

# 19

## Basic Open Hearth and Electric Arc Furnace Steelmaking

### 19.1 BASIC OPEN HEARTH STEELMAKING

As stated in Chapter 1, Section 1.3.2, the open hearth process of steelmaking was invented in 1861. Initially, acid open hearth furnaces were used, but they were soon overtaken by *basic open hearth* (BOH) steelmaking. BOH was the primary method of steelmaking for about 100 years till the advent of the basic oxygen process. With the gradual evolution of basic oxygen steelmaking, the number of open hearth furnaces decreased steadily. By the mid 1990s, all recently installed steel plants as well as older plants that had been modernised did not have any BOH furnaces. Though quality steel could be made in open hearth steelmaking, the prolonged heat cycle (stretching over several hours) and the need for external fuel (fired into the rectangular furnaces through burners positioned at either end) were the major drawbacks. At present, only a very small number of steel plants around the world, principally in Russia, continues to employ this process. For any detailed description of open hearth steelmaking, readers may consult Tukary et al. (1998) and Trubin and Oiks (1974).

Despite its obsolescence, a very brief description of open hearth steelmaking is being included here because of the following reasons.

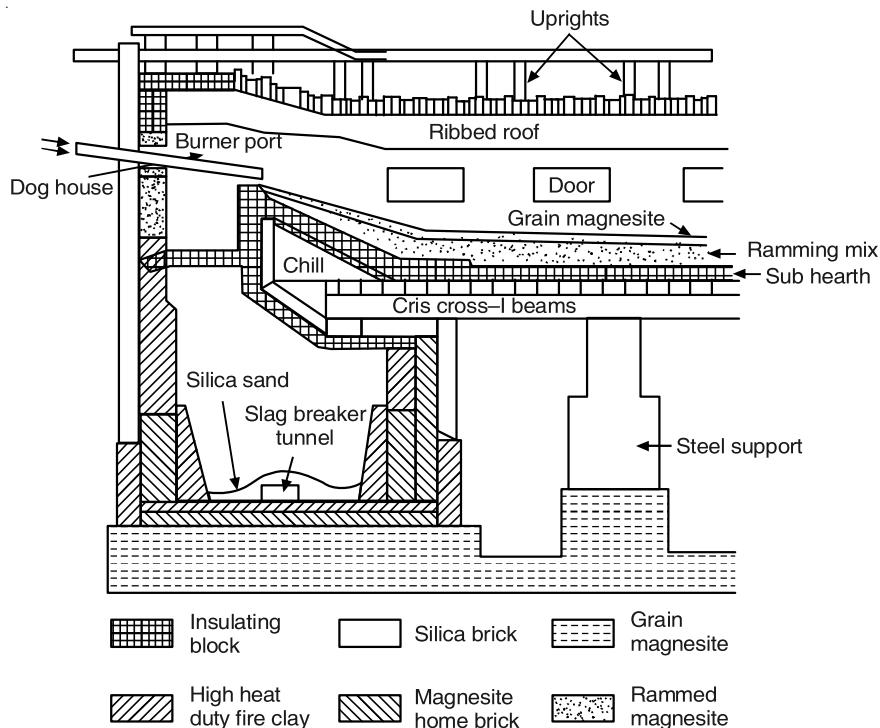
1. The knowledge of steelmaking has certainly been broadened by an understanding of the advantages of open hearth steelmaking as far as the production of high-quality steels is concerned. Similarly, an appreciation of why the process became gradually obsolete helped in formulating the processes that later came into vogue.
2. The fact that it was possible to observe the interior of an open hearth furnace periodically after each campaign, and also study the progress of steel refining by collecting a large number of metal and slag samples during each heat, contributed to a fundamental understanding of the principles involved in primary steelmaking.

### 19.1.1 The Open Hearth Furnace

The first open hearth furnace with a capacity of 2.2 t per heat and a hearth area of 3 m<sup>2</sup> was built in France in 1864. Although the operational practices adopted in BOH steelmaking changed considerably over the period of 100 years during which the process was in use, later day BOH furnaces broadly retained the original features of furnace design. Of course, the furnace size increased steadily—from 2.2 tonnes per heat in the very early stages to furnace capacities as high as 200–300 tonnes (and some even as large as 600 tonnes) by 1955, when the process had reached its maturity.

Scrap, cold pig, iron ore, manganese ore, and hot metal are used as charge in open hearth furnaces. The proportion of the solid charge consisting especially of scrap (in various forms) is seldom less than 70%, and a lot of time (at least 3–4 hours) is consumed in the process of charging and melting these solids. In fact, in any open hearth shop, extensive stock yard facilities have to be provided for scrap storage in large heaps. The scrap is then loaded into relatively small charging boxes which can be inserted into the furnaces through the front doors by using especially designed charging cars that operate on the furnace floor.

Figure 19.1 shows a sketch of the longitudinal vertical section of one-half of a BOH furnace. One end wall and burner can be seen. The furnace has another burner located at the opposite end-wall. The furnace itself, which is rectangular in shape, can either be built on a permanent foundation (in the case of stationary furnaces), or so arranged that a part comprising the hearth

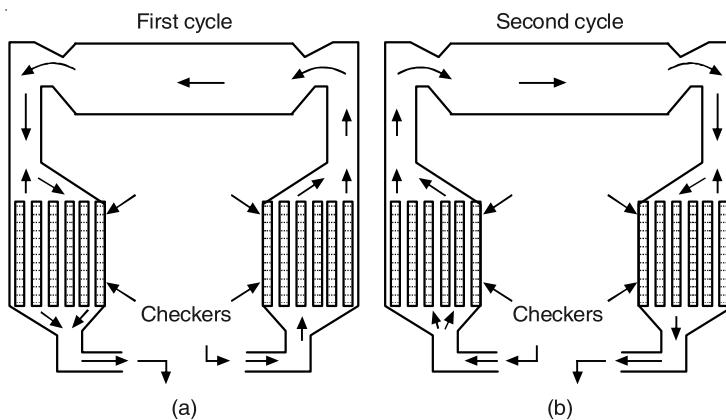


**Figure 19.1** Longitudinal vertical section of an open hearth furnace.

may be tilted (for tilting the furnace during tapping of liquid steel). The hearth of the furnace is made of steel plates (typically 25 mm thick). Different layers of refractories are laid on the steel shell to form the hearth bottom—first fireclay bricks, then magnesite bricks, and finally a layer of fritted burnt magnesite (10–30 mm). The main roof of BOH furnaces is made of basic bricks like chrome-magnesite or magnesite-chromite, while in acid furnaces, silica bricks are used.

Charging, observations of the bath during heat making as well as sampling are carried out through the doors provided on the front wall of the furnace, which can be opened or closed by lifting vertically, whenever required. These front doors, located over the entire length of the furnace are also used for fettling the hearth (adding fresh granules of refractory materials like magnesite) at the end of each heat as well as for furnace maintenance. Tapping of molten steel is done through a tap hole located on the back wall of the furnace (opposite side of the doors). The back wall also contains one or two holes that can be used for flushing out the slag during the course of heat making. This facility is particularly useful in large capacity furnaces so that slags can be tailor-made, as per refining requirements (for example, dephosphorisation). This is a unique advantage of open hearth steelmaking—time consuming, but essential for producing high-quality steels even from inferior inputs.

The furnace operating temperature is around 1650–1700°C, which cannot be obtained by combusting the fuel with cold air. Therefore, pre-heated air is normally used in the burners for the combustion of the fuel (fuel oil/coke oven gas/blast furnace gas/producer gas). Preheating of air to about 1000°C is carried out in *regenerators* containing a *checker work* (mesh) of firebricks. The regenerator consists of fire bricks arranged in such a way that the bricks fill about 75% of the total volume and gas flows through the empty regenerator space around the bricks. The brick lattice, i.e. the checkerwork, absorbs heat from the outgoing gases, and this heat is used to pre-heat cold air to 1200–1300°C. Figure 19.2 shows the regenerator arrangement. In the first cycle, air and fuel flow through the right-hand side. The hot products of combustion at about 1600°C pass through the regenerators on the left-hand side, thus heating up the refractory checkerwork. The direction of flow is reversed in the second cycle; each cycle lasting about 30 minutes.



**Figure 19.2** Heat regeneration system in an open hearth furnace: *First cycle*: checkers on left being heated by hot flue gas; checkers on right giving heat to incoming air, *Second cycle*: reverse of first cycle.

It may be noted that an open hearth shop is a fairly huge engineering structure equipped with many furnaces, regenerators, waste heat boilers (to recover heat from the exit gases) and instrument panels essentially for thermal control.

### 19.1.2 Steelmaking in Basic Open Hearth Furnaces

Heat making in BOH steelmaking involves different unit operations.

- Fettling, i.e. inspection and repair of the lining after the previous heat is tapped
- Charging of solids
- Heating the charge
- Charging of hot metal
- Melting and homogenisation of the entire charge
- Refining and finishing including flushing of slag
- Tapping liquid steel.

The charging sequence of solids is: iron ore at the bottom, then limestone, and finally scrap on top of limestone. Once heating begins and scrap reaches the point of melting, molten hot metal is poured. Because considerable oxidation of the scrap takes place during heating, the impurities in the hot metal, especially silicon and carbon, vigorously react with iron oxide. Limestone also dissociates releasing  $\text{CO}_2$ , which reacts with carbon and silicon in hot metal to form CO and  $\text{SiO}_2$  respectively. Evolution of CO results in foaming of the slag, which continues throughout the melting period.

As the impurities get oxidised, the amount of slag on the top of the horizontal bath keeps on increasing and the chemical composition of the metal bath changes continuously. Slag and metal samples are withdrawn throughout the refining period (lasting 90–120 minutes) to monitor the oxidation of carbon, manganese and phosphorus. The  $\text{SiO}_2$ ,  $\text{MnO}$  and  $\text{FeO}$  contents in the slag samples provide an idea of the extent of oxidation of the respective impurities. Iron ore added along with the charge as well as during the refining period is the major source of oxygen for these oxidising reactions. Since limited reaction sites are available, oxidation is intrinsically slow, resulting in low productivity of BOH furnaces.

Attempts to increase the productivity resulted in extensive usage of oxygen, once pure oxygen became available in larger quantities and at a relatively low price. Oxygen was used to either enrich the burner flame or was introduced directly into the molten bath using water-cooled top lances/submerged tuyeres. This helped increase the productivity of BOH furnaces by around 20% and reduced the tap-to-tap time to 8–12 hours from 16–20 hours earlier. It also resulted in reduction in fuel consumption.

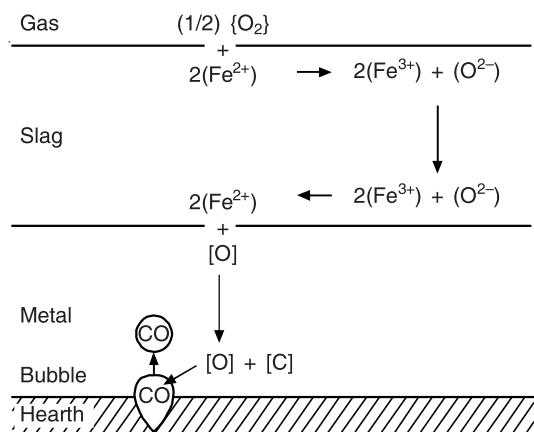
Since silicon is oxidised early and not much  $\text{CaO}$  is available from the decomposition of limestone, the foamy slag that is initially formed is rich in silica and is acidic in nature. Most of this slag comes out through the doors. After foaming subsides, fresh lime is added and a slag of high basicity (V-ratio 3 to 4) is made to begin the refining of phosphorus and carbon. Evolution of carbon monoxide bubbles provides adequate stirring to ensure homogenisation of the bath as well as helping in heat transfer. When the bath samples taken indicate that carbon in the metal bath has reached the specified level, the heat is ready for tapping. However, before

tapping, some deoxidisers are added into the bath in order to lower the bath oxygen content as well as for minor alloying. Tapping is carried out by physically opening the tap hole at the centre of the back wall of the furnace by oxygen lancing.

### 19.1.3 Transfer of Oxygen and Heat in Open Hearth Furnaces

Figure 19.3 schematically shows the mechanism of oxygen transfer from the gaseous atmosphere to the liquid metal bath in the hearth via the slag phase. Heat transfer also occurs from the hot gaseous combustion products to the bath via the slag. Radiation is the principal mechanism of heat transfer from gas to slag, for enhancing which the gas should be luminous. Luminosity of the gas is provided by unburnt carbon particles.

The oxygen potential is the highest in the gas ( $p_{O_2}$  about  $10^{-4}$  to  $10^{-5}$  atmosphere) and the lowest in the metal phase ( $p_{O_2}$  about  $10^{-8}$  to  $10^{-9}$  atmosphere). The concentration of dissolved oxygen in the metal bath depends mainly on its carbon content—the higher the bath carbon, the lower is the oxygen concentration. As shown in Figure 19.3, the transfer of oxygen to the slag occurs by oxidation of  $Fe^{2+}$  ions to  $Fe^{3+}$  ions at the gas–slag interface. The reverse process transfers oxygen from the slag to the metal.



**Figure 19.3** Mechanism of oxygen transfer from the gaseous atmosphere to the liquid metal bath in open hearth furnaces.

Dissolved carbon in the metal bath reacts with dissolved oxygen to generate carbon monoxide bubbles. The passage of these bubbles through the bath provides the stirring necessary for enhancing heat and mass transfer rates required for speeding-up all the reactions, as well as for guaranteeing adequate mixing/homogenisation. The formation of bubbles requires *nucleation* and *growth*. While growth does not require much supersaturation, theoretical calculations indicate that a pressure of CO as high as  $10^4$  atmospheres is required for *homogeneous* nucleation of the gas bubbles. Since such high thermodynamic super saturation simply does not exist in the bath of open hearth furnaces, at first there was considerable debate with regard to the reaction mechanism. The puzzle was resolved when it was demonstrated that the tiny crevices/pores in the hearth refractory lining serve as growth sites, which allows the nucleation

stage to be bypassed completely. This phenomenon also restricts the depth of the metal bath in BOH furnaces, both from the point of view of rapid heat transfer and acceptable rates of reactions.

### 19.1.4 Concluding Remarks

When the open hearth process was invented, *Acid Bessemer Converter Steelmaking* was the existing process for large-scale steel production. The open hearth process succeeded because of the following advantages that it offered.

- Ability to melt scrap which was hitherto lying unutilised
- Inherent flexibility and close control, since it was a relatively slow process that could be monitored by sampling, additions, etc. through the doors.

Later, open hearth furnaces were completely replaced by basic oxygen converters because of the following reasons:

- Slow rates of reactions and restricted productivity in BOHs
- Large consumption of extraneous fuels in BOHs
- Availability of tonnage oxygen at a relatively low cost
- Acute environmental pollution.

## 19.2 ELECTRIC ARC FURNACE STEELMAKING

### 19.2.1 General

There are basically two types of electrically-heated melting furnaces:

- Electric arc furnace (EAF)
- Induction furnace (IF).

Induction furnaces are employed for steelmaking only on a relatively very small scale since the furnace size varies from 0.5 t to maximum of 20/25 t per heat, with most furnaces below 5 t. Hence, IFs are used to a limited extent. On the other hand, arc furnace steelmaking is widely used and about 35% of world's steel is produced by EAFs at present (the rest by basic oxygen steelmaking), which is expected to become 50% in the next 10–15 years. The history of EAF steelmaking is marked by continuous improvements in efficiency and productivity. A method that was started in a small way about 100 years back principally for the production of alloy steels, later found widespread application in the production of all types of steels. While earlier EAFs were mostly between 10 t and 50 t, today 200–250 t EAFs are common and 400–500 t EAFs are available.

The advantages of EAFs for alloy steelmaking include:

- Relatively small size
- Cleaner environment
- Flexibility to produce a variety of grades
- Precise control.

Initially, for the bulk production of plain carbon steels, open hearth furnaces were less expensive because of their large size as well as the higher cost of electricity. All these started to change from around 1970, because of the following.

- (i) While the cost of liquid fuels started increasing, electricity generation costs became lower and electricity became comparatively cheaper.
- (ii) Larger and higher power EAFs could be installed because of the progress in electrical engineering and control systems.
- (iii) EAF steelmaking is intrinsically cleaner than open hearth steelmaking.
- (iv) Since EAF steelmaking is predominantly scrap based, smaller plants with lower capital investment and faster attainment of rated capacity could be set up, even compared to BF-BOF based plants.

Therefore, EAFs started gradually replacing BOHs for producing plain carbon steels as well. With EAFs ranging in size from 100 t to 250 t (and even 500 t), there are some plants around the world which are producing 1.5 to 2 Mtpa of steel from 2–3 large electric arc furnaces. This type of growth in EAF steelmaking has resulted in scrap shortage. This has been taken care of by partial substitution of scrap by sponge iron (DRI/HBI) and, in some plants with additional charging of cold pig and hot metal.

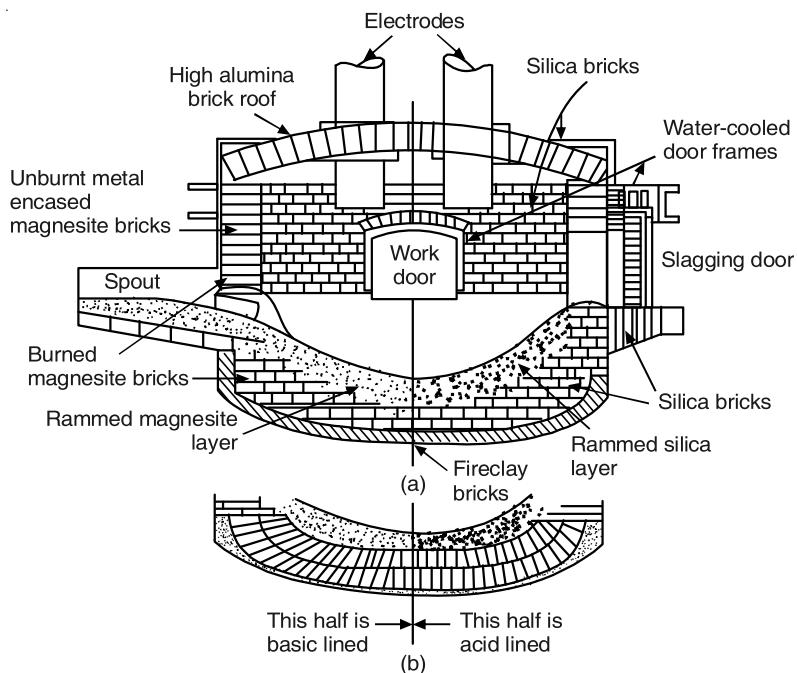
This chapter will cover the production of plain carbon steel in EAFs. Chapter 21 will separately deal with the production of stainless steel. Many books are available on EAF steelmaking: Electric Furnace Steelmaking, ISS; Making Shaping and Treating Steel, 11th ed., Vol. 2; book by Tupkary et al.

## 19.2.2 The Furnace and the Auxiliaries

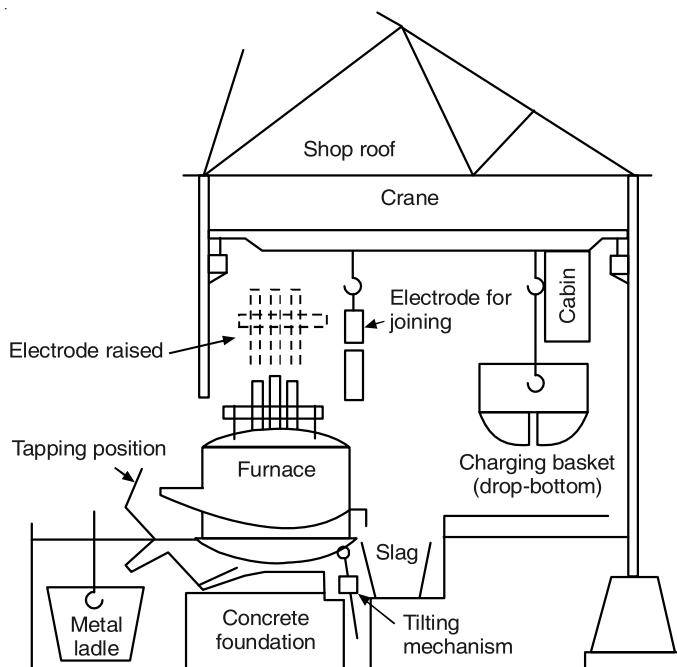
EAF is a *direct arc* furnace, where the arc is struck between the graphite electrodes and the metallic charge/metal bath. The arc temperature is above 4000°C and is used to heat the bath by radiative heat transfer. The traditional power supply is three-phase AC, requiring three electrodes; the modern trend is to go for DC arc.

Figure 19.4 shows the cross section of a conventional EAF. Basic-type electric arc furnaces are employed for steelmaking; hence, the inner lining of the hearth in such furnaces is burnt magnesite. Charging is done from the top, and during charging, the electrodes are lifted up to allow the roof to be swung horizontally to one side, thus providing open access from the furnace top.

Figure 19.5 contains a sketch of a typical EAF shop layout. EAFs can be tilted to one side for metal tapping; slag tapping is carried out through the opposite side slag door, for which the furnace is tilted the other way. The electrodes get worn out and consumed during arcing and before the length of an electrode becomes too small for operation, another electrode is joined to it at the top. In order to do this, each electrode has internal threading at the ends and the threaded ends of the two electrodes are connected by a threaded graphite nipple.



**Figure 19.4** Cross section of an electric arc furnace (both acid and basic lining shown for illustration).



**Figure 19.5** Vertical section of an electric arc furnace shop.