

# Chapter 1

# Overview of Steelmaking Processes and Their Development

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## 1.1 Introduction

This volume examines the basic principles, equipment and operating practices involved in steelmaking and refining. In this introductory chapter the structure of this volume is briefly described. Also the evolution of steelmaking processes from about 1850 to the present is given along with statistics on current production by process and speculation on future trends.

For the purpose of this volume steelmaking can be roughly defined as the refining or removal of unwanted elements or other impurities from hot metal produced in a blast furnace or similar process or the melting and refining of scrap and other forms of iron in a melting furnace, usually an electric arc furnace (EAF). Currently most all of the hot metal produced in the world is refined in an oxygen steelmaking process (OSM). A small amount of hot metal is refined in open hearths, cast into pigs for use in an EAF or refined in other processes. The major element removed in OSM is carbon which is removed by oxidation to carbon monoxide (CO). Other elements such as silicon, phosphorous, sulfur and manganese are transferred to a slag phase. In the EAF steelmaking process the chemical reactions are similar but generally less extensive.

After treating the metal in an OSM converter or an EAF it is further refined in the ladle. This is commonly called secondary refining or ladle metallurgy and the processes include deoxidation, desulfurization and vacuum degassing. For stainless steelmaking the liquid iron-chromium-nickel metal is refined in an argon-oxygen decarburization vessel (AOD), a vacuum oxygen decarburization vessel (VOD) or a similar type process.

In this volume the fundamental physical chemistry and kinetics relevant to the production of iron and steel is reviewed. Included are the critical thermodynamic data and other data on the properties of iron alloys and slags relevant to iron and steelmaking. This is followed by chapters on the support technologies for steelmaking including fuels and water, the production of industrial gases and the fundamentals and application of refractories. This volume then describes and analyzes the individual refining processes in detail including hot metal treatments, oxygen steelmaking, EAF steelmaking, AOD and VOD stainless steelmaking and secondary refining. Finally future alternatives to oxygen and EAF steelmaking are examined.

## 1.2 Historical Development of Modern Steelmaking

In the 10th edition of *The Making Shaping and Treating of Steel*<sup>1</sup> there is an excellent detailed review of early steelmaking processes such as the cementation and the crucible processes. A new discussion of these is not necessary. The developments of modern steelmaking processes such as

the Bessemer, open hearth, oxygen steelmaking and EAF have also been chronicled in detail in the 10th edition. In this volume only a summary of these processes is given. For more details the reader is referred to the 10th edition or the works of W.T. Hogan<sup>2,3</sup>.

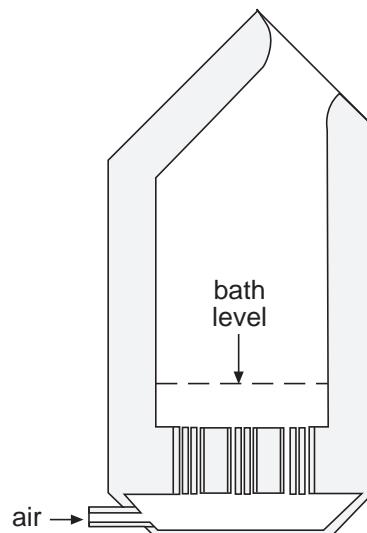
### 1.2.1 Bottom-Blown Acid or Bessemer Process

This process, developed independently by William Kelly of Eddyville, Kentucky and Henry Bessemer of England, involved blowing air through a bath of molten pig iron contained in a bottom-blown vessel lined with acid (siliceous) refractories. The process was the first to provide a large scale method whereby pig iron could rapidly and cheaply be refined and converted into liquid steel. Bessemer's American patent was issued in 1856; although Kelly did not apply for a patent until 1857, he was able to prove that he had worked on the idea as early as 1847. Thus, both men held rights to the process in this country; this led to considerable litigation and delay, as discussed later. Lacking financial means, Kelly was unable to perfect his invention and Bessemer, in the face of great difficulties and many failures, developed the process to a high degree of perfection and it came to be known as the acid Bessemer process.

The fundamental principle proposed by Bessemer and Kelly was that the oxidation of the major impurities in liquid blast furnace iron (silicon, manganese and carbon) was preferential and occurred before the major oxidation of iron; the actual mechanism differs from this simple explanation, as outlined in the discussion of the physical chemistry of steelmaking in Chapter 2. Further, they discovered that sufficient heat was generated in the vessel by the chemical oxidation of the above elements in most types of pig iron to permit the simple blowing of cold air through molten pig iron to produce liquid steel without the need for an external source of heat. Because the process converted pig iron to steel, the vessel in which the operation was carried out came to be known as a converter. The principle of the bottom blown converter is shown schematically in Fig. 1.1.

At first, Bessemer produced satisfactory steel in a converter lined with siliceous (acid) refractories by refining pig iron that, smelted from Swedish ores, was low in phosphorus, high in manganese, and contained enough silicon to meet the thermal needs of the process. But, when applied to irons which were higher in phosphorus and low in silicon and manganese, the process did not produce satisfactory steel. In order to save his process in the face of opposition among steelmakers, Bessemer built a steel works at Sheffield, England, and began to operate in 1860. Even when low phosphorus Swedish pig iron was employed, the steels first produced there contained much more than the admissible amounts of oxygen, which made the steel "wild" in the molds. Difficulty also was experienced with sulfur, introduced from the coke used as the fuel for melting the iron in cupolas, which contributed to "hot shortness" of the steel. These objections finally were overcome by the addition of manganese in the form of spiegeleisen to the steel after blowing as completed.

The beneficial effects of manganese were disclosed in a patent by R. Mushet in 1856. The carbon and manganese in the spiegeleisen served the purpose of partially deoxidizing the steel, which part



**Fig. 1.1** Principle of the bottom blown converter. The blast enters the wind box beneath the vessel through the pipe indicated by the arrow and passes into the vessel through tuyeres set in the bottom of the converter.

of the manganese combined chemically with some of the sulfur to form compounds that either floated out of the metal into the slag, or were comparatively harmless if they remained in the steel.

As stated earlier, Bessemer had obtained patents in England and in this country previous to Kelly's application; therefore, both men held rights to the process in the United States.

The Kelly Pneumatic Process Company had been formed in 1863 in an arrangement with William Kelly for the commercial production of steel by the new process. This association included the Cambria Iron Company; E.B.Ward; Park Brothers and Company; Lyon, Shord and Company; Z.S. Durfee and , later, Chouteau, Harrison and Vale. This company, in 1864, built the first commercial Bessemer plant in this country, consisting of a 2.25 metric ton (2.50 net ton) acid lined vessel erected at the Wyandotte Iron Works, Wyandotte, Michigan, owned by Captain E.B. Ward. It may be mentioned that a Kelly converter was used experimentally at the Cambria Works, Johnstown, Pennsylvania as early as 1861.

As a result of the dual rights to the process a second group consisting of Messrs. John A. Griswold and John F. Winslow of Troy, New York and A. L. Holley formed another company under an arrangement with Bessemer in 1864. This group erected an experimental 2.25 metric ton (2.50 net ton) vessel in Troy, New York which commenced operations on February 16, 1865. After much litigation had failed to gain for either sole control of the patents for the pneumatic process in America, the rival organizations decided to combine their respective interests early in 1866. This larger organization was then able to combine the best features covered by the Kelly and Bessemer patents, and the application of the process advanced rapidly.

By 1871, annual Bessemer steel production in the United States had increased to approximately 40,800 metric tons (45,000 net tons), about 55% of the total steel production, which was produced by seven Bessemer plants.

Bessemer steel production in the United States over an extended period of years remained significant; however, raw steel is no longer being produced by the acid Bessemer process in the United States. the last completely new plant for the production of acid Bessemer steel ingots in the United States was built in 1949.

As already stated, the bottom blown acid process known generally as the Bessemer Process was the original pneumatic steelmaking process. Many millions of tons of steel were produced by this method. From 1870 to 1910, the acid Bessemer process produced the majority of the world's supply of steel.

The success of acid Bessemer steelmaking was dependent upon the quality of pig iron available which, in turn, demanded reliable supplies of iron ore and metallurgical coke of relatively high purity. At the time of the invention of the process, large quantities of suitable ores were available, both abroad and in the United States. With the gradual depletion of high quality ores abroad (particularly low phosphorus ores) and the rapid expansion of the use of the bottom blown basic pneumatic, basic open hearth and basic oxygen steelmaking processes over the years, acid Bessemer steel production has essentially ceased in the United Kingdom and Europe.

In the United States, the Mesabi Range provided a source of relatively high grade ore for making iron for the acid Bessemer process for many years. In spite of this, the acid Bessemer process declined from a major to a minor steelmaking method in the United States and eventually was abandoned.

The early use of acid Bessemer steel in this country involved production of a considerable quantity of rail steel, and for many years (from its introduction in 1864 until 1908) this process was the principal steelmaking process. Until relatively recently, the acid Bessemer process was used principally in the production of steel for buttwelded pipe, seamless pipe, free machining bars, flat rolled products, wire, steel castings, and blown metal for the duplex process.

Fully killed acid Bessemer steel was used for the first time commercially by United States Steel Corporation in the production of seamless pipe. In addition, dephosphorized acid Bessemer steel was used extensively in the production of welded pipe and galvanized sheets.

## 1.2.2 Basic Bessemer or Thomas Process

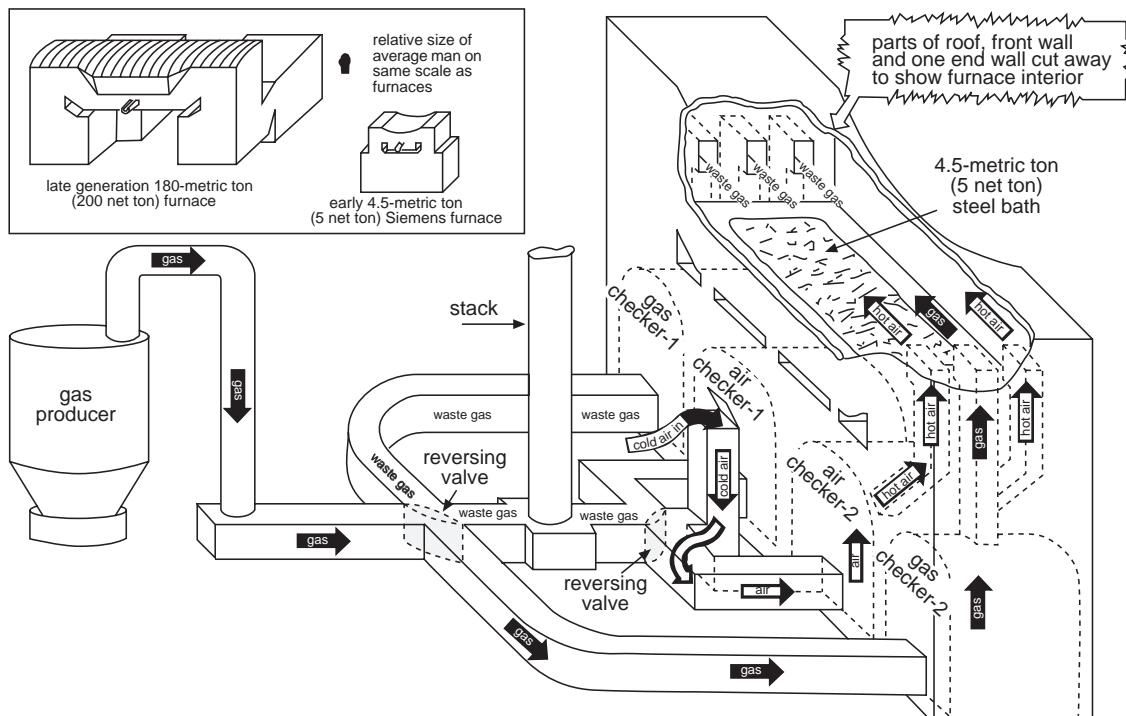
The bottom blown basic pneumatic process, known by several names including Thomas, Thomas-Gilchrist or basic Bessemer process, was patented in 1879 by Sidney G. Thomas in England. The process, involving the use of the basic lining and a basic flux in the converter, made it possible to use the pneumatic method for refining pig irons smelted from the high phosphorus ores common to many sections of Europe. The process (never adopted in the United States) developed much more rapidly in Europe than in Great Britain and, in 1890, European production was over 1.8 million metric tons (2 million net tons) as compared with 0.36 million metric tons (400,000 net tons) made in Great Britain.

The simultaneous development of the basic open hearth process resulted in a decline of production of steel by the bottom blown basic pneumatic process in Europe and, by 1904, production of basic open hearth steel there exceeded that of basic pneumatic steel. From 1910 on, the bottom blown basic pneumatic process declined more or less continuously percentage-wise except for the period covering World War II, after which the decline resumed.

## 1.2.3 Open Hearth Process

Karl Wilhelm Siemens, by 1868, proved that it was possible to oxidize the carbon in liquid pig iron using iron ore, the process was initially known as the "pig and ore process."

Briefly, the method of Siemens was as follows. A rectangular covered hearth was used to contain the charge of pig iron or pig iron and scrap. (See Fig. 1.2) Most of the heat required to promote the chemical reactions necessary for purification of the charge was provided by passing



**Fig. 1.2** Schematic arrangement of an early type of Siemens furnace with about a 4.5 metric ton (5 net ton) capacity. The roof of this design (which was soon abandoned) dipped from the ends toward the center of the furnace to force the flame downward on the bath. Various different arrangements of gas and air ports were used in later furnaces. Note that in this design, the furnace proper was supported on the regenerator arches. Flow of gas, air and waste gases were reversed by changing the position of the two reversing valves. The inset at the upper left compares the size of one of these early furnaces with that of a late generation 180 metric ton (200 net ton) open hearth.