普通高等教育“十三五”规划教材
PUTONG GAODENG JIAOYU “13·5” GUIHUA JIAOCAI

冶金工程专业英语

炼钢篇

Specialized English in Metallurgical Engineering

Steelmaking Section

孙立根　主编

冶金工业出版社
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北　京
冶　金　工　业　出　版　社
2017

内 容 提 要

本书共5章，主要内容包括现代炼钢技术发展历程、钢铁冶金的基础理论、铁水预处理工艺、氧气转炉炼钢工艺和电炉炼钢技术。

本书以讲授包括铁水预处理在内的炼钢工艺为主，同时介绍了钢铁冶金，特别是炼钢环节涉及的基础理论，以满足不同层次学生学习的需要。

本书可作为高等院校冶金工程等专业的专业英语教材（配有教学课件），所介绍内容能够满足本科生和研究生的教学要求，同时也可供从事相关专业的工程技术人员和管理人员参考。

图书在版编目(CIP)数据

冶金工程专业英语．炼钢篇/孙立根主编．—北京：冶金工业出版社，2017.8

普通高等教育“十三五”规划教材

ISBN 978-7-5024-7568-0

Ⅰ.①冶…　Ⅱ.①孙…　Ⅲ.①冶金工业—英语—高等学校—教材　Ⅳ.①TF

中国版本图书馆CIP数据核字（2017）第136436号

出 版 人　谭学余

地　　址　北京市东城区嵩祝院北巷39号　邮编　100009　电话　(010)64027926

网　　址　www.cnmip.com.cn　电子信箱　yjcbs@cnmip.com.cn

责任编辑　杜婷婷　美术编辑　彭子赫　版式设计　孙跃红

责任校对　郑　娟　责任印制　牛晓波

ISBN 978-7-5024-7568-0

冶金工业出版社出版发行；各地新华书店经销；三河市双峰印刷装订有限公司印刷

2017年8月第1版，2017年8月第1次印刷

787mm×1092mm　1/16；12.5印张；301千字；189页

36.00元

冶金工业出版社　投稿电话　(010)64027932　投稿信箱　tougao@cnmip.com.cn

冶金工业出版社营销中心　电话　(010)64044283　传真　(010)64027893

冶金书店　地址　北京市东四西大街46号(100010)　电话　(010)65289081(兼传真)

冶金工业出版社天猫旗舰店　yjgycbs.tmall.com

前　言

炼钢是钢铁冶炼过程的核心模块之一，也是高等院校冶金工程专业学生必须掌握的知识环节。随着我国国民经济的快速发展和国际交流步伐的加快，专业英语已成为学生大学阶段专业知识学习的重要组成部分，但目前专业英语教材建设相对滞后。因此，作者团队依据课程教学大纲，在多年讲授冶金工程专业英语课程和相关领域课程的基础上，参考英文书籍，编写了本书。

本书作为《冶金工程专业英语》系列教材之一，重点讲授了包括铁水预处理在内的炼钢工艺，同时还讲解了钢铁冶金，特别是炼钢环节涉及的基础理论。本书可以有效帮助学生提高查阅专业英文文献的阅读效率，同时对提升学生与国外同行专家进行技术交流的表达能力也会有很大帮助。

本书共5章。第1章现代炼钢技术发展历程，重点讲述不同类型炼钢工艺的发展历程。第2章钢铁冶金的基础理论，重点介绍了炼钢环节涉及的基本冶金反应原理。第3章铁水预处理工艺，重点介绍了铁水预脱硫工艺。第4章氧气转炉炼钢工艺，围绕转炉操作、原料、炉内反应和能量守恒、冶炼参数控制以及排放物等进行了详细的阐述。第5章电炉炼钢技术，从电炉冶炼工艺出发，阐述了电炉原料、造渣料、电炉操作和废钢熔化工艺等电炉冶炼的关键环节。

在本书编写过程中，除编写团队外，郝剑桥、刘云松等研究生为书中图表的整理和编辑做了大量工作，在此表示诚挚的感谢。

本书配套教学课件读者可在冶金工业出版社官网（http：//www. cnmip. com. cn）输入书名搜索资源并下载。

由于作者水平所限，书中不妥之处，恳请读者批评指正。

作　者

2017年5月

Preface

Steelmaking is one of the core modules for iron and steelmaking process, and it is also the key knowledge which must be mastered by the metallurgical engineering students in colleges and universities. With the rapid development of China' s national economy and the big pace of international exchanges, the specialized English has become an important part of the professional knowledge for university students, but at present, the development of specialized English textbooks is lagging behind relatively. According to the course syllabus, referring to the classical English references, and based on the abundant teaching experiences of metallurgical engineering English courses and other related courses, the author team redacted this textbook.

As one of the series of "specialized English in metallurgical engineering" textbooks, the steelmaking technology which is also included the pre-treatment of hot me-tal, and the fundamentals for steelmaking had been focused on in this book. This book can effectively help students improve the reading efficiency of professional English references, and is also helpful to enhance the ability of students to communicate with foreign counterparts.

There are 5 chapters in this book. Chapter 1 is the historical development of modern steelmaking, and focus on the development of different types of steelmaking process. Chapter 2 is the fundamentals of iron and steelmaking, and focus on the basic metallurgical reaction principle involved in steelmaking. Chapter 3 is the pre-treatment of hot metal, and focus on the pre-desulphurization process of molten iron. Chapter 4 is the oxygen steelmaking processes, and focus on the converter operation, raw material, reaction in the furnace and energy conservation, smelting parameter control and emissions control. Chapter 5 is the electric furnace steelmaking, and focus on the electric furnace smelting technology, including raw materials, slagging materials, electric furnace operation and scrap melting process.

In the preparation of this book, beside the author team, the graduate students Hao Jianqiao, Liu Yunsong etc. had done a lot of work for chart finishing and editing in this book, authors would like to express our sincere thanks to them.

The teaching courseware affiliated to this book could be downloaded from the Metallurgical Industry Press official website (http://www.cnmip.com.cn).

For the author's limited knowledge, if there are inappropriate contents in the book, please tell us to correct, thanks.

The authors
May 2017

Contents

1 Historical Development of Modern Steelmaking

1.1 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, and the actual mechanism differs from this simple explanation. 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.

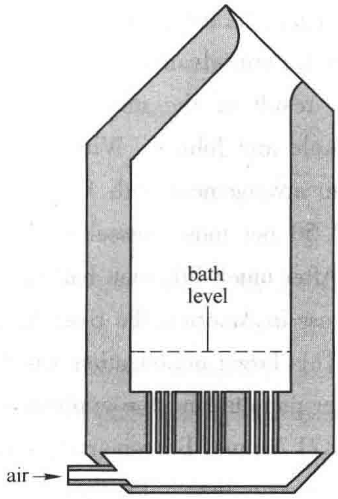

Fig. 1.1 Principle of the bottom blown converter. The blast enters the wind box beneath the vessel through the pipe indicated by the arrow and passes into the vessel through tuyeres set in the bottom of the converter

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 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 tons (2. 50 net tons) 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 tons (2. 50 net tons) 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 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.

1.3 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 (Fig. 1.2). Most of the heat required to promote the chemical reactions necessary for purification of the charge was provided by passing burning fuel gas over the top of the materials. The fuel gas, with a quantity of air more than sufficient to burn it, was introduced through ports at each end of the furnace, alternately at one end and then the other. The products of combustion passed out of the port temporarily not used for entrance of gas and air, and entered chambers partly filled with brick checkerwork. This checkerwork, commonly called checkers, provided a multitude of passageways for the exit of the gases to the stack. During their passage through the checkers, the gases gave up a large part of their heat to the brickwork. After a short time, the gas and air were shut off at the one end and introduced into the furnace through the preheated checkers, absorbing some of the heat stored in these checkers. The gas and air were thus preheated to a

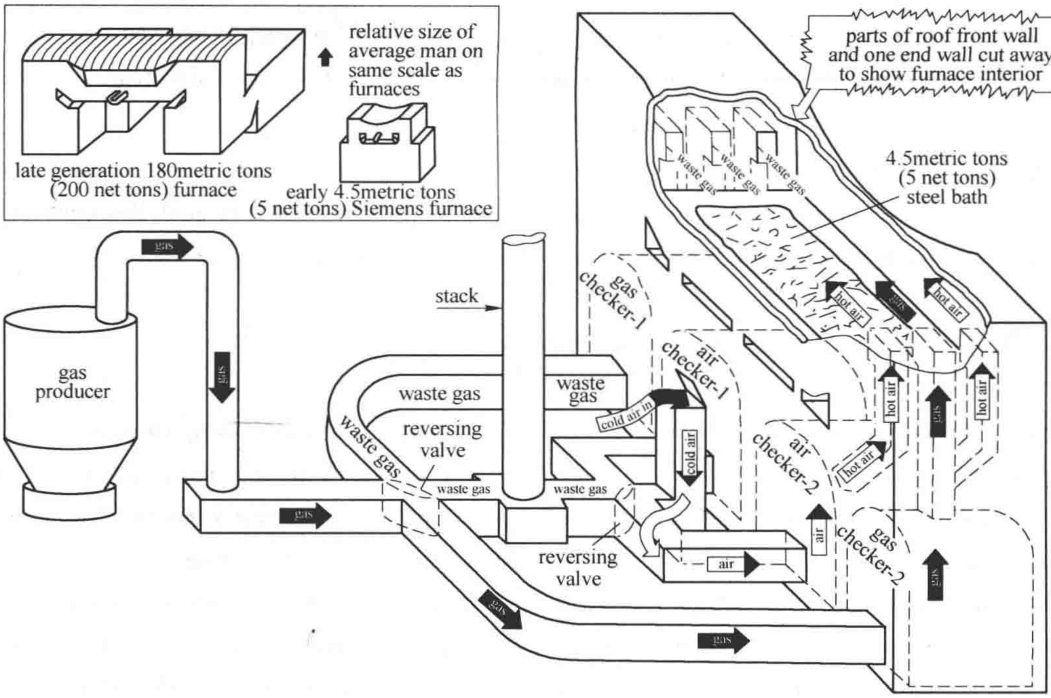

Fig. 1.2 Schematic arrangement of an early type of Siemens furnace with about a 4.5 metric tons (5 net tons) capacity

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 tons (200 net tons) open hearth.

somewhat elevated temperature, and consequently developed to a higher temperature in combustion than could be obtained without preheating. In about 20 minutes, the flow of the gas and air was again reversed so that they entered the furnace through the checkers and port used first; and a series of such reversals, occurring every fifteen or twenty minutes was continued until the heat was finished. The elements in the bath which were oxidized both by the oxygen of the air in the furnace atmosphere and that contained in the iron ore fed to the bath, were carbon, silicon and manganese, all three of which could be reduced to as low a limit as was possible in the Bessemer process. Of course, a small amount of iron remains or is oxidized and enters the slag.

Thus, as in all other processes for purifying pig iron, the basic principle of the Siemens process was that of oxidation. However, in other respects, it was unlike any other process. True, it resembled the puddling process in both the method and the agencies employed, but the high temperatures attainable in the Siemens furnace made it possible to keep the final product molten and free of entrapped slag. The same primary result was obtained as in the Bessemer process, but by a different method and through different agencies, both of which imparted to steel made by the new process properties somewhat different from Bessemer steel, and gave the process itself certain metallurgical advantages over the older pneumatic process, as discussed later in this section.

As would be expected, many variations of the process, both mechanical and metallurgical, have been worked out since its original conception. Along mechanical lines, various improvements in the design, the size and the arrangement of the parts of the furnace have been made. Early furnaces had capacities of only about 3.5-4.5 metric tons (4-5 net tons), which modern furnaces range from about 35-544 metric tons (40-600 net tons) in capacity, with the majority having capacities between about 180-270 metric tons (200-300 net tons).

The Siemens process became known more generally, as least in the United States, as the open hearth process. The name "open hearth" was derived, probably, from the fact that the steel, while melted on a hearth under a roof, was accessible through the furnace doors for inspection, sampling and testing.

The hearth of Siemens' furnace was of acid brick construction, on top of which the bottom was made up of sand, essentially as in the acid process of today. Later, to permit the charging of limestone and use of a basic slag for removal of phosphorus, the hearth was constructed with a lining of magnesite brick, covered with a layer of burned dolomite or magnesite, replacing the siliceous bottom of the acid furnace. These furnaces, therefore, were designated as basic furnaces, and the process carried out in them was called the basic process. The pig and scrap process was originated by the Martin brothers, in France, who, by substituting scrap for the ore in Siemens' pig and ore process, found it possible to dilute the change with steel scrap to such an extent that less oxidation was necessary.

The advantages offered by the Siemens process may be summarized briefly as follows:

1. By the use of iron ore as an oxidizing agent and by the external application of heat, the temperature of the bath was made independent of the purifying reactions, and the elimination of impurities could be made to take place gradually, so that both the temperature and composition of the

bath were under much better control than in the Bessemer process.

2. For the same reasons, a greater variety of raw materials could be used (particularly scrap, not greatly consumable in the Bessemer converter) and a greater variety of products could be made by the open hearth process than by the Bessemer process.

3. A very important advantage was the increased yield of finished steel from a given quantity of pig iron as compared to the Bessemer process, because of lower inherent sources of iron loss in the former, as well as because of recovery of the iron content of the ore used for oxidation in the open hearth.

4. Finally, with the development of the basic open hearth process, the greatest advantage of Siemens' over the acid Bessemer process was made apparent, as the basic open hearth process is capable of eliminating phosphorus from the bath. While this element can be removed also in the basic Bessemer (Thomas-Gilchrist) process, it is to be noted that, due to the different temperature conditions, phosphorus is eliminated before carbon in the basic open hearth process, whereas the major proportion of phosphorus is not oxidized in the basic Bessemer process until after carbon in the period termed the afterblow. Hence, while the basic Bessemer process requires a pig iron with a phosphorus content of 2.0% or more in order to maintain the temperature high enough for the afterblow, the basic open hearth process permits the economical use of iron of any phosphorus content up to 1.0%. In the United States, this fact was of importance since it made available immense iron ore deposits which could not be utilized otherwise because of their phosphorus content, which was too high to permit their use in the acid Bessemer or acid open hearth process and too low to use in the basic Bessemer process.

The open hearth process became the dominant process in the United States. As early as 1868, a small open hearth furnace was built at Trenton, New Jersey, but satisfactory steel at a reasonable cost did not result and the furnace was abandoned. Later, at Boston, Massachusetts, a successful furnace was designed and operated, beginning in 1870. Following this success, similar furnaces were built at Nashua, New Hampshire and in Pittsburgh, Pennsylvania, the latter by Singer, Nimick and Company, in 1871. The Otis Iron and Steel Company constructed two 6.3 metric tons (7 net tons) furnaces at their Lakeside plant at Cleveland, Ohio in 1874. Two 13.5 metric tons (15 net tons) furnaces were added to this plant in 1878, two more of the same size in 1881, and two more in 1887. All of these furnaces had acid linings, using a sand bottom for the hearths.

The commercial production of steel by the basic process was achieved first at Homestead, Pennsylvania. The initial heat was tapped March 28, 1888. By the close of 1890, there were 16 basic open hearth furnaces operating. From 1890 to 1900, magnesite for the bottom began to be imported regularly and the manufacture of silica refractories for the roof was begun in American plants. For these last two reasons, the construction of basic furnaces advanced rapidly and, by 1900, furnaces larger than 45 metric tons (50 net tons) were being planned.

While the Bessemer process could produce steel at a possibly lower cost above the cost of materials, it was restricted to ores of a limited phosphorus content and its use of scrap was also limited.

The open hearth was not subject to these restrictions, so that the annual production of steel by the open hearth process increased rapidly, and in 1908, passed the total tonnage produced yearly by the Bessemer process. Total annual production of Bessemer steel ingots decreased rather steadily after 1908, and has ceased entirely in the United States. In addition to the ability of the basic open hearth furnace to utilize irons made from American ores, as discussed earlier, the main reasons for proliferation of the open hearth process were its ability to produce steels of many compositions and its ability to use a large proportion of iron and steel scrap, if necessary. Also steels made by any of the pneumatic processes that utilize air for blowing contain more nitrogen than open hearth steels; this higher nitrogen content made Bessemer steel less desirable than open hearth steel in some important applications.

With the advent of oxygen steelmaking which could produce steel in a fraction of the time required by the open hearth process, open hearth steelmaking has been completely phased out in the United States. The last open hearth meltshop closed at Geneva Steel Corporation at Provo, Utah in 1991. Worldwide there are only a relative few open hearths still producing steel.

1.4 Oxygen Steelmaking

Oxygen steelmaking has become the dominant method of producing steel from blast furnace hot metal. Although the use of gaseous oxygen (rather than air) as the agent for refining molten pig iron and scrap mixtures to produce steel by pneumatic processes received the attention of numerous investigators from Bessemer onward, it was not until after World War II that commercial success was attained.

Blowing with oxygen was investigated by R. Durrer and C. V. Schwarz in Germany and by Durrer and Hellbrugge in Switzerland. Bottom-blown basic lined vessels of the designs they used proved unsuitable because the high temperature attained caused rapid deterioration of the refractory tuyere bottom; blowing pressurized oxygen downwardly against the top surface of the molten metal bath, however, was found to convert the charge to steel with a high degree of thermal and chemical efficiency.

Plants utilizing top blowing with oxygen have been in operation since 1952-1953 at Linz and Donawitz in Austria. These operations, sometimes referred to as the Linz-Donawitz or L-D process were designed to employ pig iron produced from local ores that are high in manganese and low in phosphorus; such iron is not suitable for either the acid or basic bottom blown pneumatic process utilizing air for blowing. The top blown process, however, is adapted readily to the processing of blast furnace metal of medium and high phosphorus contents and is particularly attractive where it is desirable to employ a steelmaking process requiring large amounts of hot metal as the principal source of metallics. This adaptability has led to the development of numerous variations in application of the top-blown principle. In its most widely used form, which also is the form used in the United States, the top blown oxygen process is called the basic oxygen steelmaking process (BOF for short) or in some companies the basic oxygen process (BOP for short).

The basic oxygen process consists essentially of blowing oxygen of high purity onto the surface of