcox developed, built and installed the first continuous casting unit for commerical use in the United States. It was delivered to the Roanoke Electric Steel Corporation in December 1962, following more than fifteen years of development work at Beaver Falls. Unlike the earlier Babcock and Wilcox pilot machines, the production model uses two reciprocating molds, vertically supported and water-cooled. The two-strand machine can produce castings which range from 3 x 3 inches to 6 x 6 inches. In casting 4 1/2 inch billets, hourly casting rates average about 15 tons per strand. It takes 40 minutes to cast a 22 ton heat into 700 feet of billets. This amounts to 105 inches per minute per strand.

As has been noted, the casting rates attainable with the fixed mold were limited and to increase them the "pause and pull" method of casting was used. The mold remained fixed, but instead of the withdrawal rate remaining constant in direct relation to the rate of pouring, it was interrupted - either halted completely or slowed down - at specific intervals so that a series of withdrawals occurred, each more rapid than the pouring rate. As a result, the level of hot metal within the mold was made to rise and fall. This created conditions in the mold which were similar to those obtained by moving the mold, but the continued acceleration and decleration of the pinch rolls proved a disadvantage particularly in the casting of large sections. (The pause and pull method was employed with some degree of success by Babcock and Wilcox at the Beaver Falls pilot facility.)

One step removed from the fixed or rigidly mounted mold is the spring mounted mold. The spring mounting makes it possible for the mold to move downward with the section thus increasing the time for solidification and separation of the section from the mold wall. As the mold moves downward the upward pressure imparted by the springs increases eventually forcing the separation of the casting from the mold wall and returning the mold to its original position.

The most widely used method of mold design at present is the vertically reciprocating mold. This type of mold movement made it possible to increase casting speeds significantly. The mold is mounted to move downward at the same speed as the cast section for a short distance, usually within the maximum limit of 1 inch, and to return at an accelerated rate to its original position; this accelerated rate usually is about three times the rate of withdrawal of the casting. Thus the quiescent state between the casting and the mold is maintained during the downward movement and it imparts a sound surface to the casting. The accelerated upward movement, while it does result in some disturbance, strips the mold from the skin formed during the previous downward movement, and thus permits the mold to be stripped under greatly reduced drag as compared with the fixed mold process.

The earliest continuous casting machine with a reciprocating mold to be used for casting steel was installed in 1948 at a pilot plant of the Allegheny Ludlum Steel Corporation. In this instance the process as developed for casting other metals was carried over into steel. In fact, the machine was originally designed to cast brass in slabs at 15 x 4 inches. In casting steel, temperature requirements and cooling conditions proved troublesome and the height of the tower was limited so that the distance between the mold bottom and the pinch rolls, although insufficient, could not be increased. This severely limited potential casting speeds, but the machine was still capable of casting stainless steel slabs of reasonably good quality. Subsequently continuous casting machines for steel were installed in Germany, Sweden, France, Austria, England, Japan and Canada.

An early commercial steelmaking machine with a reciprocating mold was installed at Atlas Steel, Ltd., in Welland, Ontario. Construction was begun in 1952 and square or rectangular sections were cast in molds 20 inches in length made of oxygen-free, high conductivity copper. In 1956 casting speeds of 175 inches per minute were possible.

The reciprocating mold has also been employed with negative strip, that is, in its oscillation the mold descends not at the same rate as the casting but at a slighly faster rate thus reducing mold drag during stripping to zero or to negative amounts. The skin is stripped during the downward movement of the mold, whereas in the normal procedure it was stripped during the upward movement, hence the term "negative strip." The process was first introduced in 1952 at the Barrow Steel Works in Great Britain to produce small sections at casting speeds much faster than previously achieved. Results with small sections were favorable as is indicated by a speed of 570 inches per minute attained in casting 2 inch billets. In 1959 operations were started on a machine designed to cast large sections. Improvements were apparent in surface quality and speeds of from 40 to 48 inches per minute were attained with 9 inch square blooms and slabs of 36 x 5 inches. This process is seen as a significant advance toward filling the need of higher casting speeds and increased rates of production.

The most recent development in the area of mold design and operation is "curved mold" machine. In this process the mold is still oscillated and water-cooled, but the mold itself as well as the cooling chamber are curved rather than vertically supported. This reduced the height of the casting machine to less than one-third that of a vertical unit, roughtly 20 feet as compared with 75 feet. One of the major advantages of the curved mold machine is that it simplifies building requirements since small to medium sized units can be constructed within existing plant structures. Vertical machines, with the casting floor high above ground level, require new building construction and, consequently, entail added costs. The curved mold unit further reduces costs by eliminating several machinery components. This contributes to machine lightness and reduced foundation requirements. Figure 11 illustrates the two types of machines and Figure 12 illustrates the process.

Present Status of Continuous Casting

Since 1960, alghough pilot plant work and the further development of techniques on a test basis has continued, emphasis has been turned to the installation of production facilities. The increase in the commercial application of continuous casting for steel represents a consolidation of successful procedures developed through pilot plant activity and, as a result, substantial differences which distinguished pilot facilities and early production plants have been largely eliminated. This is particularly true of the differences in molds since it has been established that some reciprocation of the mold is of advantage in a commercially acceptable process. Two types of reciprocating molds have been widely adopted, the vertical straight mold with a vertical qone of secondary cooling water sprays beneath the mold and the curved mold with a curved secondary cooling sone. Reciprocation takes place either by the Junghans method in which the descent of the mold and that of the casting are equal, or by the Barrow method wherein the descrnt of the mold slightly exceeds that of the casting.

Table 1 lists the number and location of continuous casting plants