Chapter 9

Oxygen Steelmaking Processes

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9.1 Introduction

9.1.1 Process Description and Events

The oxygen steelmaking process rapidly refines a charge of molten pig iron and ambient scrap into steel of a desired carbon and temperature using high purity oxygen. Steel is made in discrete batches called heats. The furnace or converter is a barrel shaped, open topped, refractory lined vessel that can rotate on a horizontal trunnion axis. The basic operational steps of the process (BOF) are shown schematically in Fig. 9.1.

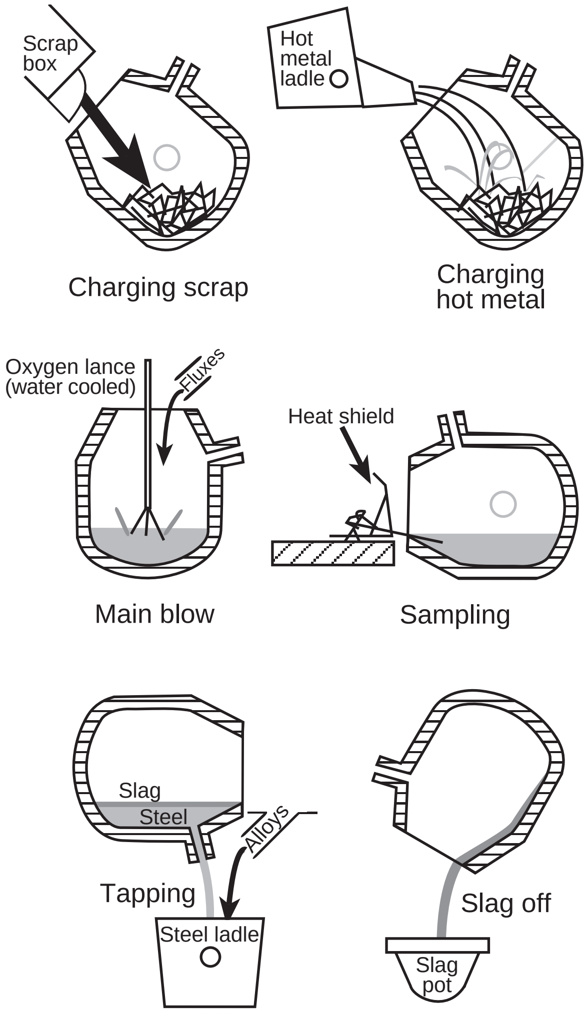

Fig. 9.1 Schematic of operational steps in oxygen steelmaking process (BOF).

The overall purpose of this process is to reduce the carbon from about 4% to less than 1% (usually less than 0.1%), to reduce or control the sulfur and phosphorus, and finally, to raise the temperature of the liquid steel made from scrap and liquid hot metal to approximately 1635°C (2975°F). A typical configuration is to produce a 250 ton (220 metric ton) heat about every 45 minutes, the range is approximately 30 to 65 minutes. The major event times for the process are summarized below in Table 9.1.

These event times, temperatures, and chemistries vary considerably by both chance and intent. The required quantities of hot metal, scrap, oxygen, and fluxes vary according to their chemical compositions and temperatures, and to the desired chemistry and temperature of the steel to be tapped. Fluxes are minerals added early in the oxygen blow, to control sulfur and phosphorous and to control erosion of the furnace refractory lining. Input process variations such as analytical (hot metal, scrap, flux and alloy) and measurement (weighing and temperature) errors contribute to the chemical, thermal and time variations of the process.

Table 9.1 Basic Oxygen Steelmaking Event Times

Event	Min.	Comments
Charging scrap and hot metal	5–10	Scrap at ambient temperature, hot metal at 1340°C (2450°F)
Refining–*blowing* oxygen	14–23	Oxygen reacts with elements, Si, C, Fe, Mn, P in scrap and hot metal and flux additions to form a slag
Sampling–chemical testing	4–15	Steel at 1650°C (3000°F), chemistry and temperature
Tapping	4–8	Steel is poured from furnace into a ladle, typical size = 250 tons
Pouring *slag off* at furnace	3–9	Most slag is removed from furnace, in some shops slag is used to coat furnace walls

The energy required to raise the fluxes, scrap and hot metal to steelmaking temperatures is provided by oxidation of various elements in the charge materials. The principal elements are iron, silicon, carbon, manganese and phosphorous. The liquid pig iron or hot metal provides almost all of the silicon, carbon, manganese and phosphorous, with lesser amounts coming from the scrap. Both the high temperatures of the liquid pig iron and the intense stirring provided when the oxygen jet is introduced, contribute to the fast oxidation (burning or combustion) of these elements and a resultant rapid, large energy release. Silicon, manganese, iron and phosphorous form oxides which in combination with the fluxes, create a liquid slag. The vigorous stirring fosters a speedy reaction and enables the transfer of energy to the slag and steel bath. Carbon, when oxidized, leaves the process in gaseous form, principally as carbon monoxide. During the blow, the slag, reaction gases and steel (as tiny droplets) make up a foamy emulsion. The large surface area of the steel droplets, in contact with the slag, at high temperatures and vigorous stirring, allow quick reactions and rapid mass transfer of elements from metal and gas phases to the slag. When the blow is finished the slag floats on top of the steel bath.

Controlling sulfur is an important goal of the steelmaking process. This is accomplished by first removing most of it from the liquid hot metal before charging and later, inside the furnace, by controlling the chemical composition of the slag with flux additions.

9.1.2 Types of Oxygen Steelmaking Processes

There are basically three variations of introducing oxygen gas into the liquid bath. These are shown schematically in Fig. 9.2. Each of these configurations has certain pros and cons. The most common configuration is the **top-blown** converter (BOF), where all of the oxygen is introduced via a water-cooled lance. The blowing end of this lance features three to five special nozzles that deliver the gas jets at supersonic velocities. In top blowing, the stirring created by these focused, supersonic jets cause the necessary slag emulsion to form and keeps vigorous bath flows to sustain the rapid reactions. The lance is suspended above the furnace and lowered into it. Oxygen is turned on as the lance moves into the furnace. Slag forming fluxes are added from above the furnace via a chute in the waste gas hood. A process description is in Section 9.4 of this chapter.

In the **bottom-blown** converters (OBM or Q-BOP), oxygen is introduced via several tuyeres installed in the bottom of the vessel, Fig. 9.2. Each tuyere consists of two concentric pipes with the oxygen passing through the center pipe and a coolant hydrocarbon passing through the annulus between the pipes. The coolant is usually methane (natural gas) or propane although some shops have used fuel oil. The coolant chemically decomposes when introduced at high temperatures and absorbs heat in the vicinity, thus protecting the tuyere from overheating. In bottom blowing, all of the oxygen is introduced through the bottom, and passes through the bath and slag thus creating vigorous bath stirring and formation of a slag emulsion. Powdered fluxes are introduced into the bath through the tuyeres located in the bottom of the furnace. The first part of Section 9.5 is a process description of the OBM (Q-BOP).

The **combination blowing** or **top and bottom blowing**, or **mixed blowing** process (Fig. 9.2 shows these variants) is characterized by both a top blowing lance and a method of achieving stirring from the bottom. The configurational differences in mixed blowing lie principally in the bottom tuyeres or elements. These range from fully cooled tuyeres, to uncooled tuyeres, to permeable elements. Section 9.5 summarizes further details about combination blowing processes.

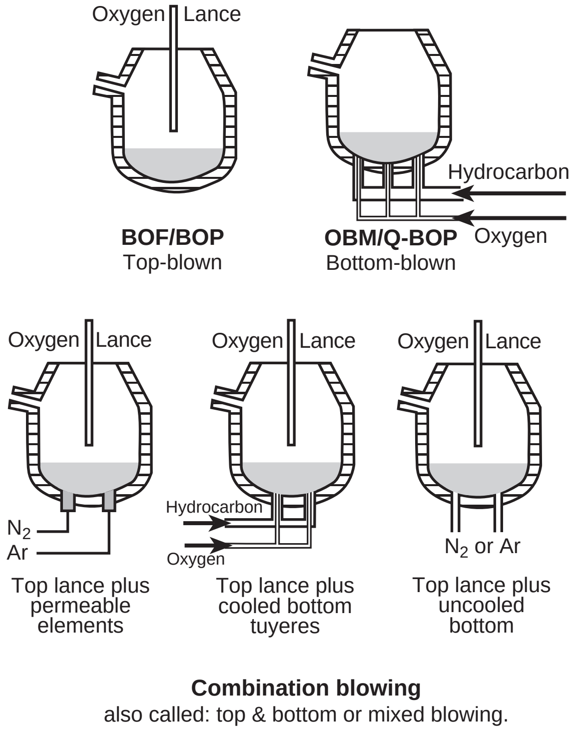

Fig. 9.2 Methods of introducing oxygen and other gases into the steelmaking converter.

9.1.3 Environmental Issues

The oxygen steelmaking process is characterized by several pollution sources and most require emission control equipment. These sources are: hot metal transfer, hot metal desulfurization and skimming of slag, charging of hot metal, melting and refining (blowing), BOF tapping, handling of dumped BOF slag, handling of fluxes and alloys, and maintenance (burning of skulls, ladle dumping. etc). Thus, compliance to emission standards is an important design and operating cost factor for the operation.

9.1.4 How to Use This Chapter

The process falls into several basic component parts which determine important control and economic parameters. Accordingly, this chapter is organized into the process component headings of Sequence of Operations, Raw Materials, Process Reactions and Energy Balance, Variations of the Process, Process Control Strategies, and Environmental Issues.

The use of this chapter depends on your level of knowledge and interest in the details. It is geared to bring together several more detailed chapters, such as furnace design, refractory practices, oxygen lance design and physiochemical principles, and to describe how these underlying factors contribute to the oxygen steelmaking process. If you are a steelmaking novice, reading this chapter first is a good way to get a brief, yet coherent description of the process. Once you have the big picture, then it is easier to focus on the chapters on detailed design and first principles. If you are more experienced and want to review or deal with a specific issue, you may turn directly to one of the component sections or to one of the underlying principle chapters.

A note on References: The material for this chapter is an assimilation of many different sources. For continuity, rather than specifically cite every source, the references are listed at the end of the chapter both as a source acknowledgment and as a supplemental reading list. This list is organized in the same chapter section format. The references are numbered for citing figures and tables.

9.2 Sequence of Operations—Top Blown

9.2.1 Plant Layout

To understand the sequence of the oxygen steelmaking process, one must examine the design, layout and materials flow of the facilities. Figs. 9.3, 9.4 and 9.5 show a 275-ton BOF that illustrates the process. Shops vary considerably in basic layout. Reasons for these layout differences are: type of product (ingots, cast product or both), the parent company's operating and engineering culture, the relationship of the infrastructure and material flows to the rest of the plant, and age of the facility. (Is the plant an updated older facility or a new greenfield site?) Flow of materials plays a key role in the design of the shop. Handling of raw materials (scrap, hot metal, fluxes, alloys, refractories), oxygen lances in-and-out, slag handling, gas cleaning, and transport of steel product must be accomplished smoothly with minimum delays and interference.

Fig. 9.3 is a plan view of a two-furnace shop and Fig. 9.4 is an elevation of the same plant but looking to the west. Figure 9.5 is an elevation looking to the north. BOFs, OBMs (Q-BOPs) and other variants can have similar layouts except for oxygen conveying and flux handling details. All shops feature transportation systems for hot metal and scrap.

9.2.2 Sequence of Operations

9.2.2.1 Scrap Handling

Scrap for a heat is ordered and prepared well in advance of actually charging the furnace. It is selected according to size and quality and then is brought into the plant via railroad cars, usually gondolas. It is loaded and mixed into an open ended scrap box which sits on a transfer car. Loading the box is usually done by magnet or grapple crane in a remote area from the shop. The box/car is frequently weighed during loading. Some shops use a crane scale to weigh and accumulate each magnet load. Weights are entered into the shop computer when the loading is completed. The transfer of scrap from rail cars to charging box is done in an attached bay to the BOF shop which is large enough to handle eight to 24 hours of scrap supply. The scrap box is then conveyed by rail to the charging aisle. A few shops use rubber tired platform carriers rather than rail cars to move the scrap box into the shop.

9.2.2.2 Hot Metal Pouring

The hot metal system consists of a track(s) and one to three pouring stations. The liquid pig iron arrives from the blast furnace in a train of torpedo shaped, refractory lined railroad cars called submarines (subs) or torpedoes. Each car is positioned over a track scale and weighed prior to pouring. There is a trunnion at each end of the car which allows the operator to rotate the open top toward a transfer ladle located in an adjacent pit. Generally, it takes one or two subs to fill the hot metal transfer ladle. The control room or operator's pulpit is equipped with controls for rotating the sub, operating the ladle transfer car, reading scales, taking temperatures, desulfurization equipment, and sending samples to a chemistry lab. The pouring operation, which generates considerable dust emissions, is accomplished under an enclosed hood equipped with an evacuation system and a baghouse. The dust generated at pouring, called kish, is mainly fine flaked graphite which precipitates from the carbon saturated metal as its temperature drops during pouring. The poured weights and measured temperatures are entered into the shop process control computer.

9.2.2.3 Hot Metal Treatment

The hot metal transfer ladle sits on a transfer car at the outside wall of the charging aisle, usually out of the crane's reach. Here many shops treat the hot metal by injecting a mixture of lime and magnesium to remove sulfur. This process is called hot metal desulfurization. During hot metal treatment, sulfur is removed from approximately 0.025 wt% to as low as 0.002 wt% and the time of injection will range from five to twenty minutes. A gas collecting and filtration system collects the fumes from