16

BOF Plant Practice

16.1 INTRODUCTION

The modern, high-performance BOF converter is the outcome of continuous developments over the past fifty years. Ever since Voest-Alpine commissioned the first LD converter in 1952 in Linz, Austria (Chapter 3), several improvements have been made to make the process more versatile. The physicochemical principles governing the chemical reactions in BOF and other processes of primary steelmaking have been introduced in Chapter 15. The metallurgical features of BOF steelmaking will be covered in greater detail in Chapter 17. This chapter will discuss some practical aspects of BOF steelmaking, including pre-treatment of hot metal.

16.2 BOF OPERATION

In steelmaking, hot metal containing carbon ranging from 4.0% to 4.5%, 0.4% to 1.5% silicon, manganese varying from 0.15% to 1.5% (sometimes even more), 0.045% to 2.5% phosphorus (normally between 0.060% and 0.250%), and sulphur 0.150% maximum (normally 0.050–0.080%) is refined. In the BOF process, all these impurities are removed virtually to zero levels so that steel of the desired composition can be produced.

The tap-to-tap time of each BOF heat, which is typically around 30–40 minutes in operations today, is sequentially made up of the following:

- Charging of scrap (for which a charging pad is normally provided) and hot metal into the converter using a charging crane with the vessel inclined towards the charging side (5–8 minutes)
- Making the vessel upright, lowering the lance and then beginning oxygen blowing at the desired rate (Mach number 1.8–2.5; flow rate 550–600 Nm^3/min. for a 160–180 t converter) for around 15–20 minutes
- Stopping the blow, raising the lance, and then inclining the vessel again towards the charging side to take a metal sample (if necessary, also a slag sample) to check the bath composition and temperature (6–10 minutes)

- Tapping the vessel by rotating it to the opposite side so that steel flows through the tap hole in the nose portion of the vessel into a ladle kept below the converter floor (4–8 minutes).

During tapping of steel, simultaneous outflow of slag is prevented to the maximum possible extent, by using a pneumatic slag stopper arrangement at the tap hole, or by introducing suitable slag arresting devices into the converter like refractory darts, that are heavier than slag but lighter than steel. Once steel is tapped, the vessel is turned further (almost to 180° from the upright position) so that most of the slag within the converter flows into a slag ladle that is subsequently sent by rail road for cooling. Some slag is often retained for slag splashing (details given later in Section 16.3.1). BOF slags containing 18–22% iron and with high basicity (sometimes, even free lime) are used in sintermaking, or as a soil conditioner for acidic soil.

The exit gas generated during blowing [120–130 Nm^3/tonne liquid steel (tls)], which is rich in CO for up to 90% of the duration of the blow, and contains dust to the extent of 20 kg/tonne liquid steel, is sent to the gas-cleaning plant before it is stored.

16.3 BOF SHOP LAYOUT AND INDIVIDUAL CONVERTER COMPONENTS

Any BOF vessel is equipped with:

- Mechanical rotating device that allows proper positioning of the vessel
- Lance carriage to keep the water-cooled lance in the vertical position
- Nose cone section through which the gases exit
- Tap hole for draining metal/slag
- Overhead bins for adding iron ore, fluxes, slag-forming agents, etc. as required during the blow, into the converter kept in the vertical position.

Figure 16.1 presents a typical layout of a two-converter BOF shop in which at least one converter is always in operation and the other, is either operating or is under relining. The heart of the shop is obviously the converter, which is a cylindrical vessel made of welded steel plates, with refractory lining inside. The entire vessel is supported by a suspension system which transmits the load to the trunnion ring as shown in Figure 16.2. The trunnion ring, in turn, is supported by a trunnion shaft so that the total load of the vessel, including the refractories and molten metal, is transferred to the foundation.

16.3.1 BOF Vessel Design and Refractory Lining

The refractory lining within the converter shell consists of a safety layer and a working layer. It is the working lining that wears out after each campaign that can normally last anywhere between 3000 and 10,000 heats. Sometimes, campaigns can be even longer, particularly when sophisticated refractories like magnesite carbon are used instead of the normal pitch-bonded dolomite or pitch impregnated fired magnesite. At the end of each campaign, the worn-out lining is mechanically dislodged before beginning work on relining *in situ*. Once relining is completed and the refractories are thoroughly dried, the converter is ready for use. This entire relining procedure normally takes 4–5 days.

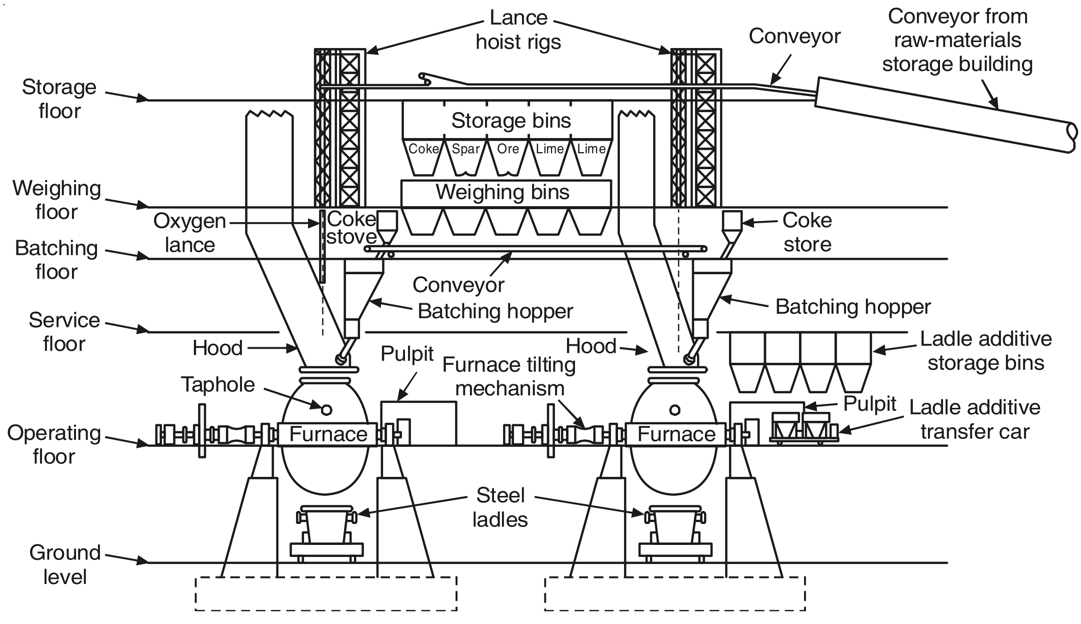

Figure 16.1 Layout of a typical two-converter BOF shop.

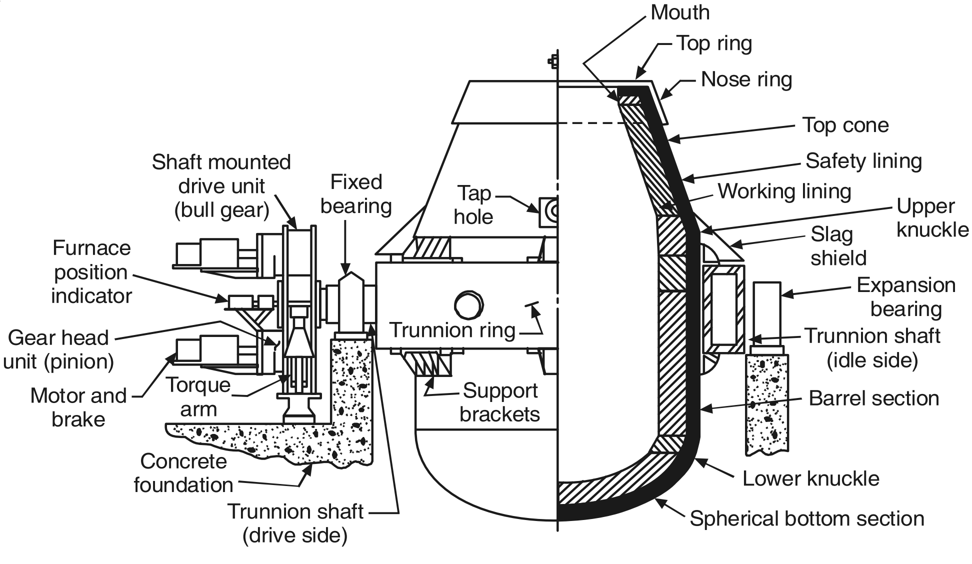

Figure 16.2 Typical components of a BOF vessel.

Since the early 1980s, dramatic improvements have taken place in the length of converter campaigns because of process developments as well as developments in refractory lining technology. This has not only resulted in considerable reduction in the refractory cost per tonne of steel, but has also reduced the downtime. One of the most innovative process improvements that have been made to increase the lining life is slag splashing. Slag splashing, as the name implies, utilises the residual slag from the previous heat to provide a coating on the refractory lining, before the next heat is charged. This is carried out by forcing molten slag by means of high pressure gas into the upper regions of the vessel, where it becomes viscous and gets attached to the converter working lining. This automatically decreases the amount of refractories that are exposed to the refining reactions, and reduces the refractory consumption. The upper sidewalls of the converter where molten slag cannot be deposited are subjected to slag attack in the subsequent heat, as well as to extremes of temperature variations between two heats.

Despite the fact that all BOF vessels have a very large inner volume (0.65–0.70 m^3/tls for 0.4–0.5% silicon hot metal and even more for high silicon hot metal), the converter contents often overflow through the tap hole or get ejected through the mouth opening. This is referred to as *spitting* (for metal droplets) or *slopping* (for slag–metal emulsion). The bath depth is an important parameter that influences the empty space available within any converter to contain spitting/slopping. In such a situation, for a given specific volume of the vessel, the diameter becomes the controlling factor that determines the inner contours of a BOF. However, with increasing wear of the lining, the bath depth can also vary substantially. Therefore, in most BOF shops, the bath depth is measured using the lance assembly at least once every 8 hours.

In combined blown BOF vessels, bottom blowing through tuyeres/canned elements and the resultant bath agitation, contribute to localised wear of the refractory components at the converter bottom. The wear is attributable to turbulent flow of molten metal giving rise to erosion of the refractories as well as to thermal stress caused by the passage of cold gases. High density and low porosity pitch bonded, impregnated magnesite carbon based upon fused magnesia, is the preferred refractory material for lining this portion of the vessel.

16.3.2 The Lance

In BOF steelmaking, oxygen of high purity (at least 99.9% oxygen) is blown at supersonic speed onto the surface of the bath using a vertical lance, inserted through the mouth of the vessel. During the initial stages of development of the BOF process, only single-hole lances were used, but with increasing vessel size, multi-hole lances have come into vogue so that large volumes of oxygen (typically 1000–1200 Nm^3/min. for 160–180 t converters) can be blown within the restricted blowing time of 15–20 minutes.

The use of multi-hole lances reduces the chances of any individual oxygen jet penetrating anywhere near the vessel bottom, since with a larger number of holes, the total jet energy gets dispersed along the diameter of the vessel rather than in the vertical direction. This has also resulted in higher productivity, since more liquid metal is exposed to oxygen. Further, the larger the number of holes in the lance, the faster will be the slag–metal reactions like dephosphorisation. Such reactions can then take place at a greater number of reaction sites.

16.3.3 Gas Cleaning System

Irrespective of the converter size, on an average, 50–60 Nm^3 of oxygen is blown through the lance per tonne of liquid steel. The gas exiting through converter mouth at the rate of 120–130 Nm^3/tls, essentially contains carbon monoxide and carbon dioxide. The gas leaves the

BOF at temperatures close to 1600°C and contains dust particles comprising iron oxides and lime, mainly below 200 mesh size. This gas has to be cooled before it can be cleaned in the gas cleaning plant. The load on the gas cleaning plant is the highest when iron ore is added as a coolant during the blow since the exit gas flow automatically increases owing to the extra oxygen. At such times, the generation of dust also increases, varying between 20 and 30 kg/tls. However, when scrap alone is the coolant, the amount of dust is restricted to 10–25 kg/tls. In some cases, hazardous pollutants like cadmium, chromium, lead, manganese, and nickel may also be present. Zinc compounds are present in BOF fume in varying amounts, if process scrap containing zinc is charged.

Carbon monoxide in the gas is partly burnt to CO_2 at the converter mouth. The remainder of the combustible gases is extracted at a largely constant air ratio, by using a hood pressure control device. Positive gas routing to avoid explosions then becomes a basic requirement for any gas-cleaning equipment. If the proper system is chosen and operated efficiently, it is possible to recover about 9600 kJ of energy per tonne of liquid steel from the waste gas. Through heat recovery in the waste gas cooling system, 210–215 kJ of additional energy per tonne of liquid steel can be recovered, i.e. 90% of the total energy content in the waste gas is recoverable.

The equipment used for gas cleaning and dust collection include: a quencher for cooling, venturi-type washer and cooling tower in series for dust extraction, and a clarifier or thickening basin for handling water containing dust that settles as sludge. Clean water leaving the clarifier contains less than 0.25 g solids per litre of water, and the clean gas stored in the gas holder contains a maximum of 1.6 g of solids per cubic metre.

16.3.4 Engineering Features of BOF Shops

The success of any BOF shop operation is heavily dependent on proper utilisation of the space available, so that efficient and economical flow of materials to/from/in the shop can be ensured. This calls for careful plant engineering, taking factors like logistics, complexity, time required for each operation, etc. into consideration.

All the inputs used in BOFs, viz. molten iron, steel scrap, and fluxes enter from one end of the shop. The fluxes are handled by conveyors and stored in bins above the converters. Molten iron arrives in torpedo ladle cars and is then poured into transfer ladles (sent for desulphurisation and slag removal when necessary) before charging into the converter, using the charging-side overhead crane. Steel scrap (normally 10–15% of the total charge), collected either in-house or purchased from external sources, is filled in scrap boxes and charged first into the BOF using the same overhead charging crane. In some cases, hot metal coming from the blast furnaces is stored in a mixer (a barrel-shaped, cylindrical, refractory-lined vessel of 1000–1500 tonnes capacity) located at the entry-end of the BOF shop. The mixer serves dual purposes, viz. as a storage vessel as well as means for mixing successive lots of hot metal coming from blast furnaces. In this way, the chemical composition of the hot metal charged can be made more uniform. Although hot metal mixers were earlier always an integral part of any steel melting shop, with the advent of large capacity torpedo ladles, they are now seldom utilised since torpedo ladles serve as 'mini' mixers.

16.4 REFINING

In Chapters 17 and 18, the details of the metallurgical features and process control in basic oxygen steelmaking will be presented. Hence in this section, only a brief outline is given.

During refining, controlled oxidation of the impurities in hot metal (with the exception of sulphur) takes place once oxygen is blown at supersonic speeds (Appendix II contains more details of supersonic jets and their relevance to BOF steelmaking) onto the liquid bath. The interaction of the oxygen jet(s) with the bath produces crater(s) on the surface, from the outer lip(s) of which, a large number of tiny metal droplets get splashed. These droplets reside for a short time in the slag above the bath. Therefore, the existence of a metal–slag–gas emulsion within the vessel, virtually during the entire blowing/refining period is an integral part of BOF steelmaking. This is the reason why the slag–metal reactions like dephosphorisation and gas–metal reactions like decarburisation proceed so rapidly in the BOF process (earlier, it was erroneously believed that the existence of a high temperature, 2500–2600°C, zone on the bath surface was responsible for the high rates of reactions). The droplets ultimately return to the metal bath. The extent of emulsification varies at different stages of the blowing period, as depicted schematically in Figure 16.3.

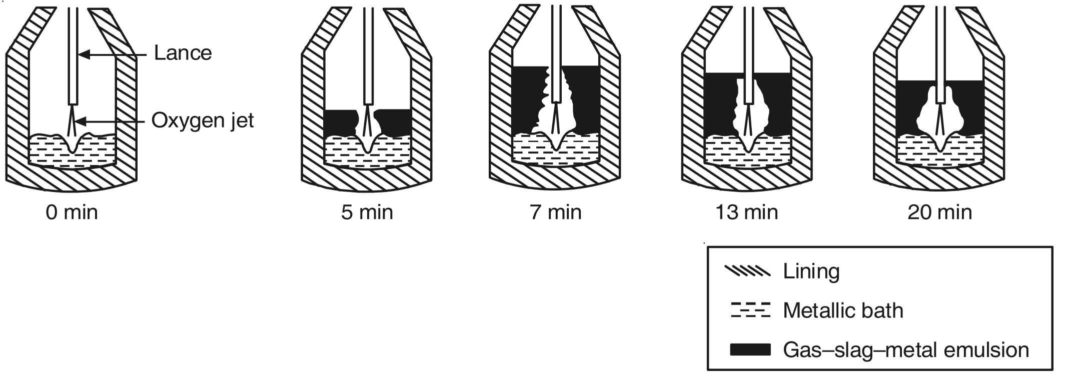

Figure 16.3 Schematic representation of the bath conditions within a BOF at various stages of the blow.

A minimum amount of slag, with the desired characteristics, is necessary for ensuring that the emulsion is stable, i.e. the slag should not be too viscous, or too 'watery'. Only in this way can the kinetics of the removal of the impurities be enhanced. For encouraging quick formation of the appropriate type of slag, lime/dolomite/other fluxing agents with adequate *reactivity* are added right from the beginning of the blow. The reactivity of the fluxing agents, primarily lime (consumption 60–100 kg/tls), determines how quickly slag is formed (typically within 4–5 minutes after the commencement of the blow). The rate at which oxygen is blown through the lance, the number of openings (holes) on the lance tip, the distance between the lance tip and the bath surface (lance height), the characteristics of the oxygen jets as they impinge on the bath surface, the volume, basicity and fluidity of the slag, the temperature conditions in the bath, and many other operational variables influence the rate of refining. In most cases, to encourage slag formation a high lance height (1.5 – 2.0 m) is used at the beginning of the blow, and then the lance is lowered (0.8 – 1.2 m) for decarburisation.

The basic design of the converter, the extent of combustion of waste gases, the total blowing time, characteristics of the slag during the entire blowing period, post-blow operations (if any), etc. have a profound influence on the composition and the temperature of the bath at the end of refining. If the desired end-point, in terms of composition and/or temperature, is not reached (i.e. the *hit rate* is suboptimal), oxygen has to be blown again—this is referred as *reblowing*. Hit rates of 88–92% can be achieved if adequate process control measures are adopted.

In order to withdraw a sample to check the bath composition/temperature, the blow has to be temporarily suspended, the lance withdrawn, and then a spoon inserted after inclining the converter in such a way that the bath becomes horizontal. Once the sample is taken, the vessel is made upright before resuming blowing. This is a time-taking procedure. To avoid such delays, most modern BOF shops are equipped with a *sublance*. The sublance is an inclined lance positioned next to the oxygen lance, which can be mechanically lowered into the bath to collect metal/slag sample and measure the bath temperature, keeping the converter in the vertical position. Solid probes attached to the sublance tip are used for this purpose. They have to be renewed after each dip, and can add to costs since they are quite expensive.

16.5 MAJOR INPUTS FOR BOF STEELMAKING

16.5.1 Hot Metal

Hot metal quality is clearly of prime importance in BOF steelmaking. The importance becomes more when high *hot metal ratios* (the proportion of hot metal in the total charge) of the order of 95 – 99% are used. The reverse is true when scrap (or other coolants) is abundantly available and the hot metal ratio is intentionally lowered to 70 – 75%. The subject of hot metal composition has already been discussed in Chapter 11 and will not be elaborated further. However, another characteristic of hot metal, viz. its temperature is also of significance in BOF steelmaking. The hot metal temperature has to be high enough to permit easy transfer from the torpedo ladles to the transfer ladle, efficient pre-treatment without giving rise to problems like skull formation on the injection lance, smooth charging into the BOF, etc.

16.5.2 Coolants

In determining the amount of solid charge used in a BOF at any point of time, the primary factors are cost/availability of hot metal, cost/availability of scrap or iron oxide (both are coolants) and the amount of fluxes required. The physical condition of all these solids is also important, since it influences their melting rate during the progress of the blow.

The quality and the composition of scrap are of particular significance in achieving the final composition of the steel tapped. If the scrap charged contains elements like copper, tin and nickel, these elements do not get removed as oxides, and the metals report to steel, resulting even in off-grade products. Another area of concern is the degree of oxidation of the scrap, which may have a significant influence on the *charge balance* (proportion of liquid to solid charge), since