open-hearth process brought the final victory to the steel because it produced a better quality of steel that could take up higher working stresses.

The present age is of steel and as a matter of fact, the industrial progress and financial stability of a nation are estimated directly by the volume of its yearly steel output. Japan, U.S.A. and former U.S.S.R. are producing nearly 1100 to 1250 million kN of steel each per year. Britain, West Germany and France produce about 350 to 400 million kN of steel each annually. The steel produced by India is about 100 to 120 million kN per year. The overall control of the whole steel industry both in the public and private sectors is exercised by the Steel Authority of India Limited (SAIL) with its headquarters in New Delhi.

In this chapter, some of the salient aspects of this important building material will now be discussed.

Manufacture of steel:

The steel is manufactured by the following processes:

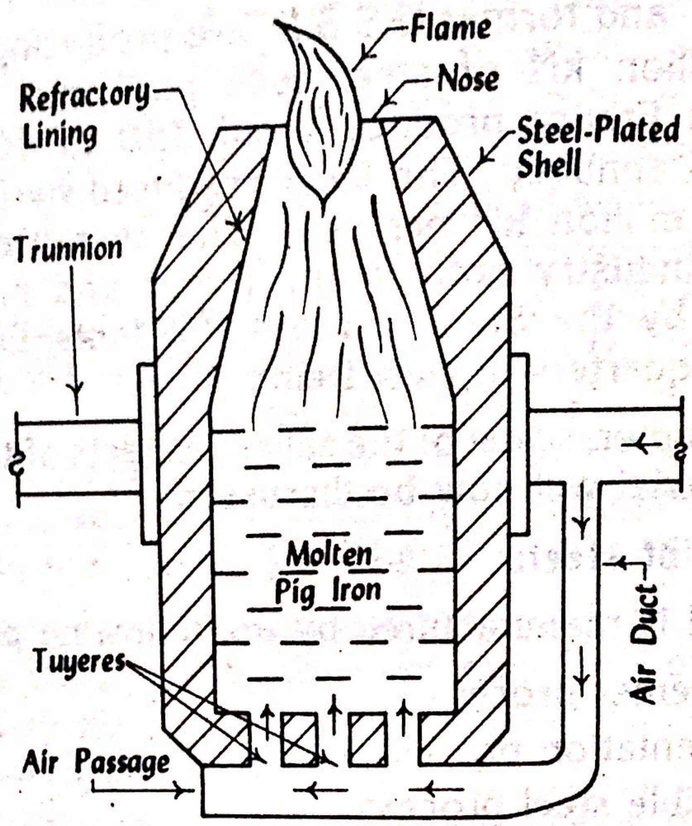
(1) Bessemer process
(2) Cementation process
(3) Crucible steel process
(4) Duplex process
(5) Electric process
(6) L.D. process
(7) Open-hearth process.

Each of the above process will now be briefly described.

(1) ***Bessemer process:*** This process was invented by British engineer who patented more than 100 inventions over his lifetime. He is most famous for inventing this process. He was knighted in 1879.

Depending upon the nature of lining material of converter, this process may be acidic or basic. In acidic process, the lining material is acidic in nature such as clay, quartz, etc. It is adopted when iron ores are free from or when they contain very small amount of sulphur and phosphorus. In basic process, the lining material is basic in nature such as lime, magnesia, etc. It is adopted for pig-iron containing impurities of any type. The basic process is commonly adopted.

The Bessemer converter is wide at bottom and narrow at top as shown in fig. 10-1. It is mounted on *two* horizontal trunnions so that it can be tilted or rotated at suitable angle. The tuyeres are provided at the bottom to allow passage of air from the air duct to the pig-iron. The working of converter is as follows:



Bessemer converter
FIG. 10-1

(i) The converter is tilted and it is charged with molten pig-iron from cupola furnace or sometimes even directly from the blast furnace.

(ii) The converter is brought in an upright position and a blast of hot air is forced through the tuyeres.

(iii) The air passes through the molten pig-iron. It oxidizes impurities of pig-iron and a brilliant reddish-yellow flame is seen at the nose of converter.

(iv) The flame is accompanied by a loud roaring sound and within 10 to 15 minutes or so, all the impurities of pig-iron are oxidized. The order of oxidation of various impurities is silicon, carbon, manganese, sulphur and phosphorus.

(v) When the intensity of flame has considerably reduced, the blast is shut off and the required amount of suitable material such as ferro-manganese, spiege-leisen, etc. is added to make steel of desired quality.

(vi) The blast of air is started for a few minutes. The converter is then tilted in discharge position and the molten metal is carried into ladles or containers.

(vii) The molten metal is poured into large rectangular moulds for solidification. Such solidified mass is known as the *ingot*. These ingots are then further treated to form steel of commercial pattern.

(2) *Cementation process:* This process was formerly used to manufacture steel. It is costly and it is now, therefore, practically not adopted. It consists in converting pig-iron to almost pure wrought-iron and then preparing steel by adjusting carbon content. This process is carried out as follows:

(i) The bars of pure wrought-iron are taken and they are placed between the layers of powdered charcoal. The dome-shaped furnace known as the *cementation furnace* is generally used for this purpose.

(ii) The furnace is heated and the bars are subjected to an intense heat for a period of 5 to 15 days as per quality of steel required.

(iii) The wrought-iron combines with carbon and steel of desired composition is formed. This steel is covered with blisters or thin bubbles and it is, therefore, known as the *blister steel*. Its structure is not homogeneous and it is full of cavities and fissures. The blister steel cannot be used for making edge tools. It can only be used for machine parts and facing hammers.

(3) *Crucible steel process:* This process is adopted to produce small quantity of high carbon steel. In this process, the fragments of blister steel or short bars of wrought-iron are taken and they are mixed with charcoal. They are then placed in fire clay crucibles and heated. The molten iron is poured into suitable moulds. The steel produced by this process is known as the *cast steel*. It is hard and uniform in quality. It is used for making surgical instruments, files, cutlery of superior quality, etc.

(4) *Duplex process:* This process is a combination of the following *two* processes:

(i) Acid Bessemer process

(ii) Basic open-hearth process.

Following operations are, therefore, performed in preparing steel by the Duplex process:

(a) The molten pig-iron is given treatment in acid-lined Bessemer converter. The impurities such as silica, manganese and carbon are eliminated at this stage.

(b) It is then treated in basic lined open-hearth. The impurities such as sulphur and phosphorus are eliminated at this stage.

It is thus seen that the Duplex process is found out to take advantages of both the processes, namely, Bessemer process and open-hearth process. This process is economical and it results in considerable saving of time.

To improve the quality of steel further, the Duplex process may be extended to the Triplex process. The molten pig-iron, as obtained from basic lined open-hearth, is further treated in electric furnace to produce steel of high quality.

(5) *Electric process:* In this process, the electricity is used for heating and melting the metal. The other procedure is same as in case of Bessemer process or open-hearth process.

An electric furnace may either be rectangular or circular. It is made from steel plates. It is lined with basic refractory material. It is mounted on rollers so that it can be tilted as required. It is provided with electrodes. When electric current is switched on, the electric arcs are formed between electrodes and surface of metal and with the intense heat of these arcs, the metal is heated and melted. The capacity of electric furnace is about 100 to 150 kN and it is, therefore, not suitable for manufacturing steel on a large scale. It is, however, used to prepare special steel on a small scale.

Following are the *advantages* of this process:

(i) The heat is quickly supplied and it is possible to have a wide range of possible temperatures.

(ii) It presents a neat and clean operation.

(iii) The quantity of slag formed is small.

(iv) The temperature can be properly controlled.

(v) There is absence of ash and smoke.

(6) ***L.D. process:*** This process is a modification of Bessemer process. It is named as the Linz—Donawitz process or L.D. process as it was first invented in Austria in 1953 and adopted in *two* towns—Linz and Donawitz.

In this process, the pure oxygen is used instead of air. In L.D. converter, a jet of pure oxygen is blown at extraordinary speed on molten metal. The high temperature developed in the converter burns away impurities of metal and highly pure low carbon steel is prepared.

The furnace vessel is similar to that of the Bessemer converter except that the capacity is between 500 to 1000 kN. The process is economical in initial cost as well as in maintenance cost. This is the only process where sulphur can be effectively reduced. This process of steel making is specifically suitable for the Indian pig-irons and it has been adopted on a large scale at the SAIL projects of Rourkela, Bokaro and Bhilai. The process has also superceded all other processes of steel making in Europe, America and Japan.

The L.D. process using basic lined oxygen vessels is much quicker and cheaper and it has practically replaced the open hearth process. In Japan, nearly 80% of the installed capacity is by the L.D. process. In the modern sophisticated L.D. converters, the computer controls the oxygen blow, continuous casting of different sections, rolling operations and inspections of finished products. The operators now sit in comfortable air-conditioned cabins and exercise remote control in the true sense.

Following are the *disadvantages* of this process:

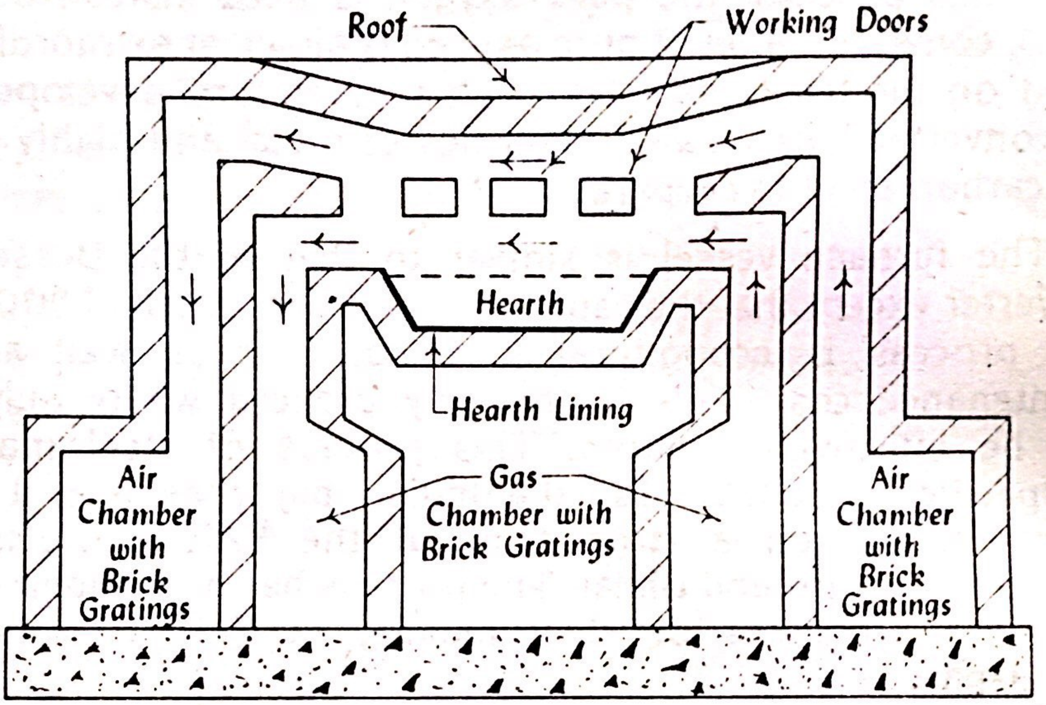
(i) An oxygen plant to prepare oxygen is required.

(ii) It cannot treat pig-iron of all grades and varieties.

(iii) It is not possible to control temperature precisely.

(7) ***Open-hearth process:*** This is also sometimes referred to as the *Siemens-Martin process* as Siemens of Germany first invented this process by about the year 1862 and Martin made some improvements in the process. The open-hearth process may either be acidic or basic as in case of Bessemer process. The basic open-hearth process is more commonly adopted.

This process is carried out in open-hearth furnace as shown in fig. 10-2. This furnace resembles the reverberatory furnace which is used in the manufacturing process of wrought-iron.



Open-hearth furnace
FIG. 10-2

The working of furnace is as follows:

(i) The hearth is filled with molten pig-iron from cupola furnace or sometimes even directly from the blast furnace.

(ii) A mixture of pre-heated air and coal gas is allowed to pass over the hearth. This mixture catches fire and because of the peculiar shape of the roof, it attacks the molten metal. This produces intense heat and impurities of metal are oxidized.

(iii) When impurities of metal are removed to the desired extent, suitable material such as ferro-manganese, spiege-leisen, etc. is added to make steel of required quality.

(iv) The molten metal is then poured into moulds for forming ingots. These are then further treated to form steel of commercial pattern.

This process is extensively used in the manufacturing process of steel as it possesses the following *advantages*:

(i) The basic slag obtained from the open-hearth process contains phosphorus. This slag in powder form can, therefore, be used as good fertilizer.

(ii) The great economy can be achieved by providing regenerative chambers on either side of the hearth as shown in fig. 10-2. These chambers make use of the waste heat of hot gases of combustion. The hot gases are allowed to pass through brick gratings of regenerative chamber before they escape through chimney. The directions of entering and leaving for air and gas are reversed at regular short intervals. The heated brick gratings pass on heat preserved by them to the entering air and gas.

(iii) The operations involved in the process are simple.

(iv) This process makes it possible to utilize a high percentage of scrap and this scrap is converted into new useful steel by this process.

(v) The time required to remove impurities is short.

(vi) The steel manufactured by this process is homogeneous in character.

Uses of steel:

Depending upon the carbon content, the steel is designated as the *mild steel* or *medium carbon steel* or *high carbon steel*. The various uses of steel are governed by the amount of carbon contained in it.

The carbon content of mild steel is about 0.10 to 0.25 per cent. When carbon content is less than 0.10 per cent, it is known as the *dead steel* or *very low carbon steel*.

The carbon content of medium carbon steel is about 0.25 to 0.60 per cent.

The high carbon steel is also known as the *hard steel* and its carbon content varies from 0.60 to 1.10 per cent or so.

It is observed that steel is required for the existence of the heavy and light engineering industries, for ship building, railways and rolling stock, automobiles, sheet metal industries, power generation and electrical industries, etc. It should also be noted that the entire range of electrical engineering industry depends upon the property of magnetism of steel.

Table 10-1 shows the various uses of steel of each category.