# BLAST FURNACE IRONMAKING AND BASIC OXYGEN STEELMAKING

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## 1.0 SCOPE

This data sheet covers the iron and steelmaking using blast furnace and basic oxygen furnace technologies.

This data sheet does not cover the production of raw materials for making iron, such as coke and coke oven processes. Direct iron reduction is not covered in this data sheet, either, because the process has no molten phases (there is a brief description of the process in Section 3.0; however, because this process is not currently covered in any other FM data sheet).

Refer to Data Sheet 7-21, *Rolling Mills*, for guidance on hot and cold rolling of steel products. Refer to Data Sheet 7-104, *Metal Treatment Processes*, for guidance on steel pickling operations and steel coating operations. For more information on remelting or sceondary iron and steelmaking technologies such as a cupola or electric arc furnace, continuous casting, and/or ferroalloy production, refer to Data Sheet 7-33, *Molten Metals and Other Materials*.

### 1.1 Changes

**January 2024.** Interim revision. The following changes were made as part of the FM Global Data Sheet 7-33, *Molten Metals and Other Materials*, revision.

A. Changed the title of the data sheet from *Molten Steel Production* to *Blast Furnace Ironmaking and Basic Oxygen Steelmaking*.

B. Relocated electric-arc furnace and continuous caster guidance to DS 7-33.

C. Consolidated radioactive contamination guidance to DS 7-33.

## 2.0 LOSS PREVENTION RECOMMENDATIONS

### 2.1 Construction and Location

#### 2.1.1 General

2.1.1.1 Use high-grade refractory in the construction and relining of all molten metal vessels, such as the blast furnace, basic oxygen furnace, and ladles.

2.1.1.2 Locate control rooms and stations so they are not exposed to molten metal spills. If exposure cannot be avoided, provide protection for these areas.

2.1.1.3 Route all electrical cables and equipment for monitoring and operating critical equipment and auxiliary equipment away from molten metal exposures. If exposure cannot be avoided, provide heat shielding between potential molten metal spill areas and the electrical cables and equipment.

#### 2.1.2 Blast Furnaces

2.1.2.1 Protect all structural steel, including major supporting steel for the furnace and casting floor, from molten metal breakout and other extreme temperature exposures (e.g., super-heated air from furnace exhaust). The use of masonry covering on structural elements is appropriate.

2.1.2.2 Protect all support equipment (mud guns, tap drills, blowers, tuyeres, tanks, and pumps) and their foundations from molten metal exposure.

2.1.2.3 Provide sloped floors and drainage around and about the furnace to keep water accumulation from lying in areas subject to molten metal spills.

2.1.2.4 Locate below-grade storm sewage and drainage openings so that molten metal spills cannot enter the system.

2.1.2.5 Locate bag houses outside, with explosion venting directed away from the building. Refer to Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosion and Fire*, for further guidance.

#### 2.1.3 Basic Oxygen Furnaces

2.1.3.1 Locate bag houses outside, with explosion venting directed away from the building. Refer to Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosion and Fire*, for further guidance.

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## 2.2 Occupancy

### 2.2.1 Basic Oxygen Furnace

2.2.1.1 Provide radioactive detection for all scrap metal in accordance with Data Sheet 7-33, *Molten Metals and Other Materials*.

2.2.1.2 If scrap steel is stored uncovered outside, develop a procedure for drying the scrap steel prior to it entering the basic oxygen furnace (e.g., scrap pre-heaters). If the facility is located in a cold climate, develop a procedure that will address the possibility of ice collecting within the compacted scrap steel.

## 2.3 Protection

### 2.3.1 General

2.3.1.1 For electrical cable runs near molten material, provide heat detection connected to a constantly attended location.

2.3.1.2 Provide smoke detection in all electrical control rooms and pulpits.

2.3.1.3 Protect under-floor cables in accordance with Data Sheet 5-31, *Cables and Bus Bars*.

2.3.1.4 Protect bag houses in accordance with Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fire.*

2.3.1.5 Protect cooling towers in accordance with Data Sheet 1-6, *Cooling Towers*.

2.3.1.6 Provide sprinkler protection in accordance with Data Sheet 7-98, *Hydraulics*, for all hydraulic oil systems. An alternative to sprinkler protection is to use an FM Approved industrial fluid.

2.3.1.7 Protect steam-drive turbo blowers in accordance with Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*.

## 2.4 Equipment and Processes

### 2.4.1 Blast Furnaces

2.4.1.1 Provide cooling water monitoring that includes leak detection, high and low temperature, high and low air flow, and arrange it to alarm to a constantly monitored location.

2.4.1.2 Provide refractory thickness monitoring, particularly in areas where gunnite has been applied.

2.4.1.3 Perform predictive wear analysis of the furnace using, at a minimum, the following information:

A. Erosion, based on burden material and size

B. Chemical, based on auxiliary fuels and quality of burden materials

C. Thermal attack, based on heating enrichment resulting in higher operating temperatures

2.4.1.4 Provide alarms linked to a constantly attended location if the fans associated with the bag house fail.

2.4.1.5 Provide thermocouples throughout the blast furnace, including the following locations:

- Cooling water (to monitor heat and load)
- Under the hearth
- Within the hearth walls
- Within the stack
- Near the stockline
- Throughout the inner wall both above and below the burden

2.4.1.6 Undertake regular thermographic scans of potential weak points in the blast furnace (i.e., at tap holes, slag holes, and tuyeres).

2.4.1.7 Provide additional refractory thickness monitoring of the hearth that allows an estimation of the salamander size and hearth wear.

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2.4.1.8 Provide the following blast furnace monitoring and controls:

• Blast pressure
• Blast temperature
• Stock line temperature
• Top pressure
• Blast volume
• Stove-stack temperature
• Stove-dome temperature
• Hot-blast temperature
• Combustion control for stove burners with dome and stack temperature control
• Sequence recorder for large-bell movement and revolving distributor operation

2.4.1.9 Provide alarms linked to a constantly attended location for the following:

• Low gas pressure
• High stove-dome temperature
• High stack temperature
• Low blast pressure

### 2.4.2 Basic Oxygen Furnaces (BOF)

2.4.2.1 Provide cooling water monitoring that includes leak detection, high and low temperature, high and low air flow, that alarms to a constantly monitored location.

2.4.2.2 Provide refractory thickness monitoring of all furnaces, particularly in areas where gunnite has been applied.

2.4.2.3 Provide alarms linked to a constantly attended location if the fans with the bag house fail.

2.4.2.4 Provide the following interlocks for the oxygen lances: limit tilt switches, high pressure and low water within the hood.

2.4.2.5 Provide cooling water monitoring for the oxygen lances and hood cooling. Examples of cooling water monitoring are differential pressure cells, temperature differential, and flow metering.

2.4.2.6 Provide, at a minimum, the following computer controls with alarms if abnormal conditions occur linked to a constantly attended location:

• Oxygen pressure
• Hood temperature
• Raw material hoppers/chute
• Oxygen volume
• Bag house temperature

### 2.5 Operation and Maintenance

Establish and implement a furnace inspection, testing, and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program. Also establish and implement an operator training program. See Data Sheet 10-8, *Operators*, for guidance. Develop and maintain standard operating procedures (SOP) and emergency operating procedures (EOP) for furnace and casting operations.

### 2.5.1 Basic Oxygen Furnaces

2.5.1.1 Implement a management system for all control program changes for the continuous caster that includes a record of authorization by the process control manager. Keep a written record of all control program changes for a minimum of 24 months.

2.5.1.2 Implement a management system to log any by-passes made to individual devices or protective functions in the continuous caster control system. Keep a written record of each change. Include the following information:

• When the device was by-passed
• When it was returned to service
• What was by-passed

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- Why it was by-passed
- What hazard existed while it was being by-passed

Also include a space for all involved parties to sign the log when they bypass the system and when it is returned to normal. Keep a copy of log entries for a minimum of 24 months. This will allow systemic issues to be identified and addressed.

2.5.1.3 Undertake annual inspections of the basic oxygen furnace trunion for cracks or water leaks.

2.5.1.4 Monitor creep and deformation in the basic oxygen furnace trunion ring at least every 6 months. Maintain a written record of the results to track the condition of the trunion. Replace or repair the rings if there is a large shift in the creep or deformation trend.

2.5.1.5 Monitor the flow and quality of gases (e.g., oxygen, nitrogen, argon, and hydrocarbon coolants) into the BOF. Connect the monitors to a constantly attended location.

### 2.6 Human Factor

2.6.1 Develop a procedure for safe operation of the electrical systems for the furnaces. Include in the procedure the direction not to reclose the primary circuit breaker before whatever caused the primary switch to operate is corrected. Ensure the procedure is easily accessible by the furnace operators.

2.6.2 Develop and maintain an emergency plan for process upsets for all furnaces onsite. Review the plan every 12 months and keep the line of authority for critical decisions up to date.

2.6.3 Develop a written operating philosophy for all furnaces onsite that covers relines, patching, and minor repair/relines, and lists the last major reline and the planned next full reline. Include de-sculling procedures for the basic oxygen furnace vessels, lances, and slag pots.

2.6.4 Develop and maintain an emergency plan for process upsets or molten metal breakout on the casting machines. Include in the plan actions to be taken in the event of the loss of electrical power, loss of cooling water, and molten metal breakouts. Conduct regular training involving the operators.

### 2.7 Contingency Planning

#### 2.7.1 Equipment Contingency Planning

When a furnace breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable furnace equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

2.7.1.1 In addition, include the following elements in the contingency planning process specific to furnaces:

A. Raw material feeds: Include in the plan an alternative method for delivering the raw materials to the blast furnace.

B. Basic oxygen furnace trunion failure: Include in the plan a process for bringing the equipment breakdown spare trunion or BOF vessel online and repairing or replacing the damaged trunion.

C. Consider provisions for an alternative supply of cooling water (e.g. emergency pumps and emergency water) for loss of cooling water to hot blast blower systems and power supply for the furnace control system.

#### 2.7.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by a furnace breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

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### 2.7.3 Routine Spares

Routine furnace spares are spares that are considered to be consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the furnace, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer. See Section 3.2 for routine spare guidance.

### 2.7.4 Equipment Breakdown Spares

Equipment breakdown spares for furnaces are spares intended to be used in the event of an unplanned outage of a furnace to reduce downtime and restore operations. Provide the following equipment breakdown spares for furnaces:

#### 2.7.4.1 Blast Furnaces

A. Ore handling equipment: skip cars, rails, hoist drums, a gearbox and motor for the hoist. For modern blast furnace feed conveyor, spares for all moving parts, and a spare feed belt.

B. The furnace top: Complete spare top, bell segments, distributor gear, and bell rods.

C. Water-cooled components: multiple cooling plates, staves, hot blast valves, stove valve, and tuyere coolers.

D. Bustle pipe, blow stock material, and tuyeres: multiples of these components to expedite an emergency repair. Provide additional inventory of tuyeres above the number typically needed to replace those that are consumed in normal operation.

E. Tap hole assembly: Complete set of spares for the mud gun and drill. Spare tap hole refractory and assembly, including refractory block for the local hearth side wall.

F. Furnace hearth: Hearth steel of proper thickness and curvature, and sufficient spare hearth side wall block material for patch repair in case of breakout. Maintain a complete set of spare beams for the bottom of the hearth for furnaces that are near end of life or have known hearth problems.

G. Flue gas and bag house: spare in-line fans and motors for the bag house.

H. Turbo blowers: At least one in-line assembled spare blower. In addition to the in-line spare blower, provide a spare set of rotors and diaphragms and key parts. Provide spare parts for any gear box present between the driver and blower.

#### 2.7.4.2 Basic Oxygen Furnace

A. Vessel: a complete BOF vessel, preferably not in service (new or rebuilt).

Alternatively, redundant capacity can be built into the process with two large BOF vessels, with a documented procedure in place to order a replacement vessel when wear and creep measurements show the in-production vessel is approaching end of life.

B. Trunion: A complete BOF trunion (preferably not in service).

C. Tilt drive: trunion shaft, bull gear, tilt drive pinions, tilt motors, and gearboxes.

D. Off-gas systems: large fans and motors.

E. Degassing station: snorkels, dome, or spare vessel for degassing.

F. Argon-oxygen degasser station: a complete new or rebuilt vessel.

### 2.8 Process Safety

2.8.1 For the following processing operations, implement a comprehensive process safety program in accordance with Data Sheet 7-43, *Process Safety*. The facility complexity, hazards, and exposures present in these operations often warrant a comprehensive process safety program.

- Blast furnace
- Blast furnace top gas recovery and downstream combustion, processing, and/or emission
- Sinter, pulverized coal and charcoal production plants associated with blast furnaces
- Coke oven gas combustion and/or emission

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- Coke oven gas recovery and distillation plants.
- Metal distillation processes (zinc, cadmium)
- Blast furnace utility and support systems furnaces including cooling water, cooling air, hot blast air, electrical, fuel, combustion air, and oxygen enrichment.

The following operations would benefit from the core elements of a comprehensive process safety program tailored based on facility complexity, hazards, and exposures:

- Basic oxygen furnaces
- Furnace utility and support systems furnaces including cooling water, cooling air (wind), electrical, fuel, combustion air, and oxygen enrichment.

For these less complex operations, implement the following core process safety elements:

- Management Commitment
- Process hazard analysis (PHA)
- Management of change (MOC)
- Asset integrity
- Contractor Management
- Operators
- Incident Investigation

## 3.0 SUPPORT FOR RECOMMENDATIONS

### 3.1 General

In the iron-making process, iron is separated from the iron ore by one of three processes: blast furnace, direct reduction, or iron smelting.

Technology is continually improving and production control systems are more sophisticated, so blast furnace campaign lives have been increased from 5 years to more than 10 years.

An integrated mill is a large, high-capacity facility that includes all the different processes to make steel from ore. A typical integrated mill will have coke ovens for turning coal into coke, a blast furnace for turning ore into molten pig-iron, a basic oxygen furnace to turn pig iron into steel (probably with some scrap added), a ladle furnace and/or vacuum furnace for adjustment of chemistry, a caster, a re-heat furnace, and a rolling mill. A blast furnace/basic oxygen furnace operation is difficult to start and stop. The blast furnace is a continuous chemical process with product stored in hot molten form waiting in rail cars for the basic oxygen furnace.

A mini-mill is a smaller, secondary steel producer using scrap steel as raw material. A typical mini-mill will have electric arc furnaces or induction furnaces for scrap melting, a ladle furnace and/or vacuum furnace for adjustment of chemistry, a caster, a re-heat furnace, and a rolling mill.

Because the electric arc furnace can be easily started and stopped on a regular basis, mini-mills can follow the market demand for their products easily, operating on 24-hour schedules when demand is high and cutting back production when sales are lower.

An induction furnace is typically used in small capacity facilities and where electrical supplies are uncertain. The lower capital costs also make them an attractive alternative to electric arc furnaces. Refer to Data Sheet 7-33, *Molten Metals and Other Materials*, for further information on molten induction furnaces.

Figure 3.1 shows process flows for integrated steel mills and mini mills.

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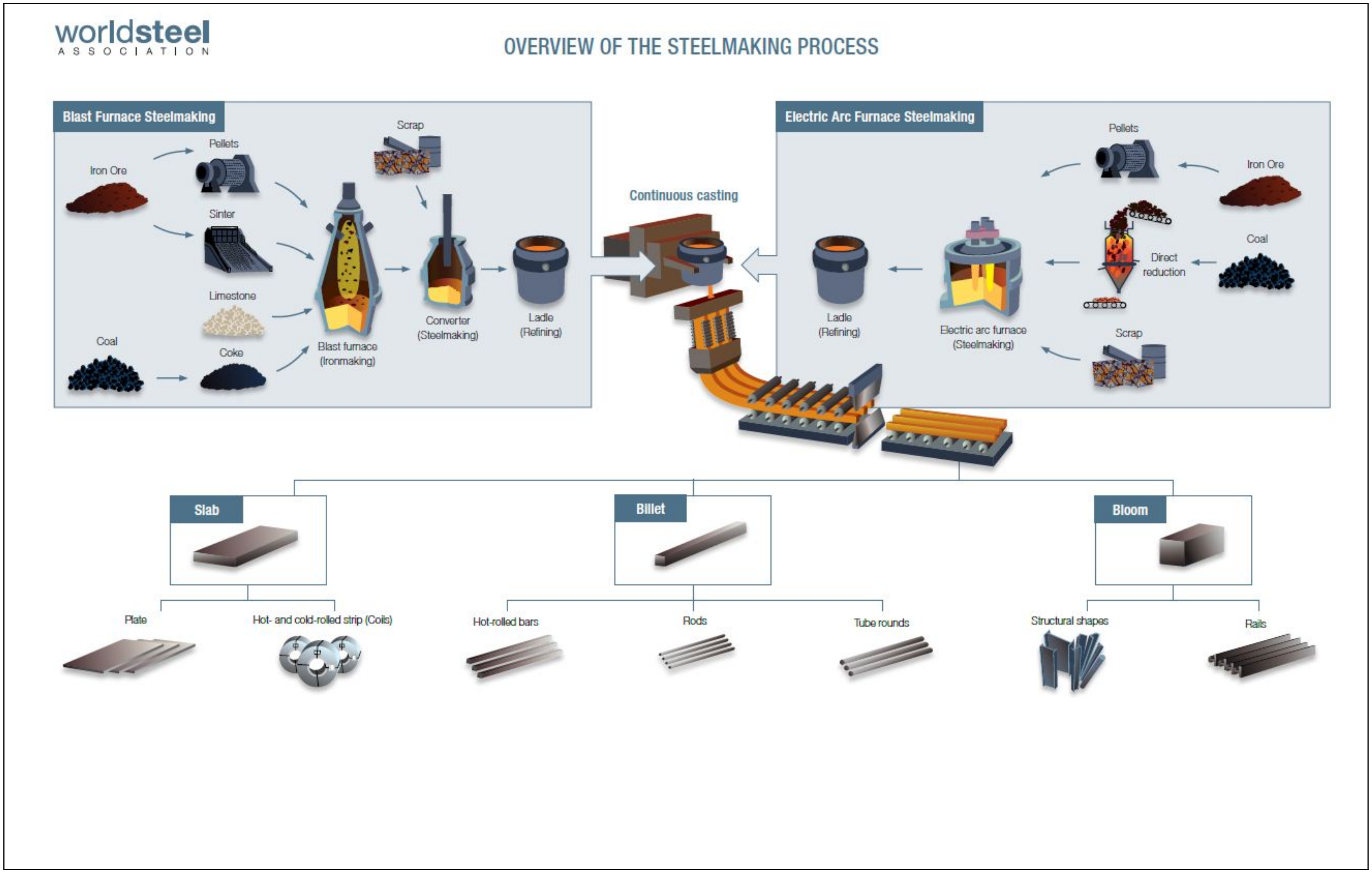


*Fig. 3.1. Process flows for integrated steel mills and mini mills (courtesy World Steel Association)*

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### 3.1.1 Blast Furnace (BF)

The basic steps of ore-based production in blast furnaces are:

A. The ore is crushed, homogenized, and mixed with limestone, then sintered.

B. The sintered ore is fed with coke, iron ore pellets, mill scale, flux (limestone, dolomite, etc.), and basic oxygen furnace scale into a blast furnace.

C. Heated air (blast), coal, and gas injection burns part of the coke to produce heat for the chemical reactions involved and to melt the iron.

Blast furnaces are costly investments; to increase productivity the volume is increased, typically to the extent that daily production has increased from 100 tons to 1000 tons (102 metric tons to 1016 metric tons). This increased productivity causes even more problems with the refractory lining. The thermal level within a blast furnace is very unstable due to irregular fluxes of gas in the furnace associated with noncontinuous combustion of coke. Since coke is very expensive, the industry has tried to use other combustibles such as atomization of pre-heated oil, gas, or coal powder mixed with oil. However, coke is still the most common combustible.

Blast furnaces operate continuously until they need to be relined.

The product produced from a blast furnace is liquid pig iron or solid sponge iron. Both of these products contain large amounts of impurities. The next stage in the production of steel is the refining process, in which these impurities are removed. This is done using a basic oxygen furnace.

Pig iron is tapped from the iron notch at the bottom of the furnace and put into torpedo cars where it is transferred to the basic oxygen furnace.

### 3.1.2 Direct Reduction Iron (DRI)

While direct reduction iron processing is not strictly a molten metal process, a brief description of the process and the hazards is provided below because the subject is not currently covered in any other FM data sheet.

The direct reduction iron process is an alternative way of making iron using natural gas or coal. The process involves the direct reduction of fine iron ore concentrates in a series of reducing gas reactors. The iron is reduced in a solid state (in contrast to blast furnaces, which create iron in a molten state) at temperatures ranging from 1472˚F to 2012˚F (800˚C to 1100˚C). Hot briquetted iron (HBI) is a compacted form of DRI designed for easier handling, shipping, and storage.

In the HBI process, iron ore is reduced to approximately 93% metallic iron using a reduction gas comprised of carbon monoxide (CO) and hydrogen ($H_2$). The process operates at pressures as high as 160 psig (11 bar) and temperatures up to almost 1400˚F (760˚C).

### 3.1.3 Basic Oxygen Furnace (BOF)

Basic oxygen furnaces take molten iron produced in a blast furnace along with scrap steel and various raw materials and refine them into molten steel. In the refining stage iron is processed in either a basic oxygen furnace (BOF), or an electric arc furnace. The BOF is a pear-shaped vessel in which the molten iron is refined by blowing oxygen into the liquid metal by water-cooled lances, and combined with various fluxes and alloys.

The basic oxygen furnace vessel is cradled in a complex water-cooled trunion with shaft and mechanisms to provide tilting (nearly 360 degrees of motion) for skimming slag and pouring steel “heats” (industry term for a batch of molten steel) into ladles. The tilt is usually accomplished with several planetary drive gears turning a large bull gear that rotates the trunion shaft (Figure 3.1.3-1).

The molten pig iron is tapped from a blast furnace at regular intervals (usually every few minutes) and the iron is carried to the blast oxygen shop (also known as the BOF shop or blast oxygen process [BOP] shop) via heavy iron refractory-lined tank cars. Basic oxygen furnaces need to be kept in production to maintain the flow of pig iron from the blast furnace; otherwise, the blast furnace would have to shut down.

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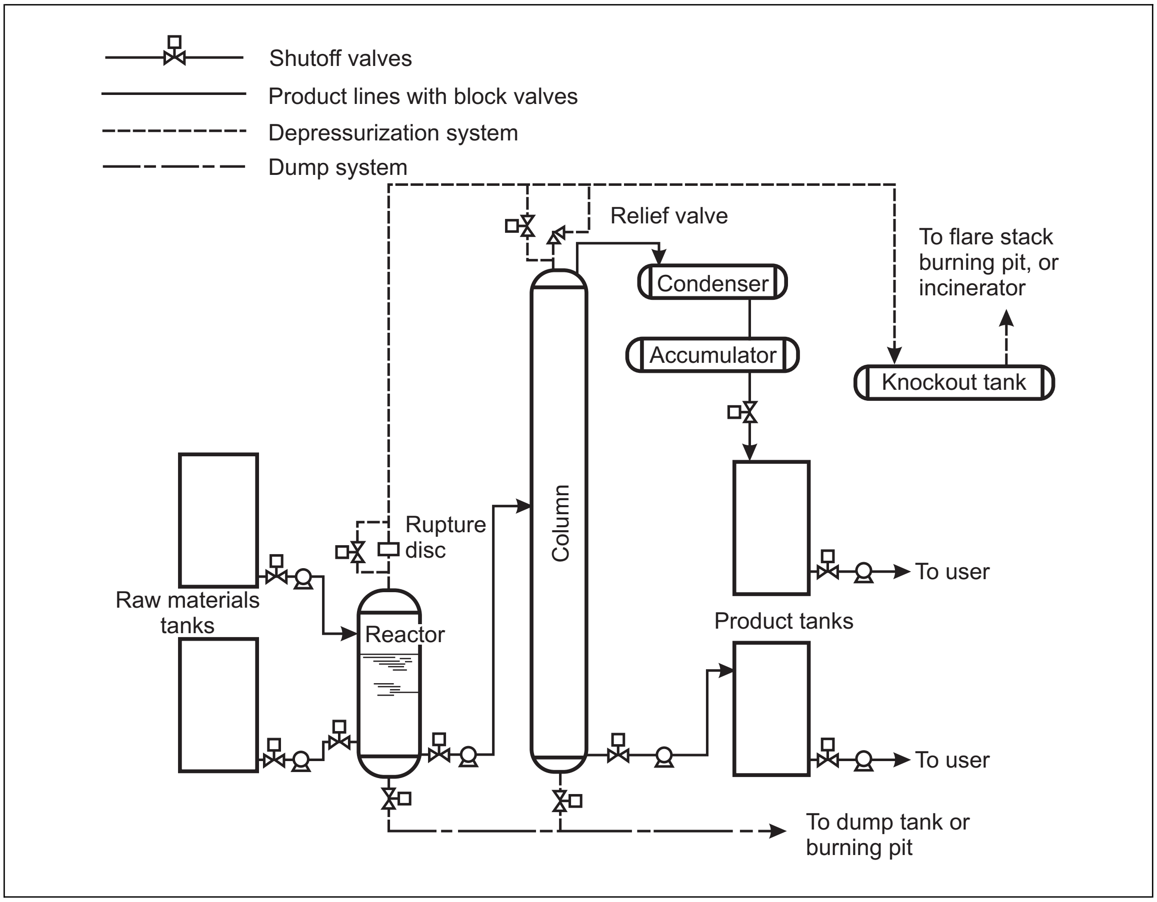


*Fig. 3.1.3-1. Basic oxygen furnace components*

### 3.1.4 Steel Refining Process

Following the steel-making stage, which can be done via a basic oxygen furnace or an electric arc furnace, the liquid steel may go through a ladle refining process where the primary function is the tailoring of the heat chemistry to produce specific grades of steel. Ladle refining refers to the metallurgical processes that are done in the ladle, such as: alloying, degassing, reheating, and stirring. Producing the correct steel chemistry can be done by simply adding bulk alloy, lumps or chunks of alloy, or injectable or wire-encased powders during the ladle refining process. Most ladle refining is accomplished using electric arc furnaces, although some locations use plasma torches.

### 3.2 Routine Spares

The following are common routine spares for furnaces. Store and maintain the routine spares per original equipment manufacturer recommendations to maintain viability. Refer to Data Sheet 9-0 for additional guidance.

- Spare lining/refractory material is available for unplanned/emergency repairs due to very localized thinning or penetration
- Furnace water-cooled components

## 4.0 REFERENCES

### 4.1 FM

Data Sheet 1-6, *Cooling Towers*
Data Sheet 1-62/17-16, *Cranes*
Data Sheet 5-4, *Transformers*

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Data Sheet 5-31, *Cables and Bus Bars*
Data Sheet 7-11, *Conveyors*
Data Sheet 7-21, *Rolling Mills*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-33, *Molten Metals and Other Materials*
Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*
Data Sheet 7-104, *Metal Treatment Processes*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-8, *Operators*

## APPENDIX A GLOSSARY OF TERMS

**Basic oxygen furnace (BOF):** This process is used to transform iron into steel and is the most efficient way of producing low and medium carbon and alloy steels. Oxygen is blown onto the surface of the molten iron to help assist in the process.

**Blast furnace (BF):** A blast furnace is used to make iron from raw materials such as iron ore, lime, and coke.

**Breakout:** The uncontrolled release of molten material from the inside of a furnace, ladle, mold, or other vessel.

**Directly reduced iron (DRI):** Also known as “sponge iron,” it is produced by reducing the raw iron ore into pellets and is an alternative way of making iron (as opposed to using a blast furnace).

**FM Approved:** The term “FM Approved” is used to describe a product or service that has satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide* for a complete list of products and services that are FM Approved.

**Hot briquette iron (HBI):** Hot briquette iron is a compact form of directly reduced iron. HBI is produced to improve the ease of handling, storing, and shipping iron products.

**Integrated mill:** An integrated mill has both iron- and steel-making processes on the same site, as well as downstream casting, rolling, and finishing. The integrated mill will have at least one blast furnace onsite.

**Trunion:** The cradle that the basic oxygen furnace vessel sits in. The trunion also houses the water cooling system for the furnace and provides the means to tilt the vessel to skim off the slag and pour the steel into the waiting ladles.

**Tuyeres:** The nozzles used to deliver oxygen and combustion air into the interior of the blast furnace.

## APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

**January 2024.** Interim revision. The following changes were made as part of the FM Global Data Sheet 7-33, *Molten Metals and Other Materials*, revision.

A. Changed the title of the data sheet from *Molten Steel Production* to *Blast Furnace Ironmaking and Basic Oxygen Steelmaking*.

B. Relocated electric-arc furnace and continuous caster guidance to DS 7-33.

C. Consolidated radioactive contamination guidance to DS 7-33.

**July 2023.** Interim revision. Added additional guidance on standard and emergency operating procedures.

**July 2022.** Interim revision. Minor editorial changes were made.

**January 2022.** Interim revision. Minor editorial changes were made.

**July 2021.** Interim revision. Minor editorial changes were made.

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**July 2020.** Interim revision. Updated contingency planning and sparing guidance. Added process safety guidance.

**October 2013.** Removed recommendation 2.4.1.2 on top gas monitoring on blast furnaces as it was technically invalid.

**January 2013.** This is the first publication of this document.

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