

I Introduction of the Blast Furnace Process

1.1 Global steel consumption

Two different process routes are available for the production of steel products, namely the blast furnace with oxygen steelmaking and the electric arc steelmaking route. The routes differ with respect to the type of products that can be made, as well as the raw materials used. The blast furnace–oxygen steelmaking route mainly produces flat products, while electric arc steelmaking is more focused on long products. The former uses coke and coal as the main reductant (fuel) sources and sinter, pellets and lump ore as the iron-bearing component, while the latter uses electric energy to melt scrap. The current trend is for electric arc furnaces to be capable of also producing flat products. Nevertheless, the blast furnace–oxygen steelmaking route is the primary source for worldwide steel production: about 70% of the steel consumed is produced via this route, as shown in Figure 1.1.

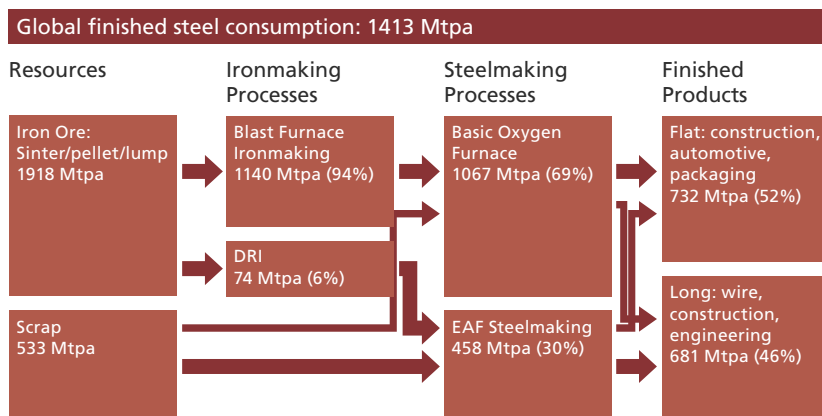


Figure 1.1 Steelmaking routes and raw materials (Steelconsult International, based on data in the IISI Steel Statistical Yearbook and World Steel in Figures, 2012 — Corex and Open Hearth omitted)

From a geographic perspective, the world has observed major changes in steel consumption. Figure 1.2 shows the regional steel consumption in 2012. Steel consumption in China amounted to 646 million tons in 2012, while in 2000 it was 124 million tons. World production capacity has increased even more, since China has become a major steel exporter.

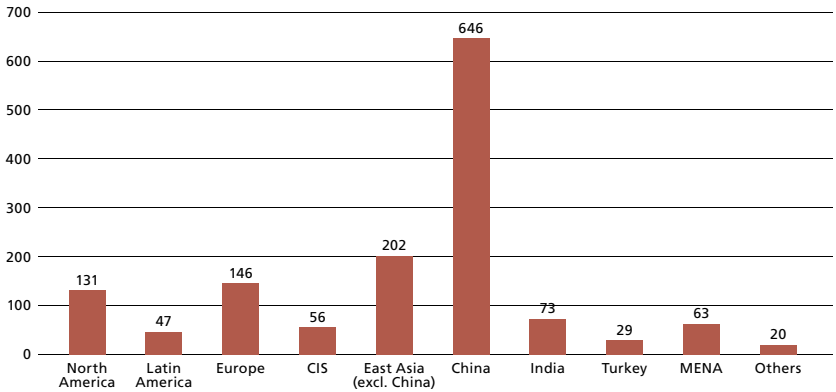


Figure 1.2 *Geographical distribution of steel consumption*

The present book discusses blast furnace ironmaking. Hot metal is produced in a blast furnace, from where it is transported as liquid hot metal to the steel plant, where refinement of hot metal to steel takes place by removing elements such as sulphur, silicon, carbon, manganese and phosphorous.

In the blast furnace process, iron ore in the form of lump ore, sinter and pellets is transformed into hot metal consuming “reducing agents” (coke, coal and natural gas). Slag is formed from the gangue of the ore burden and the ash of coke and coal. Hot metal and liquid slag do not mix and remain separate from each other with the slag floating on top of the denser iron. The iron can then be separated from the slag in the casthouse.

In the introductory chapter, we discuss the basics of the process and the internal layer structure in the furnace as well as some major aspects of furnace design, like the profile of the blast furnace and the cooling systems.

1.2 Short description of the process

The inputs and outputs of the furnace are given in Figure 1.3. A blast furnace is filled with alternating layers of coke and iron ore–containing burden. Hot blast is compressed air that is blown into the blast furnace via tuyeres. A tuyere is a cooled copper conical nozzle, numbering up to 12 in smaller furnaces, and up to 42 in bigger furnaces, through which pre–heated air (1000–1300 °C) is blown into the furnace.

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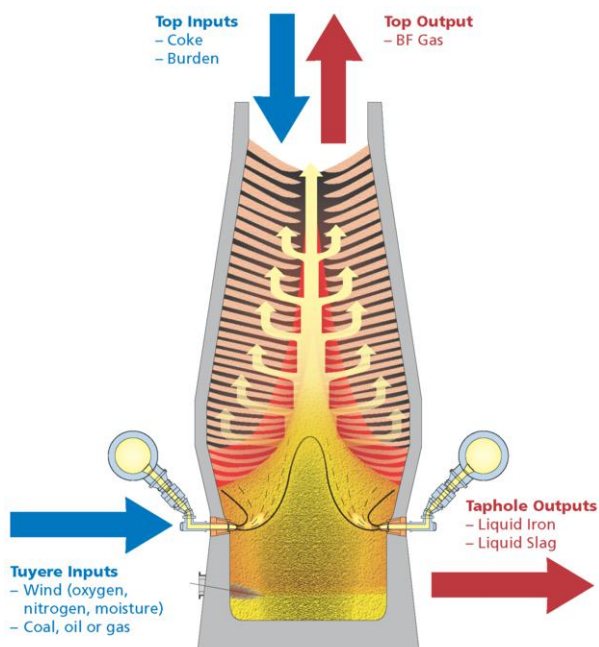


Figure 1.3 Input and output of a blast furnace

This hot blast gasifies coke and other carbon-based materials injected via the tuyeres, mostly coal, natural gas and/or oil. In this process, the oxygen in the blast is transformed into gaseous carbon monoxide. The resulting gas has a high flame temperature of between 1900 and 2300 °C . Coke in front of the tuyeres is consumed, thus creating voidage. The driving forces in the blast furnace are illustrated in Figure 1.4 on the next page.

The very hot gas ascends through the furnace, carrying out a number of vital functions as listed below:

- Heating up the coke in the bosh/belly area.
- Melting the iron ore in the burden, creating voidage.
- Heating up the material in the shaft zone of the furnace.
- Removing oxygen of the iron ore burden by chemical reactions.
- Upon melting, the iron ore produces hot metal and slag, which drips down through the coke into the hearth, from which it is removed by casting through the taphole. In the dripping zone, the hot metal and slag consume coke, creating voidage. Additional coke is consumed for final reduction of iron oxide and carbon dissolves in the hot metal, which is called carburization.

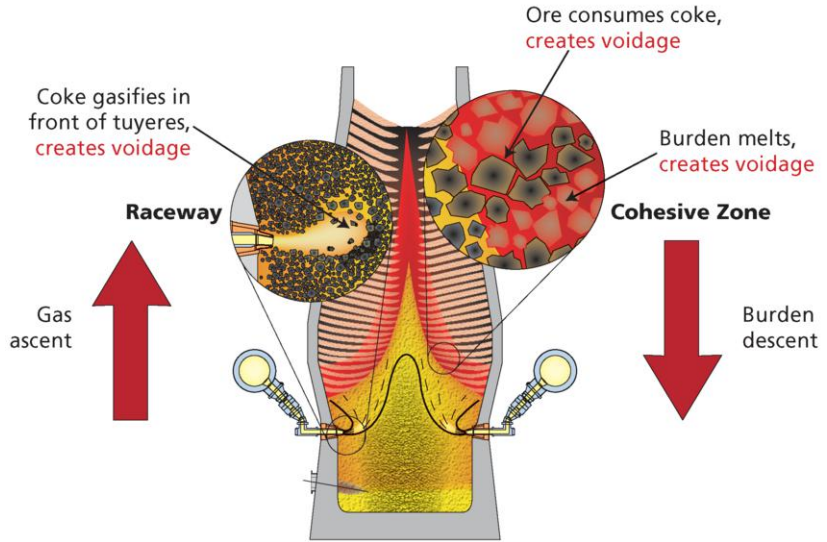


Figure 1.4 The driving force of a blast furnace: the counter–current process creates voidage at the indicated areas causing the burden to descend

A typical example of the temperature profile in the blast furnace is shown in Figure 1.5. It is shown that the softening/melting zone is located in an area where temperatures are between 1000 and 1350 °C. The temperature differences in the furnace are large. In the example, the temperature gradients are bigger in the horizontal direction than in the vertical direction, which will be explained in Chapter VI.

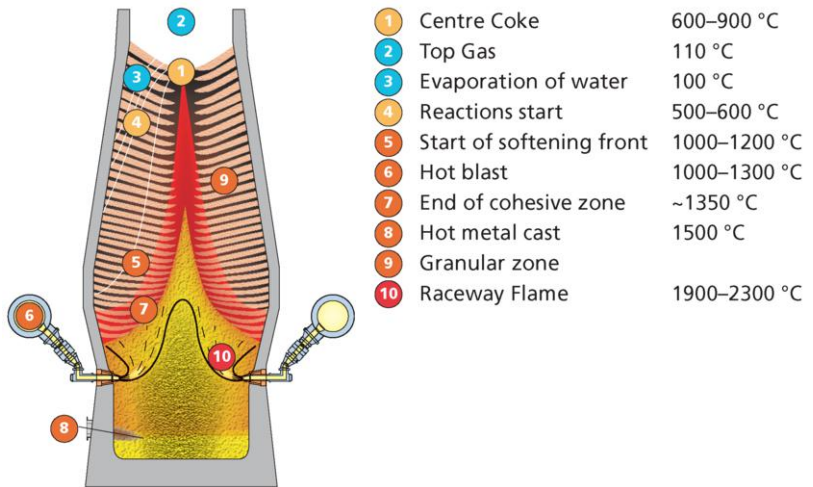


Figure 1.5 Temperature profile in a blast furnace (typical example)

1.3 The layer structure within a furnace

Ore and coke are charged in discrete layers at the top of the furnace and processed more downwards. The structure of layers is maintained throughout the furnace until all ferrous burden materials have been molten. This is derived from studies of quenched furnaces: it was evident that these layers of ore and coke remain until the temperatures are high enough for softening and melting of the ore to begin. Quenched furnaces are “frozen in action” with the help of water or nitrogen and examples of quenched blast furnaces as well as a solidified cohesive zone are presented in Figures 1.6a and 1.6b.

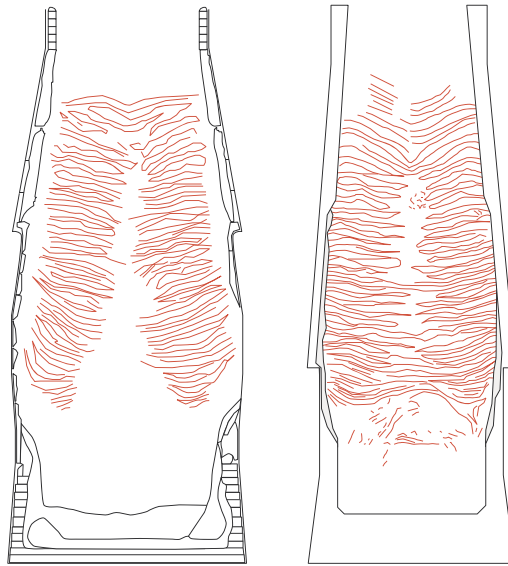


Figure 1.6a Dissections of quenched blast furnaces Kakogawa 1 and Tsurumi (Based on Omori et al, 1987)



Figure 1.6b Cohesive zone after blow-down

The quenched blast furnace clearly shows the layer structure of coke and ore. Further analysis reveals information about the heating and melting of the ore as well of the progress of chemical reactions.

As indicated in Figure 1.7, at any moment, an operating blast furnace contains, from top downwards:

- Layers of ore and coke.
- An area where ore starts to soften and melt, known as the softening–melting zone or cohesive zone.
- An area where there is only coke and liquid iron and slag, called the “active coke” or dripping zone.
- The deadman or “inactive coke zone”, which is a stable pile of coke in the hearth, extending into the bosh of the furnace.

A blast furnace has the shape of two truncated cones that are joined at their widest points. The sections are, from the top down:

- The throat, where the burden surface is located.
- The stack, where the ores are heated and reduction reactions start.
- The bosh parallel or belly.
- The bosh, where the reduction is completed and the ores are melted down.
- The hearth, where the molten material is collected and cast via the taphole. The liquid iron and slag are collected in the voids between coke particles in the hearth. The solid coke is pushed down to the bottom of the furnace by the weight of the charge.

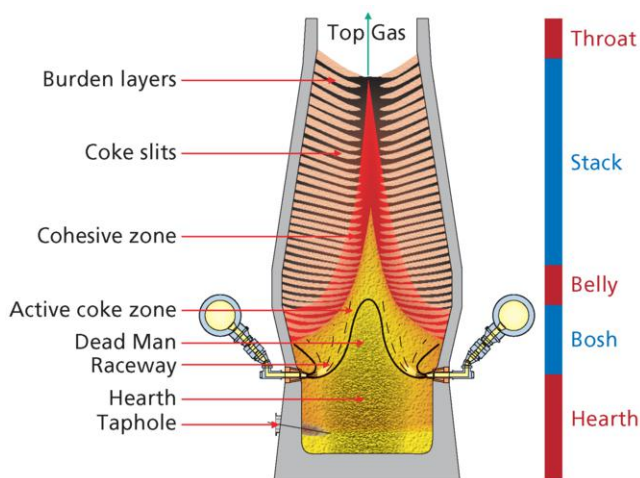


Figure 1.7 The zones in the blast furnace

1.4 The equipment

1.4.1 Equipment overview

An overview of the major equipment is shown in Figure 1.8. These include:

- Hot Blast Stoves. Air preheated to temperatures between 1000 and 1300 °C is produced in the hot blast stoves and is delivered to the furnace via a hot blast main, bustle pipe, tuyere stocks and finally through the tuyeres. The hot blast reacts with coke and injectants. The high speed gas forms the area known as the raceway in front of the tuyeres.
- Stock house. The burden materials and coke are delivered to a stock house. The materials are stored, screened and then weighed before final delivery into the furnace. The stock house is operated automatically. Corrections for coke moisture are generally made automatically. The burden materials and coke are brought to the top of the furnace via skip cars or via a conveyor belt, where they are charged into the furnace in separate layers of ore and coke.
- Gas cleaning. The top gas leaves the furnace via uptakes and a downcomer. The hot top gas contains a substantial quantity of fine particles, so it is required to remove these particles and cool the gas in a gas cleaning system consisting of a dust catcher or cyclone, a scrubber for wet cleaning of the gas and finally a demister for removing the water.
- Casthouse. The liquid iron and slag collect in the hearth of the furnace, from which they are tapped via the taphole into the casthouse and to transport ladles. Depending on the size of the furnace, there may be one to five tapholes and one or two casthouses.
- Slag granulation. The molten slag may be quenched with water to form granulated slag, which is used for cement manufacturing.

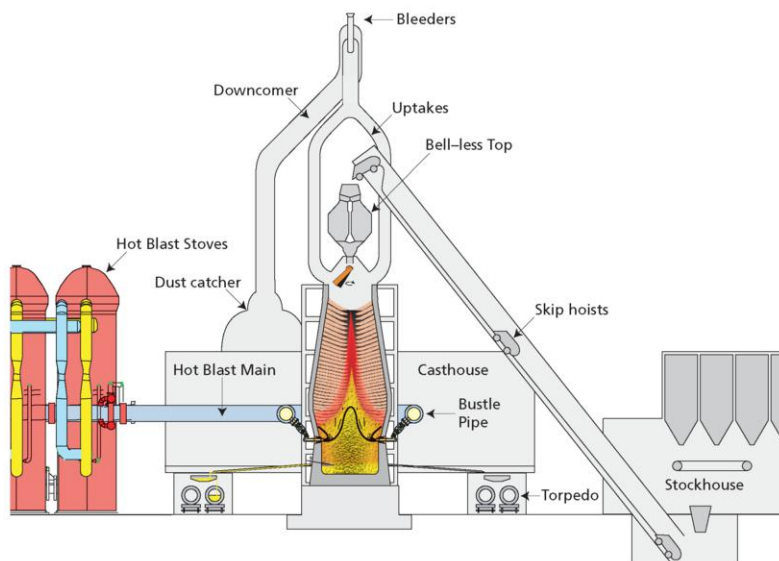


Figure 1.8 Blast furnace general arrangement

The top of the blast furnace is closed, as modern blast furnaces tend to operate with a high top pressure. There are various different systems:

- The most common system is the bell-less top, which allows burden distribution with a rotating and tilting chute.
- The double bell system was the predecessor of the bell less top. It is often equipped with a movable throat armour.
- Newly developed systems, such as the “Totem-top” and “No-bell top”.

Examples of various types are schematically shown in Figure 1.9.

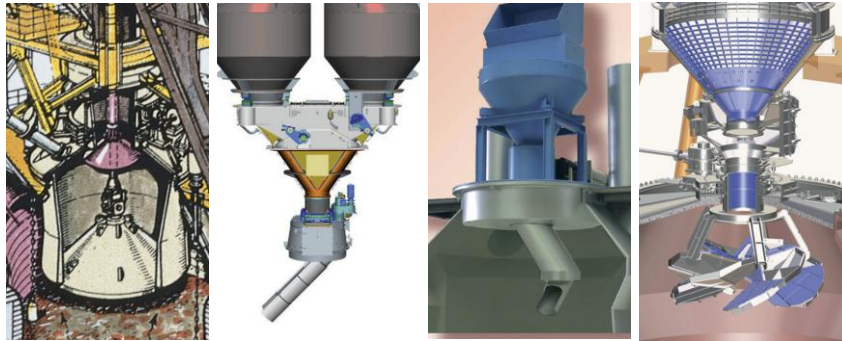


Figure 1.9 Selection of blast furnace top charging systems, from left to right
 Bell-type charging (“McKee Top”)
 Chute-type charging (“Paul Wurth Bell-Less Top”)
 Double Chute-type charging (“Zimmermann & Jansen No-Bell Top”)
 Rotor-type charging (“Totem Top”)
 Pictures taken from company websites.

1.4.2 Blast furnace construction

There are basically two construction techniques to support blast furnaces. The classic design utilises a supported ring, or lintel at the bottom of the shaft, upon which the higher section of the furnace rests. The other technique is a freestanding construction, requiring an independent support for the blast furnace top and the gas system. The required compensator allowing for expansion (thermal as well as from the pressure) is below the lintel for the lintel furnace, while in the freestanding furnace it is located at the top, as indicated in Figure 1.10.

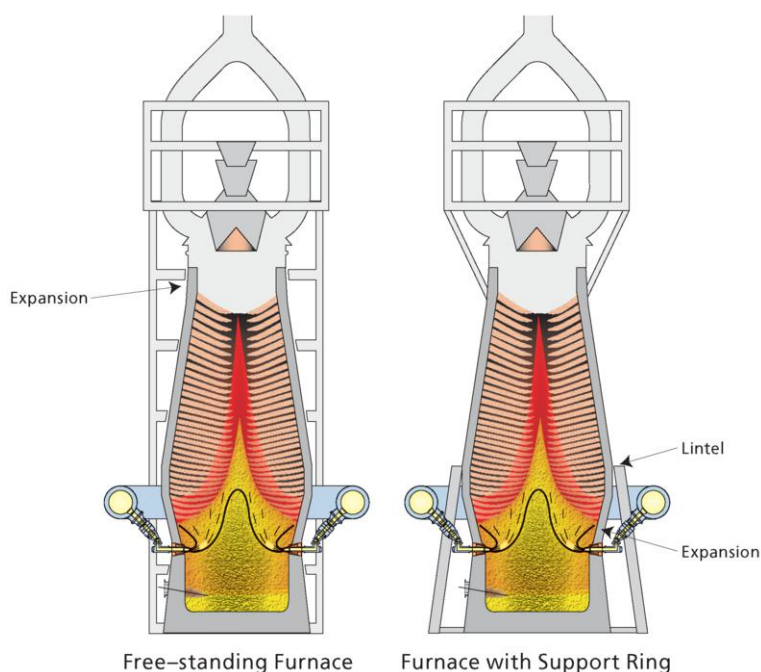


Figure 1.10 Blast furnace constructions

1.4.3 Blast furnace development

Blast furnaces have grown considerably in size during the 20th century. In the early days of the 20th century, blast furnaces had a hearth diameter of 4 to 5 metres and were producing around 100,000 tonnes hot metal per year, mostly from lump ore and coke. At the end of the 20th century, the biggest blast furnaces had hearth diameters between 14 and 15 metres and were producing 3 to 4 million tonnes per year.

The ore burden developed, so that presently high performance blast furnaces are fed with sinter and pellets. The lump ore percentage has generally decreased to 10–15 % of the ferrous burden or lower. The reductants used developed as well: from all coke operation to the use of injectants through the tuyeres. In the 1960s, oil was the prevalent tuyere injectant, while since the early 1980s coal injection is used extensively. Presently, about 30–40 % of the earlier coke requirements have been replaced by injection of coal and sometimes oil or natural gas. As a result of a new technology to access natural gas deposits, the cost of natural gas has decreased in some areas of the world and now natural gas has become 20–25% of the total reductant. Currently, the co-injection of coal and natural gas is being optimized in the blast furnace.

The size of a blast furnace is often expressed in terms of its hearth diameter or as its “working volume” or “inner volume”. The working volume is the volume of the blast furnace that is available for the process i.e. the volume between the

tuyeres and the burden level. Definitions of working volume and inner volume are given in Figure 1.11.

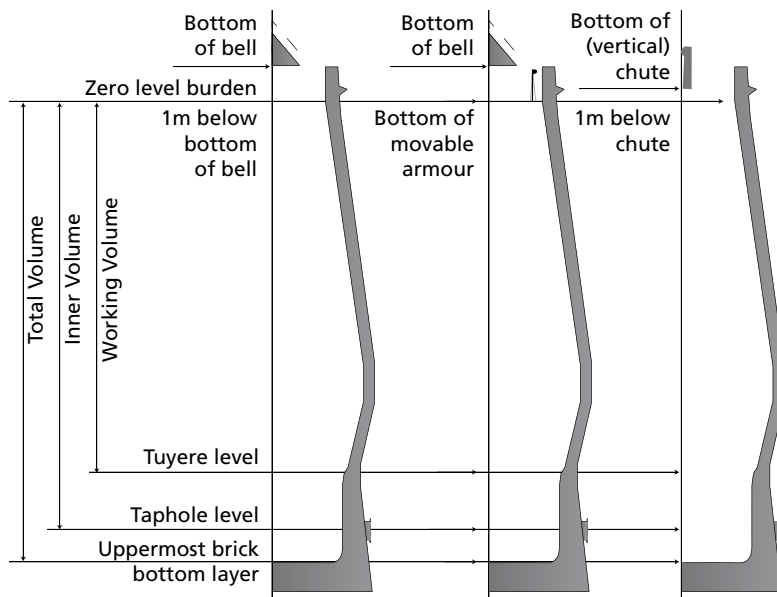


Figure 1.11 Definitions of working volume and inner volume

Presently, very big furnaces reach production levels of 12,000 t/d or more. E.g. the Oita blast furnace No. 2 (operated by Nippon Steel & Sumitomo Metal Corporation) has a hearth diameter of 15.6 meter and a production capacity of 13,500 t/d. In Europe, the ThyssenKrupp Steel Schmelzern No. 2 furnace has a hearth diameter of 14.9 m and a daily production of 12,000 t/d. In Russia, NLMK Blast Furnace No. 7 (13.1 meter hearth diameter) reached an average production of 12,500 tHM/d. In 2013, POSCO commissioned their Gwangyang No. 1 blast furnace with an inner volume of 5800 m³ and a rated capacity of 5.65 million ton per year (around 16,000 tHM/d). It is the largest furnace at the time.

1.4.4 Blast furnace profile

There is no scientific, theoretically justified practice of calculating the blast furnace profile. The dimensions are estimated based on empirical formulas and past experience, which takes different operating conditions, like the type of burden materials, into account.

The design of a blast furnace starts with the production target for the furnace. Taking into account the quality of the burden, a productivity target as tHM (ton Hot Metal) per m³ working volume per 24 hours can be derived from benchmarking with comparable furnaces. Then the working volume can be derived. Hot metal production, together with the expected slag volume, can be

used to calculate the production of the total liquid volume, which is required to define the hearth diameter and tuyere-to-taphole distance.

As soon as these primary dimensions are known, the next step is to derive the total furnace dimensions, such as the height from tuyere to stockline and to bottom, the number of tuyeres, the bosh dimensions, stack dimensions, throat dimensions and the number of tapholes (Figure 1.12). Of special importance are the slopes or angles of the bosh and shaft, which vary from furnace to furnace in the range of 81–86 degrees and 76–82 degrees respectively.

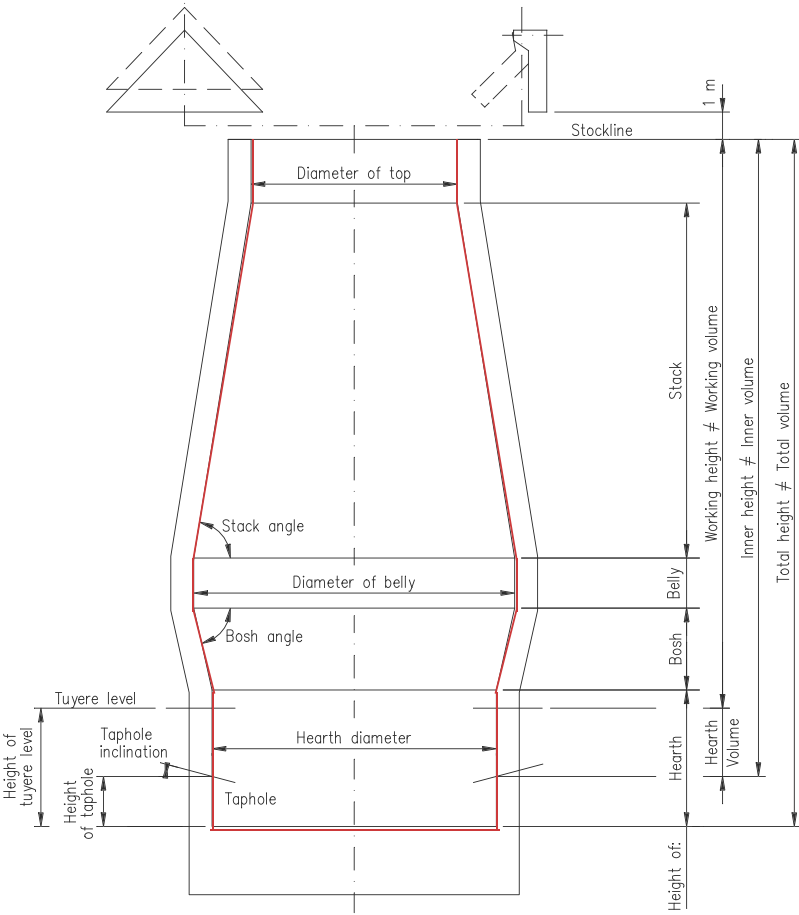


Figure 1.12 Major dimensions of a blast furnace

1.4.5 Cooling systems

In order to maintain the integrity of the steel shell of the furnace and because of the high temperatures, the inside of the shell is protected by a water-cooled refractory lining. An extensive discussion of cooling systems and specifications is beyond the scope of this book.

There are two main shell cooling systems in use: stave cooling and horizontal cooling plates, as shown in Figure 1.13 for the bosh of a furnace. Cooling plates are water-cooled, typically produced from copper castings, with a relatively small distance between plate locations and an insert depth of 40–50 cm. When leaking, they can be replaced from outside the steel shell during a blast furnace stop within a few hours.

Staves are vertical cooling elements, which can be made from cast iron, steel or copper, covered with refractories on the hot face. The insert depth is smaller, which leads to an increase in working volume of a blast furnace when cooling plates are replaced by staves.

The advantage of staves is that when the burden descends, the material can follow the wall rather easily. This is especially an advantage in the stack. The advantage of cooling plates is that the cooling plates can work as an anchor for freezing a protective skull, which is difficult with staves. So especially in the lower part of the furnace cooling plates are more forgiving than staves. Therefore, hybrid systems are presently being developed and installed.

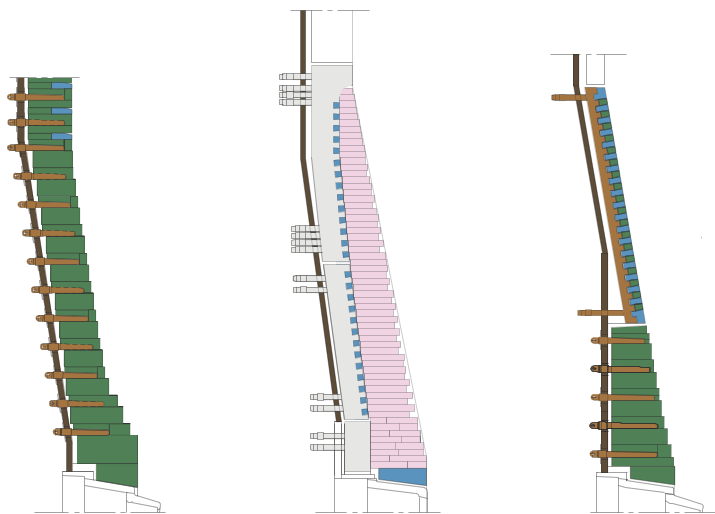


Figure 1.13 Cooling systems: plate coolers, staves and hybrid

1.5 Book overview

Blast furnace ironmaking can be discussed from three different perspectives:

- The operational approach: discussing the blast furnace with its operational challenges.
- The chemical technology approach: discussing the process from the perspective of the technologist who analyses progress of chemical reactions and heat and mass balances.
- The mechanical engineering approach focussing on equipment.

The focus of this book is the “operator’s view”, with the aim to understand what is going on inside the blast furnace. To this end, the principles of the process are discussed (Chapter II), followed by the demands on burden quality (Chapter III) and coke and auxiliary reductants (Chapters IV and V). Simplified calculations of burden and top gas are made (Chapter VI). The control of the process is discussed in Chapter VII: burden descent and gas flow control. The issues pertaining to understanding the blast furnace productivity and efficiency are presented in Chapter VIII. Subsequently, hot metal and slag quality (Chapter IX), casthouse operation (Chapter X) and special operational conditions like stops and starts, high moisture input or high amounts of fines charged into the furnace (Chapter XI) are discussed.

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