Chapter 9

The Blast Furnace Facility and Equipment

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9.1 Introduction

As an introduction to a discussion of blast furnace construction, it is desirable to establish an understanding of the terms applied to the important dimensions of the furnace. These are shown graphically in Fig. 9.1. However, the following terms may require additional explanation.

Hearth Diameter—The diameter of the circle determined by the inside face of the refractory lining, excluding any increases in the wall thickness at the tapholes.

Hearth Line—The horizontal line at the intersection of a vertical line through the nose of the tuyere cooler and sloping line of the bosh. With ceramic-lined boshes, the line through the noses of the bosh plates determines the slope of the bosh.

Height of Hearth—The vertical distance between the hearth line and the centerline of the taphole. The latter is determined by the center of the taphole opening in the hearth jacket.

Bosh Angle—The acute angle formed by a horizontal line and the slope of the bosh.

Bosh Line—The horizontal line at the intersection of the slope of the bosh and the vertical section of the lower stack or, if there is no vertical section, at the intersection of the slope of the bosh and the batter of the inwall.

Bosh Diameter—The diameter of the inside face of the lining at the bosh line. (This is also the diameter of the straight section above the bosh.)

Height of Bosh—The vertical distance between the hearth and bosh lines.

Inwall Batter—The negative slope of inwall expressed numerically as the base of a right triangle whose altitude is 12 in. and whose hypotenuse is the slope of the inwall.

Bottom Inwall Line—The horizontal line through the intersection of the vertical line of the straight section and the inwall batter. (In furnaces without a straight section above the bosh, the bottom inwall line coincides with the bosh line.)

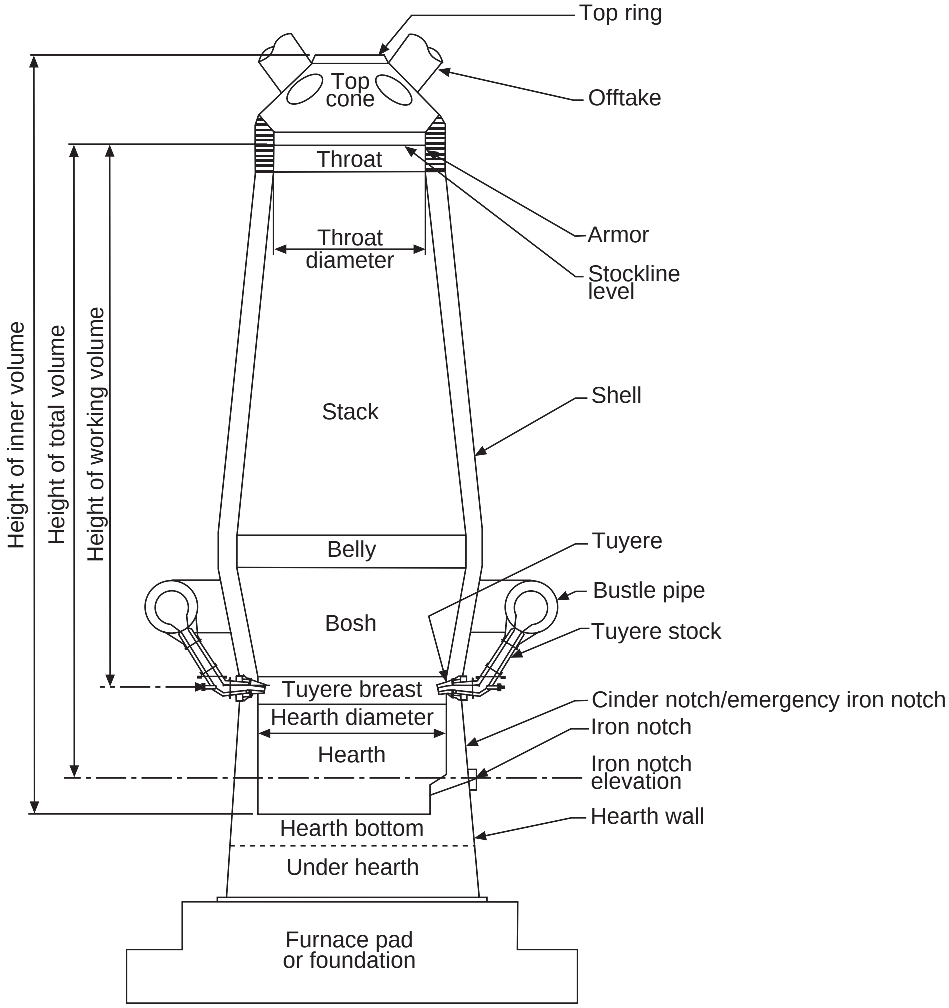


Fig. 9.1 Schematic of a blast furnace, illustrating some of the defined terms.

Belly—A cylindrical section of the lower stack, which connects the upper bosh diameter with the largest diameter of the lower stack.

Bend Line—The horizontal line at the upper termination of the inwall batter.

Height of Inwall—The vertical distance between the bottom inwall line and the bend line.

Stockline Level—1. For bell-top furnaces it is the horizontal line at the bottom of the large bell when closed. Accordingly, a 1.83 m (6 ft) stockline, for example, is the horizontal line 1.83 m (6 ft) below the large bell when closed. 2. For bell-less top furnaces, it is the horizontal line located below the tip of the rotating chute in the 90° (vertical) position.

Stockline Diameter—The diameter from face to face of the brickwork, imbedded armor, or inner face of moveable armor where used at a plane 1.83 m (6 ft) below the stockline level.

Height of Throat Section—The vertical distance from the bend line to the top of the armor or lining.

Throat Bell Height—The vertical distance between the upper termination of the throat section and the bottom of the large bell when closed.

Height between Bottom of Large Bell and Top of Hopper—The vertical distance between the bottom of the large bell closed and the intersection of the hopper or the hopper extension with the gas seal.

Height of Large Bell Hopper—The vertical distance between the inner large bell seat and the intersection of the hopper or the hopper extension with the gas seal.

Bell Overhang—The vertical distance between the bottom of the large bell closed and the inner bell seat.

Annular Space—The difference between the stockline radius and the large bell radius.

Total Height of Furnace—The vertical distance between the centerline of the taphole and the intersection of the large bell hopper or hopper extension with the gas seal.

Working Height of Furnace—The vertical distance between the centerline of the tuyeres and, for bell-top furnaces, and a line 1.83 m (6 ft) below the closed large bell. For bell-top furnaces with moveable armor, the line is 0.91 m (3 ft) below the lower edge of the moveable armor in the vertical position. For bell-less top furnaces, the line is 0.91 m (3 ft) below the tip of the rotating chute in the 90° (vertical) position.

Volume below Tuyeres—The cubical content between horizontal planes through the centerline of the taphole and the centerline of the tuyeres.

Working Volume—The cubical content between a plane through the centerline of the tuyeres and, for bell-top furnaces, the horizontal plane 1.83 m (6 ft) below the closed large bell. For bell-top furnaces with moveable armor, the horizontal plane is 0.91 m (3 ft) below the lower edge of the moveable armor in the vertical position. For bell-less top furnaces, the horizontal plane is 0.91 m (3 ft) below the tip of the rotating chute in the 90° (vertical) position.

Total Volume of Furnace—The cubical content between a horizontal plane at the centerline of the taphole and the bottom of the closed large bell.

9.2 Furnace Proper

9.2.1 Foundation

The weight of a large modern blast furnace is in excess of 10,000 tonnes (11,023 net tons) and at any one time it might contain as much as 5,000 tonnes (5,512 net tons) additional weight in product and burden material. Consequently, the foundation must be capable of supporting this type of load. H-beam piles usually are driven down into bedrock and on top of these is placed a reinforced concrete pad approximately 2.7–4 m (about 9–13 ft) thick.

9.2.2 Support Structure

For most of the modern blast furnaces the hearth rests directly on the foundation and the bosh shell supports the bosh. The stack of the furnace is supported by a mantle ring, which is independently supported by columns (usually 8 to 10) that rest on the foundation. The columnar supported blast furnace is shown schematically in Fig. 9.2. The stack of the furnace is completely encased in a steel shell made from 25 to 51mm (1 to 2in.) thick plates butt-welded together. In some of the older furnaces, the steel plates are overlapped in shingle-fashion and are riveted together. With the columnar supported blast furnace, all of the top charging gear, the topgas uptakes and the top of the skip incline are supported from the steel shell of the stack.

In the mid 1970s a few new blast furnaces were built in the United States with a modification of this general design. This is called the 4-poster construction and is also shown in Fig. 9.2. In this type of construction, the hearth and bosh are supported directly from the foundation, but the mantle, which supports the stack, is suspended by tension members from a heavy box girder that encircles the

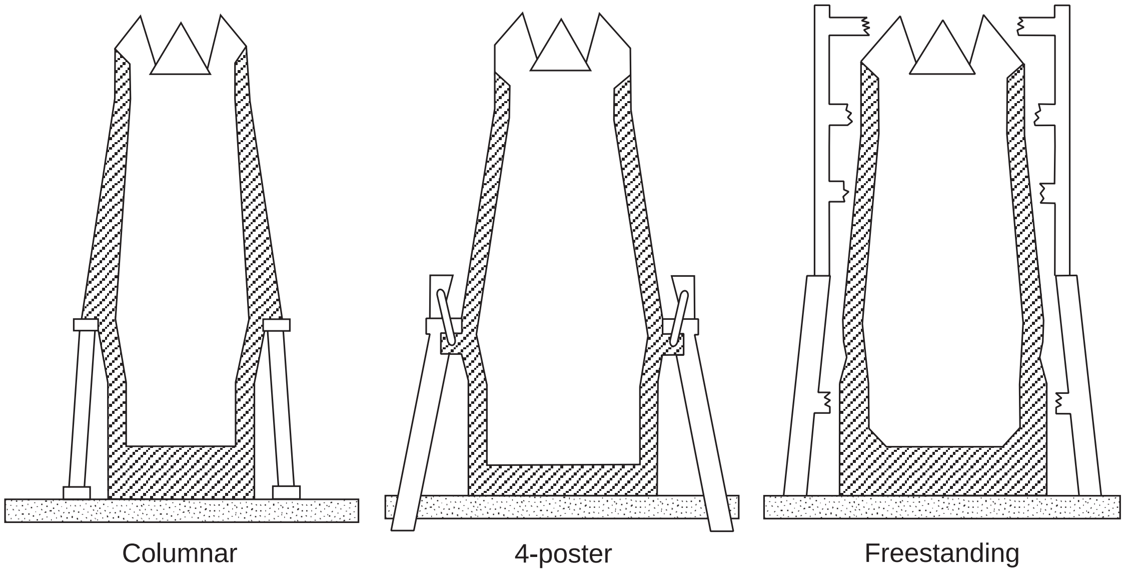


Fig. 9.2 Blast furnace support structures.

furnace. The box girder is supported from the foundation by four tubular steel posts filled with concrete. The design is such that the box girder will remain in position even if one of the posts is completely destroyed.

The other design that new blast furnaces use is a freestanding type of construction which is also shown in Fig. 9.2. In this design, the hearth rests on the foundation and the hearth shell supports the bosh shell, which must be a continuously welded structure, although it will be equipped with openings for various types of coolers. The steel shell of the stack is then supported by the steel bosh shell. A square frame steel structure is built around the furnace, and this supports some of the weight of the stack and of the weight of the top charging gear and uptakes. It also supports the top of the skip incline or charging conveyor belt gallery, whichever is used.

9.2.3 Hearth

The construction of the blast furnace hearth varies widely around the world. In North America, the hearth configuration tends to be a cylindrical shape, externally cooled by water sprays or enclosed water panels or by cast iron staves placed between the steel jacket and the refractories Stave coolers are cast iron segments, containing internal water pipe circuits embedded in the iron block.

In Europe and Asia, most hearth configurations are conical-shaped, which permits a thicker wall at the location of the hearth pad and wall lining interface. This location in the lining has been historically very troublesome in Europe and Asia, as was discussed previously in detail in Section 4.3. Cooling of conical hearths is identical to cylindrical hearths.

The best hearth configuration is one that provides a completely gas-tight shell including a bottom sealing plate. This is the only way to assure that gas migration, and consequently air gaps, will not form between the cooling surface and the refractory cold face. Refractory life can be drastically reduced if contact with the cooling contact is lost. However, many North American blast furnaces and other smaller diameter worldwide furnaces have non-gas-tight bottoms. In these furnaces, gas leaks through the brickwork requiring that the gas be ignited when the furnace is in operation. If gas leaks are too pronounced, periodic injections of a carbonaceous, thermally conductive material are pumped (grouted) between the cooling surface and the refractory cold face. This grout material serves two purposes: (1) it seals off the gas leaks, which, if severe, can pose a safety risk, and (2) it reestablishes contact between the cooling surface and the refractories.

The ideal hearth configuration will include a pad of conductive refractories and will also include underhearth cooling of the bottom pad. This cooling is utilized to enable the relatively thick, conductive refractory mass of the pad to achieve a thermal equilibrium and to locate the solidification temperature isotherm as high in the pad as possible. This will assure that any molten material that migrates below this solidification isotherm location (the *freeze point*), will be chilled and thus solidified.

The cooling methods used vary and can include forced or induced draft air flow through pipes located within the pad refractories, or through plenum weldments located below the conductive refractories of the pad or below the sealing plate. The most effective cooling method is to utilize water circuits via pipe coils located below the sealing plate. Earlier furnaces utilized oil instead of water as the cooling medium because of the perceived danger of steam oxidation of carbonaceous refractories or explosions in the event of water pipe leakage or molten iron contact with the pipes. The connections of all cooling pipes should include a gas-tight seal where the pipes penetrate the pressure-containing shell components. Additionally, design provisions must be made at these connections for the different expansion of the cooling pipes relative to the steel shell.

Many North American and worldwide blast furnaces with hearth diameters smaller than approximately 9.1 m (30 ft) are not equipped with underhearth cooling. Generally, on very small blast furnaces with hearth diameters below 7.9 m (26 ft), cooling of the underhearth can be accomplished by utilizing the conductive carbon walls and hearth pad alone, without a separate under-pad cooling system. However, optimum pad performance requires that some type of underhearth cooling be utilized above this size.

Graphite refractories with a very high thermal conductivity can be utilized in these non-underhearth cooled pads as a cooling layer. A layer of graphite approximately 419 mm (16.5 in.) thick can simulate the effects of air underhearth cooling. This is accomplished by the graphite layer, which intercepts heat from the pad and directs it towards the wall water cooling. When this graphite underhearth cooling layer is utilized, it is also important that the entire graphite layer thickness be in contact with the water cooled shell or stave and that refractory materials be located below the graphite layer to protect the sealing plate or furnace foundation from high temperatures conducted through the graphite.

It should also be noted that there are smaller blast furnaces in North America and worldwide that are not gas-tight and not underhearth cooled that utilize ceramic instead of conductive carbon in the hearth pad refractories. This traditional hearth configuration depended upon the ceramic to contain the molten materials as they slowly penetrated into the large ceramic mass. It is impossible to achieve a thermal equilibrium in this type of configuration, so the penetration into the pad depth never stopped as long as the furnace operated. Of course, as the distance between the taphole and the penetration increased, the rate of penetration was slower. This is because iron viscosity increases as temperatures drop and thus erosion of the ceramic slows considerably. However, it never stops and thus this configuration depends upon having enough mass of ceramic available to survive the penetration expected for the lifetime goal. This estimate of lifetime is usually based on historical performance of pads of this type for the particular furnace in question. Obviously, the larger the furnace diameter, the deeper the provided ceramic would have to be to contain the expected penetration. However, most blast furnace campaign life goals, preclude the use of these traditional, full ceramic pads (sometimes called ceramic *plugs*).

The preferred, modern hearth pad will include a system of leveling which may consist of a thin, ceramic castable layer, leveled graphite tiles or other leveled carbonaceous layer. On top of this leveled layer is placed the conductive, carbonaceous refractories which comprise the pad. These materials can be graphite, carbon, semi-graphite or semi-graphitized carbon, or combinations of one or more of these same materials. Descriptions of these products and their characteristics are provided in Section 4.3. The materials utilized are generally in large block form, with cross sections up to 749×597 mm (29.5×23.5 in.) and lengths up to 5.3 m (17.5 ft). A rammed annulus of carbonaceous materials is usually used between the pad blocks and the cooling member or shell wall. Many furnaces also incorporate a top layer of ceramic to contain the molten materials and keep them away from the carbonaceous zone. The philosophy of which materials to utilize in this zone is also discussed in Section 4.3.

The total pad thickness will vary depending on many factors. Usually, the top-of-foundation elevation and the taphole centerline elevations are fixed and impossible to change. Thus, total pad thickness is determined by considering the thermal efficiency of the pad configuration necessary to locate the solidification isotherm high in the pad and still retain an acceptable taphole centerline to top-of-pad distance.

This distance from taphole centerline to top-of-pad varies considerably depending on geographical location. In North America, this distance is usually approximately 762–1143 mm (30–45 in.) depending upon furnace diameter. In Europe and Asia, this distance can be 1.83–1.98 m (6–6.5 ft), again depending upon furnace diameter.

The reasons for this greater distance are to provide a deep well of molten materials, which provides slower velocities during furnace tapping. It is believed by some operators that high fluid velocities during furnace tapping contribute to hearth refractory erosion, especially when the hearth refractory concept prevents protective accretions (skulls/scabs) from forming on the walls. This is discussed in detail in Section 4.3. However, in North America, relatively short taphole-to-pad distances are utilized with success, apparently because the hearth refractory concepts utilized are successful in achieving long term protective accretion formation.

It is also theorized that deep-well hearths also offer a possibility of providing buoyancy for the stagnant coke zone (*deadman*). This material forms a column or bed of packed coke that extends into the hearth. This mass of coke sinks into the molten metal and slag and it is theorized that the depth to which it penetrates is determined by the equilibrium between the downward force on the column from above and the buoyancy force exerted by the molten liquids. If the downward force is greater than the buoyancy force, it is theorized that the column will rest on the top of the hearth pad. This would then result in a relatively impermeable mass of coke in the furnace center, resulting in peripheral wall flow of molten materials during furnace tapping. This would theoretically result in wall wear if a protective accretion were not present. Conversely, if the downward force on the coke column is less than the buoyancy force, the column would float in the molten mass of metal and thus more flow area would be available during furnace tapping, thus reducing velocities of the molten materials. This phenomenon underscores the desire for a deep well.

Hearth wall refractory configurations also vary geographically and in accordance with historical experience. These concepts are described in detail in Section 4.3. In North America, walls are configured utilizing high conductivity, hot-pressed carbon, in small brick form, laid tightly against the cooling member in a film of carbonaceous mortar. The walls themselves are comprised of multiple rings of bricks so that from hot face to cold face each ring can expand independently and differentially from each other, Fig. 9.3(a). This prevents stress cracking, which can adversely affect heat transfer, as discussed in detail in Section 4.3.

Hearth walls in Europe and Asia typically are configured in large blocks of carbon or semi-graphite, which requires an annulus of carbonaceous ram between the cooling surface and the refractory cold face. This rammed annulus is an impediment to effective heat transfer, especially if the ram material is improperly installed, which happens very often. The wall blocks are installed radially in a single thickness from hot face to cold face,. Fig. 9.3(b). This arrangement is subject to stress cracking and pinch spalling of the blocks due to a lack of differential expansion accommodation capability. This cracking, which creates air gaps, and the ineffective heat transfer of the rammed annulus combine to result in wall material deterioration over time. For this reason, alternative corrective actions are sometimes utilized to prolong hearth wall life, such as the charging of titanium-bearing ores or sands with the burden to help provide a temporary build-up of titania on the wall surfaces. However, this results in a fuel rate penalty, and if the charging of these materials is stopped, the build-up also wears away and stops. Sometimes these titanium-bearing materials are injected into the tuyeres in an attempt to utilize hot metal movement in the hearth to deposit them on the walls. These practices have not proven reliable or predictable, however.

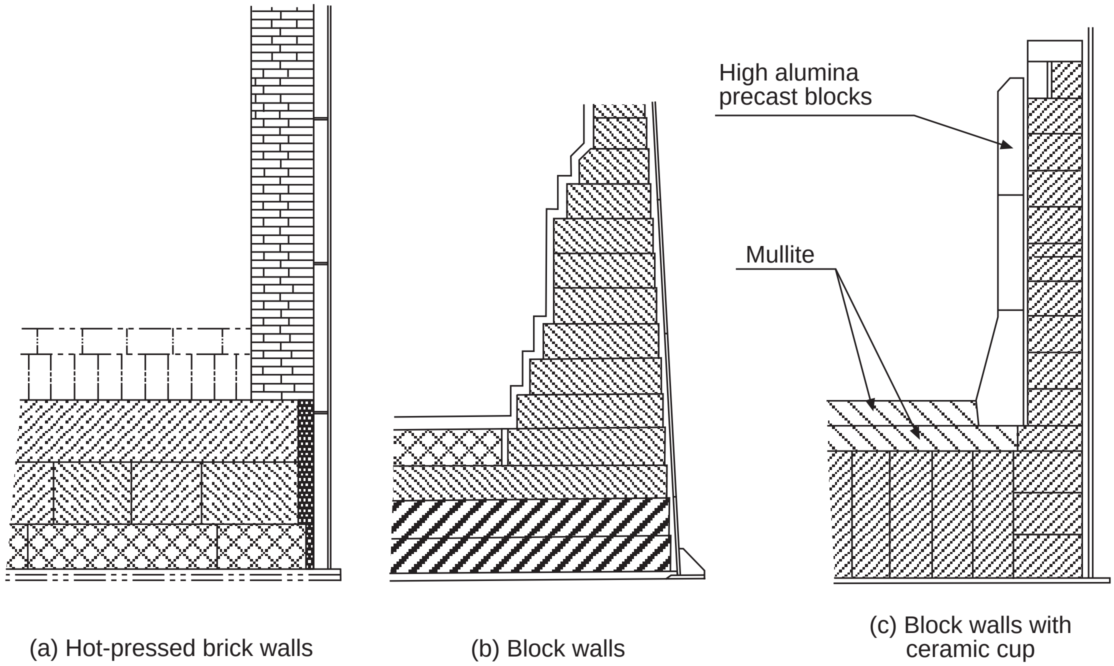


Fig. 9.3 Hearth wall refractory configurations.

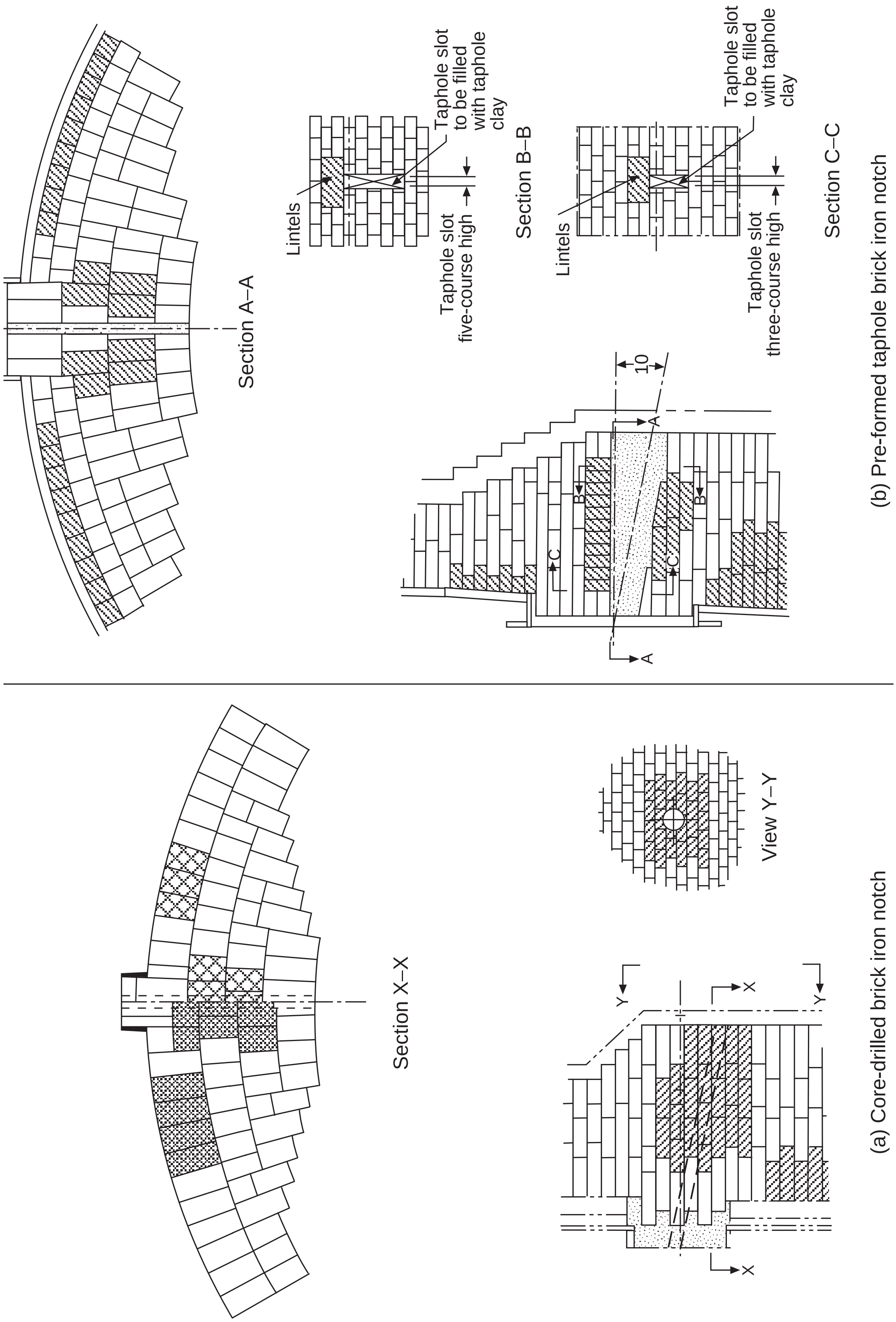
Another corrective action that has been utilized in Europe and Asia is to incorporate a layer of high melting point ceramics on the wall hot face, Fig. 9.3(c). The idea is to provide an insulating wearing surface on the hearth wall to protect the carbon as long as the ceramic remains in place.

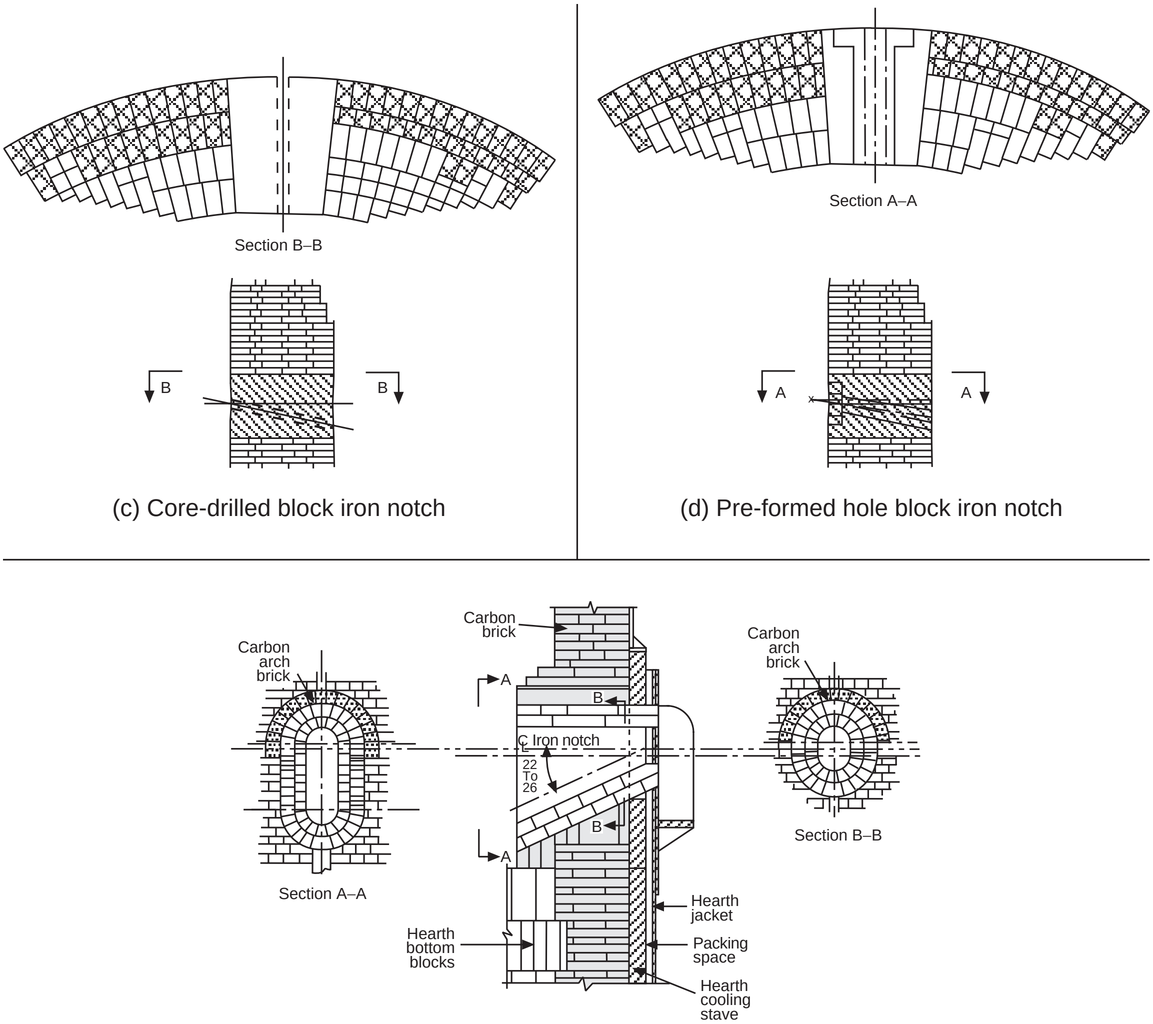
Survivability of this ceramic layer depends upon uninterrupted cooling by the carbon wall behind it. The rammed annulus used between the carbon and the ceramic liner proves to be a weak link and, combined with carbon block deterioration, ultimately causes the loss of cooling integrity required. Long lifetimes are therefore contingent upon the success of heat transfer capability, which is impossible to predict with any certainty due to the dynamic environment of the heat furnace. This concept discussed in detail in Section 4.3.

The North American hot-pressed carbon brick wall concept has also been successfully utilized in Europe, Asia and Africa, replacing large block wall concepts. Often the hot-pressed brick is extended downward into the pad zone to provide a shell wall between the large block pad carbon and the cooling member. This configuration is shown in Fig. 9.3(a). The purpose of this shell wall is to provide a chilled surface *safety lining* that will result in the solidification of any molten materials which may migrate towards the walls during extended campaigns. This often happens as the result of bottom pad carbon block cracking during previous shutdowns and restart-ups, which allows molten materials to penetrate into the pad and sometimes towards the shell.

The hearth wall also contains various openings in the furnace to permit the evacuation of molten materials. One or more iron notch openings are provided to tap iron and slag intermittently from the furnace. Often, on very large or very high productivity blast furnaces, tapping of iron and slag occurs almost continuously utilizing multiple iron notches. Most older furnaces contain a single iron notch. Modern, high productivity furnaces will contain at least two, preferably three, and as many as four iron notches.

The configuration of iron notches varies considerably. There are too many variations to describe completely, but each iron notch usually reflects historical operating practice requirements. Typical iron notch configurations are shown in Fig. 9.4. The actual taphole will be a drilled hole, usually on a downward angle between 3° and 15° (or more on smaller, older furnaces). The taphole angle is usually shallower the higher the operating pressure of the blast furnace. This is to prevent an


Section A–A
Lintels
Taphole slot
to be filled
with taphole
clay
Taphole slot
five-course high
Section B–B
Lintels
Taphole slot
to be filled
with taphole
clay
Taphole slot
three-course high
Section C–C
10
A
B
C
(b) Pre-formed taphole brick iron notch
Section X–X
View Y–Y
Y
X
(a) Core-drilled brick iron notch



(e) Ceramic iron notch

Fig. 9.4 Typical iron notch configurations

arced discharge stream of iron and slag that would result from a steep taphole angle on a high pressure furnace. The splashing and turbulence of such a stream would be objectionable for safety, environmental and refractory wear reasons. Smaller tapholes angles result in tighter, high velocity streams that reduce turbulence and emissions.

Often, the furnace operator prefers an iron notch configuration that will provide the capability of tapping at variable angles from true horizontal (0°) to 15° downward or more. This can be accomplished by merely drilling additional holes in the iron notch wall at the predetermined location. Some operators prefer that a slotted opening configuration be provided in the iron notch, approximately 102–152 mm (4–6 in.) wide, that is rammed with taphole clay. The multiple holes that are drilled then penetrate cured taphole clay and not the iron notch wall refractories. This configuration is shown in Fig. 9.4(b) and 9.4(d).

Iron and slag are generally removed from the iron notch. Traditionally, one or more auxiliary openings located approximately 0.91–1.5 m (3–5 ft) above the taphole centerline were utilized to tap furnace slag. These *cinder notches* (or slag notches) were required because of the very high slag volumes that resulted from raw ore burdens in the past years. It was an advantage to periodically remove these large slag quantities prior to tapping the iron to decrease the high level of liquids in the hearth. Additionally, the slag attacked the traditional iron notch ceramic refractories that were previously used quite easily. Thus, the tapholes could erode severely if large volumes of slag were encountered, making closing of the tapholes very difficult. Today, almost all modern furnaces utilize conductive refractory materials and carbonaceous or resin taphole clays, which are more suitable for slag contact. Additionally, slag volumes are low enough to allow their removal during furnace tapping. As slag is lighter in density than iron, the appearance of slag during the tap signals that the casting period at that taphole is near an end because all of the heavier iron, which is below the slag, has been evacuated.

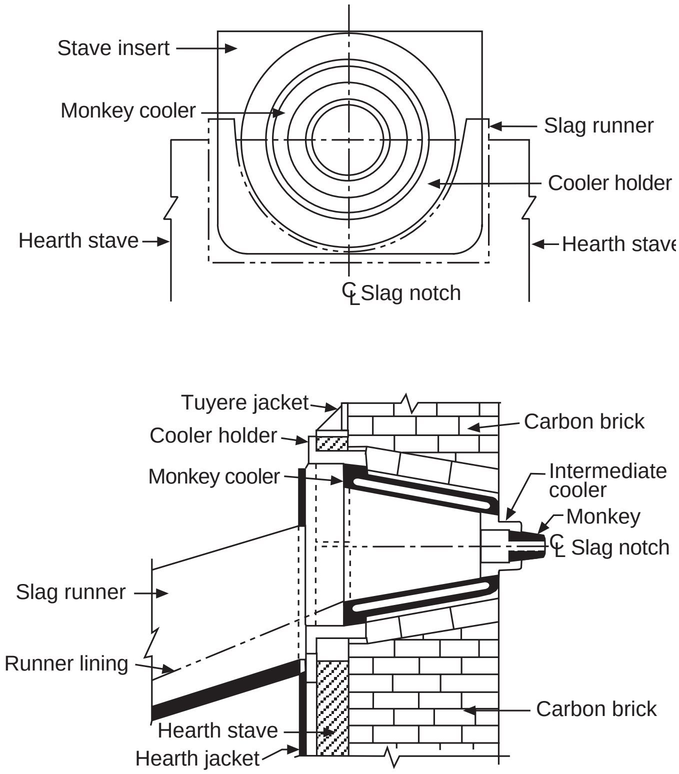


Fig. 9.5 Section and developed view of a cinder (slag) notch.

When a cinder notch is utilized on a furnace, it is generally comprised of water-cooled copper elements, configured concentrically as shown in Fig. 9.5. Liquid slag does not dissolve copper, as liquid iron would do, therefore this proved to be an effective configuration. Sometimes, a furnace operator desires the capability of a slag notch for removing slag from the furnace that develops immediately after blow-in. However, after normal operation is achieved, there would no longer be a need for a separate slag notch. In this case, the copper-cooled element slag notch configuration would not be used. Instead, either an auxiliary taphole located above the normal taphole would be provided, or provisions made in the furnace jacket cooling, to allow for drilling a special carbon or graphite plug, located in the hearth wall, to tap the slag. After initial use, the plug is filled with taphole clay and a water-cooled element installed on the plug cold face for the duration of the campaign.

Good taphole practice requires that taphole length be suitable to provide the desired tapping rate (speed) compatible with the furnace internal pressure. This also requires that the tapping rate be relatively constant during the entire casting time. This requires that the actual drilled taphole must not erode significantly during the cast. Otherwise, as the hole erodes, casting rate increases, disrupting burden descent and increasing turbulence and refractory wear.

Most modern furnace hearth linings incorporate a thicker wall in the iron notch area. The total taphole length desired, including the nozzle length attached to the furnace shell, generally determines this *abutment* thickness. Total taphole length is calculated from the taphole drill impact workpoint, to the hot face of the iron notch abutment wall, measured on the slope of the taphole angle. Most high performance blast furnace operators prefer taphole lengths of 1.5–2.1 m (5–7 ft).

The thicker abutment walls required to provide these taphole lengths sometimes require additional zones of high conductivity refractories such as graphite and semi-graphite on their cold face. These materials extend the reach of the sidewall cooling and thus lower the abutment hot face temperature so that protective accretions may form. This is shown as the cross-hatched areas in the configurations shown in Fig. 9.4.

The iron notch configuration can also include zones of high conductivity refractories surrounding the taphole in the center of the abutment. These highly conductive materials are carefully arranged so that they are isolated from the wall cooling by lower conductivity carbon. Thus, during the actual casting, these highly conductive refractories absorb the heat of the cast and, because they are isolated from the cooling by the lower conductivity wall refractories, act as heat sinks. Once casting is terminated and taphole clay is injected to stop the hole, this superheated zone of high conductivity refractory intensely bakes the clay in the center of the abutment. This assures that the clay in the taphole is cured completely along the entire taphole length. Sometimes a metal rod (soaking bar) is driven into the newly injected taphole clay immediately after taphole plugging. This bar is intended to provide a means to transfer heat from the furnace interior, along the taphole length, for clay curing. Additionally, the bar provides an easy and dependable method for opening the hole for casting. The bar can be withdrawn in a swift, continuous motion, opening the taphole like pulling a stopper out of a bottle. However, this practice often can only be utilized 80–90% of the time, so the incorporation of the high conductivity refractory core in the abutment center will assure proper clay curing 100% of the time. Many furnaces that utilize the soaking bar practice, but that do not incorporate the high temperature refractory core, often cannot properly cure the central part of the taphole clay. This is because the casting frequency and the abutment thickness combine to prevent proper clay curing in the time available between casts despite the conductive steel bar. This can be seen quite easily when the bar is withdrawn for casting when a dark zone will be evident between two, bright orange, luminous zones in the bar. This dark zone is evidence of the cold zone in the abutment that prevents proper clay curing.

As the blast furnace operates over time, the hearth refractories will slowly reach a thermal equilibrium condition. At this time, depending upon the refractory concepts employed, some refractory material will be lost to thermochemical wear and erosion. This was discussed in detail in Section 4.3. The hot metal that resides in the hearth below the taphole location at the hot face of the abutment cannot be removed from the furnace. As time progresses, the wear penetration into the hearth pad increases this unavailable metal volume. At the end of the campaign, some operators will drill and tap this reservoir of metal, which is called the *salamander* or *bear*. Other operators will allow this mass to chill during rebuild or relining of the bosh and stack when the hearth refractories are scheduled for reuse without repair. The solidified salamander is then re-melted during the subsequent start-up as temperatures rise after blow-in . Care must be taken to assure that considerations for differential thermal expansion between the salamander and the wall refractories are incorporated prior to blow-in. These measures can include trenching the salamander (digging an annular space) around the interior of the hearth wall or allowing the furnace jackets to be heated during blow-in by not using cooling towers in the water circuits or by the use of steam to heat the steel.

9.2.4 Tuyere Band

The upper zone of the hearth wall contains the openings for the tuyeres which are used to introduce the hot blast wind into the furnace. The furnace jacket in the tuyere zone contains steel reinforced openings within which copper-cooled elements are installed, similar to that shown in Fig. 9.6. The steel reinforcements in the jacket are called tuyere cooler holders. The large copper cooler that is installed within the machined inner surface of the cooler holder is called the tuyere cooler. The copper cooler that actually introduces the hot blast wind into the furnace is called the tuyere. It is installed within a machined, inner seating surface on the tuyere cooler. The blowpipe is part of the tuyere stock wind distribution piping, which delivers the hot blast from the bustle pipe, and which mates with the tuyere, to direct the wind into the furnace.

The tuyere breast walls are usually made of carbon brick and the cooling is generally external with jacketed cooling channels on the outside of the shell. Some furnaces have internal staves in the tuyere breast between the tuyere coolers as a cooling design for the tuyere breast.

Fig. 9.6 also shows the arrangement of the tuyere cooler holder, which fits in the opening of the steel shell, the tuyere cooler that fits into the holder and the tuyere that fits inside the cooler. The surfaces where the tuyere and the cooler contact each other are machined to give an airtight fit.

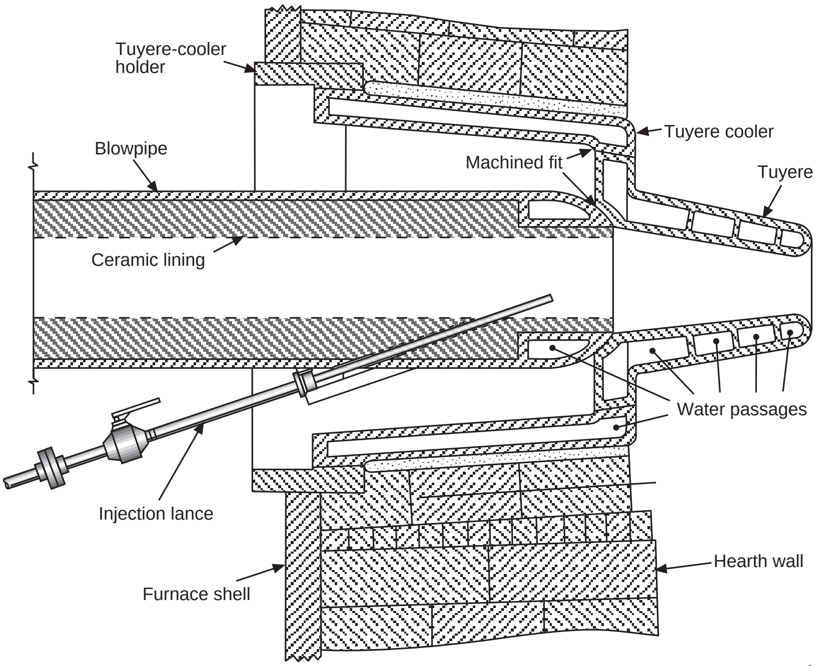


Fig. 9.6 Tuyere and blowpipe assembly.

9.2.5 Bosh

The bosh of the blast furnace is the region just above the tuyere breast and can be described as the frustum of an inverted cone that connects the tuyere breast to the level of maximum diameter of the stack. In the blast furnaces of 100 or more years ago, the bosh angle was very shallow so that the bosh supported much of the weight of the burden material and had only enough slope to allow the melted slag and iron to flow down into the hearth. On modern blast furnaces, however the bosh angle is much steeper and is usually about 80°. Many of the blast furnaces in the United States have bosh angles between 79° and 82°, but the most recently constructed ones tend to have smaller bosh angles. The ideal bosh angle for a 12,000 tonnes per day (13,228 net ton per day) blast furnace has been reported as 76°. This angle is reported to give smoother and more uniform movement of the burden material.

The ideal bosh configuration consists of a gas-tight steel shell. Many older furnaces utilized an open-type bosh jacket

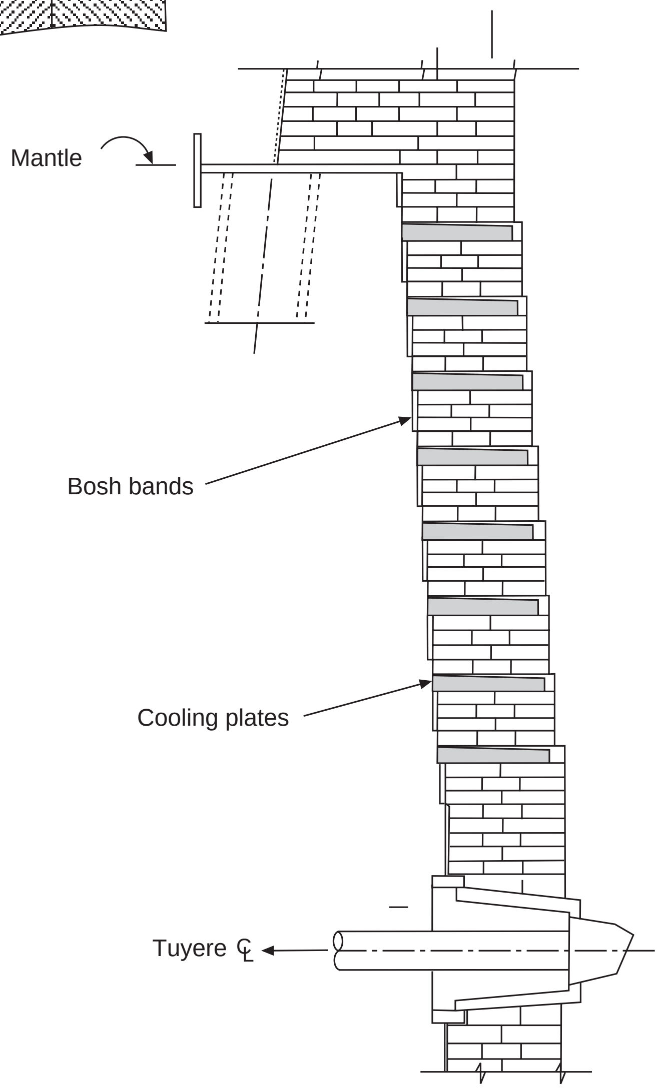


Fig. 9.7 Bosh band configuration with copper plate cooling.

comprised of a series of steel rings called bosh bands, arranged in a step-like ascending arrangement. Each successive band was larger that the one below it and the lining utilized with this scheme also stepped back so that its cold face rested against the corresponding band. Because the bosh was not pressure-tight, gases easily escaped this configuration and were ignited and left to burn as long as the furnace operated. This resulted in a bosh exterior that was covered in lazy blue gas flames. This type of configuration is shown in Fig. 9.7.

Open-type bosh configurations are not compatible with modern, high productivity, high pressure furnace operations. Enclosed, gas-tight jackets are utilized instead. Cooling can be provided externally on the jacket exterior utilizing water sprays or enclosed water panels. This is shown in Fig. 9.8. The panel-type cooling has a distinct disadvantage because water velocities are generally low. This results in material and sediment build-up within the water chambers, hindering heat transfer. Additionally, if chemically untreated water is utilized, mineral build-ups occur on the interior of the water chambers, seriously impeding heat transfer and jeopardizing refractory life. Another problem is that the jackets cover the entire surface of the pressure-containing jacket, which prevents visual indication of abnormal shell conditions such as cracks or hot spots. Both types of external cooling remove heat from the refractory cold face. This requires special attention to refractory type and configuration, to assure proper hot face temperature. This is discussed in detail in Section 4.4.

Most high productivity blast furnaces will utilize either stave cooling or plate cooling in the bosh. Stave cooling utilizes cast iron or copper elements, which contain pipes or integrated flow passages for the water, installed within the steel jacket. A typical stave arrangement is shown in Fig. 9.9. The stave system also cools the bosh refractory from the cold face only, which requires special attention to refractory type and configuration, to assure proper hot face temperature. Additionally,

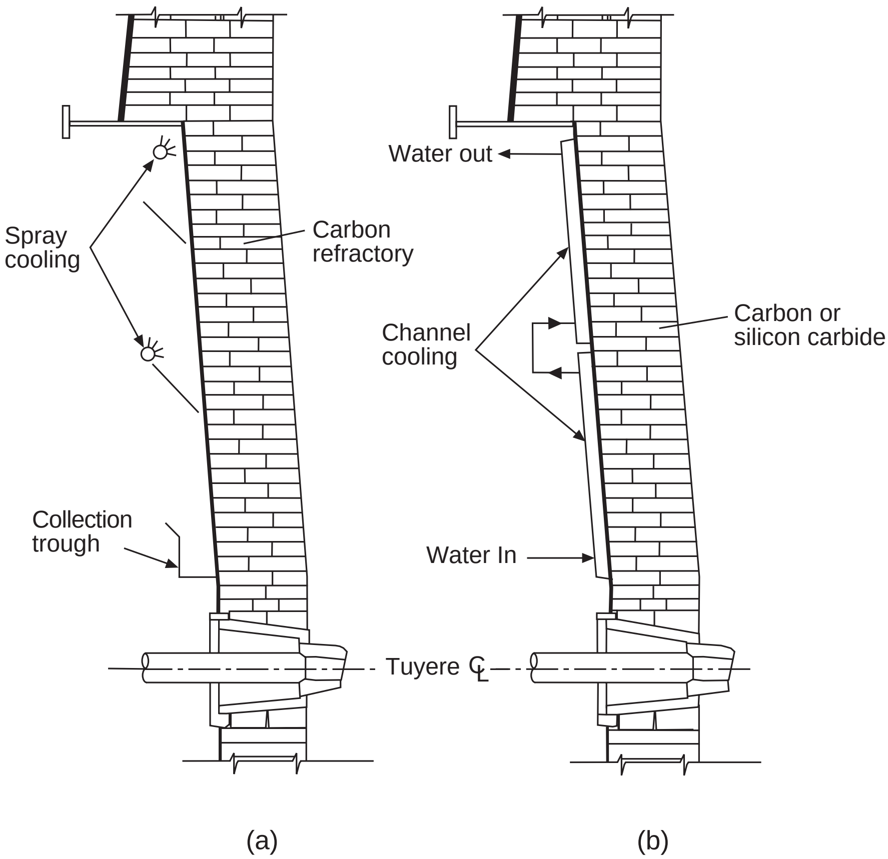


Fig. 9.8 Cooling types for gas-tight bosh jackets: (a) spray cooling, (b) enclosed water panels or channel cooling.

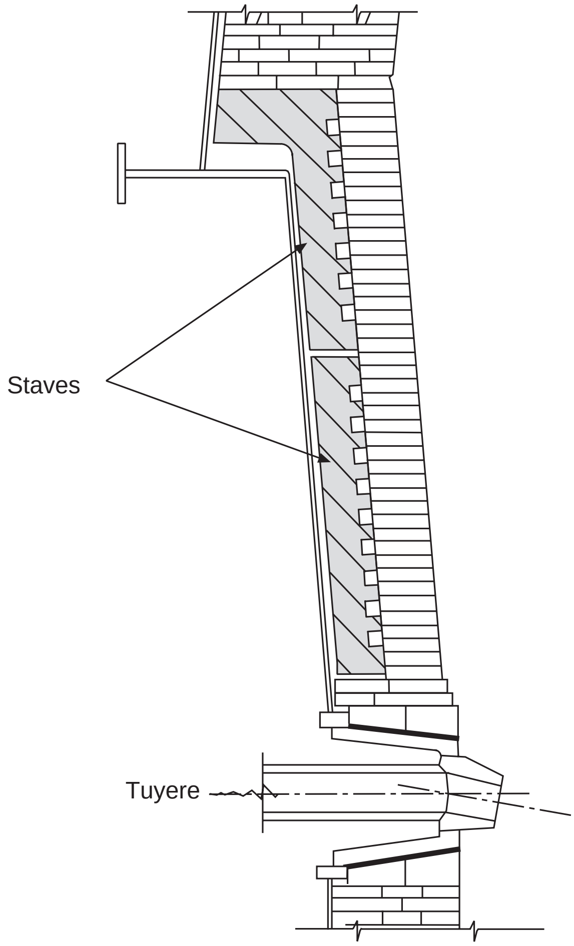


Fig. 9.9 Cast iron stave cooling.

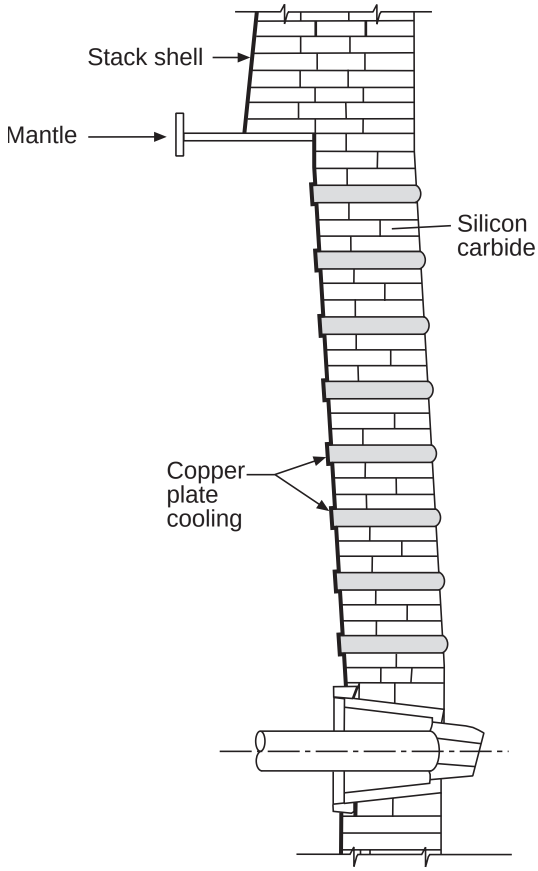


Fig. 9.10 Bosh cooling by radially spaced copper elements.

because staves are installed totally within the pressure-containing vessel, replacement of damaged components requires operations interruption and blow-down.

The original intention for stave cooling was that refractories would be quickly lost and that the staves would have to operate *naked*, that is, with no refractories on the hot face. This situation would then subject the staves to the process environment and ultimate wear and failure. However, the chilled surface of the stave encouraged the formation of protective accretions on the stave hot face. Unfortunately, as furnace gas patterns change these protective accretions often fall off exposing the stave to thermal shock, high heat load and ultimately wear and sometimes failure. The optimum situation for stave coolers is to be able to maintain a refractory hot face for as long as possible to isolate the stave from the process environment. Refractories resistant to shock and chemical attack are available to accomplish this purpose, including the adoption of conductive stave *insert* linings. These philosophies are discussed in detail in Section 4.4.

Another popular bosh cooling method utilizes individual copper cooling elements inserted radially in a dense pattern from the hot face of the refractory to a gas-tight connection on the jacket. This arrangement is shown in Fig. 9.10. These coolers are arranged in rows, and are radially spaced so those coolers located in the above row overlap gaps between coolers in the lower row. This arrangement has the advantage of cooling the refractories from within the wall and the added advantage that the coolers are individually replaceable during short off-line periods such as maintenance stops.

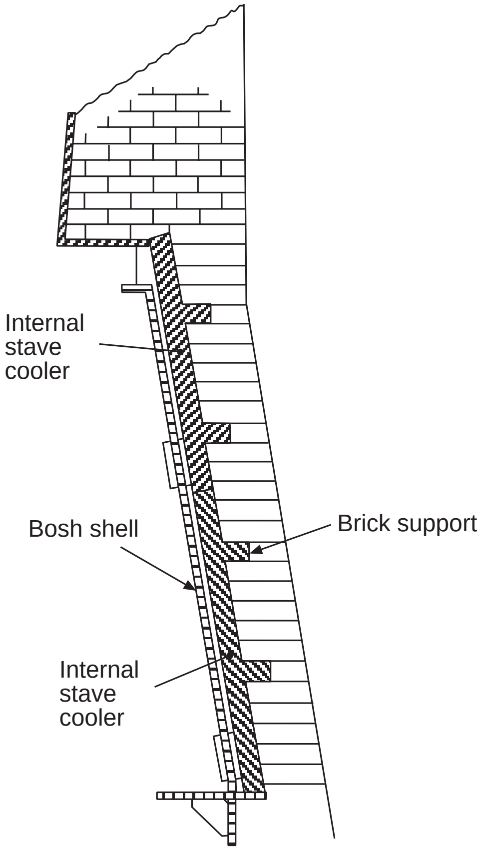


Fig. 9.11 Cast iron staves with brick supports.

Another important function that inserted copper coolers provide for the refractories is physical support. This is important as refractories wear. Often, this wear occurs more deeply in the upper part of the bosh. If it were not for the supporting action of the inserted copper coolers, this wear could result in the collapse of refractories above the wear zone. Similar support can be provided by brick supports (or shelves) built into the face of cooling staves as shown in Fig. 9.11.

The inserted copper coolers also provide chilled surfaces that protrude beyond the refractory wall wear and promote the formation of protective accretions. Process materials and vapors also can condense on these cooled surfaces, providing abrasion protection. It is also possible to configure the refractories to achieve the same purpose and to provide support and anchorage for sprayed-on gunite-type hot face linings.

The trend is to design and configure bosh cooling and lining systems that will satisfactorily perform for ten to fifteen years after installation with a minimum of repair. This requires careful consideration of a variety of external and internal factors relative to the bosh lining. These factors are described in detail in Section 4.4.

Modern bosh lining configurations are comprised of a variety of materials, often in composite linings containing two or more types of refractories. This is done to combat expected wear mechanisms and to control refractory temperature. This is discussed in detail in Section 4.4. Because the bosh is subjected to severe temperature fluctuations, thermal shock resistant refractories such as semi-graphite and graphite have found favor.

9.2.6 Belly and Stack

In most blast furnaces, the widest dimension of the inside of the lining is at the top of the bosh, and there is usually a vertical, straight section just above the bosh with the same diameter as the top of the bosh. This section is called the *belly*. Above this vertical section, the lining of the stack tapers inward up to the stockline area. In some older furnaces, there is no vertical section or belly and instead the outwardly sloping inner surface of the bosh intersects the inwardly sloping stack lining directly.

The configuration of the lining at the top of the bosh is impacted by the method of supporting the furnace shell structure. Traditionally a horizontal ring girder called a mantle or lintel supports the upper furnace shell structure. This mantle girder is supported by eight (8) sloping steel columns or a 4-poster design. Both of these concepts are shown in Fig. 9.2. The bosh, tuyere and hearth jackets are self supporting and only attach to the mantle for stability and gas tightness. The stack shell was installed to a greater inner diameter than the top of the bosh shell, which provided a distinct step on which the stack refractories could rest. This is depicted in Fig. 9.10.

The disadvantage of such an arrangement was the very thick refractory wall that was formed, which required very long inserted coolers to properly control wall temperature. Another problem was that these long coolers often could not be installed close to the mantle or be changed for maintenance because of interference with the structural elements of the massive ring girder and column

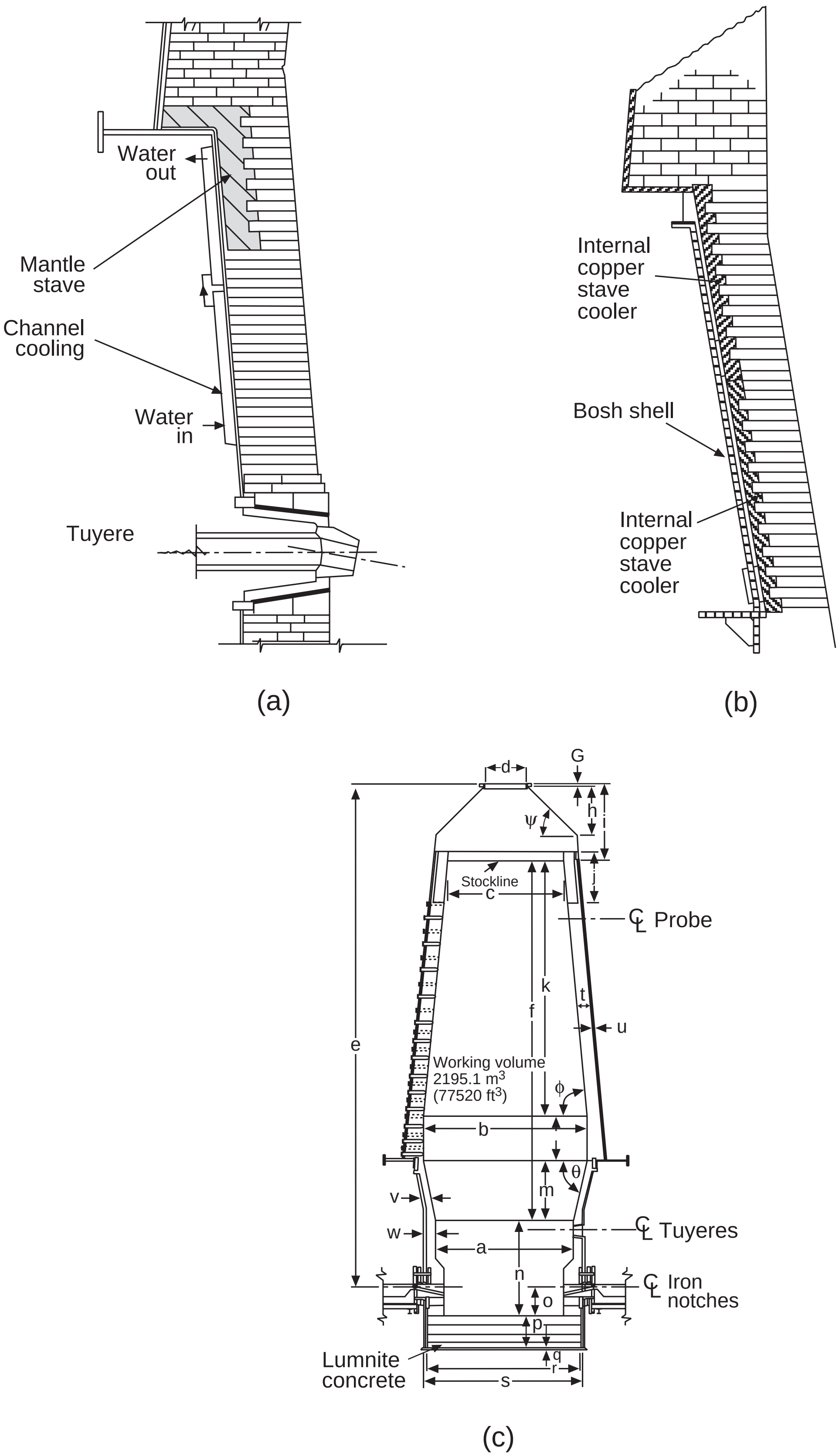


Fig. 9.12 (a) Mantle stave cooling; (b) bosh cooling by copper staves; and (c) furnace lines of a typical, mantle-supported North American blast furnace. Dimensions for the furnace in (c) are presented in Table 9.1.

cap mounting. As a result, linings in this type of mantle supported furnaces exhibited severe historical wear at this location, resulting in a myriad of mantle and shell structural problems due to overheating.

An improvement incorporated an inverted L-shaped cast iron cooling stave extending downward at the mantle, Fig. 9.12(a). This stave prevented heat from affecting the critical structural components and stack shell. Similar protection was also provided on some furnaces by incorporating other types of internal coolers such as cast iron or copper panels at the inner mantle flange or upper bosh jacket.

A development in the mid 1980s has been the installation of stave coolers made from rolled copper plate. The increased cooling capacity of the copper staves has significantly improved the performance in the high heat load areas of the upper bosh and lower stack (belly). This is due primarily to the ability of the copper stave to rapidly form or promote the formation of a protective accretion layer. Additionally the difficult area to cool in a mantle supported furnace is more easily configured. An example of this type of installation is shown in Fig. 9.12(b).

Another way to address the problem of the step or offset at the top of the bosh and lower stack interface is with modern furnace shell configurations that are totally self-supporting from the hearth bottom to the top of the stack. The hearth bottom shell must be anchored to a foundation. The shell plate is thicker due to load requirements, but it is totally self-supporting and therefore no mantle ring is required. This permits the refractory wall to have a consistent profile, which can simplify installation of the cooling elements and thus reduces the difficulties of trying to keep this area cool.

The geometry of the furnace lining, especially the shape and configuration of the lining dimensions, is called the *furnace lines*. These furnace lines follow tradition and experience and can vary from plant to plant and furnace to furnace within a plant. Lines also vary depending on the quality and type of burden materials. Fig. 9.12(c) shows the furnace lines of a typical, mantle-supported North American furnace. It should be noted that there are no standard furnace lines. They are all unique except for duplicate furnaces of the same design in the same plant or company. The dimensions for the furnace illustrated in Fig. 9.12(c) are presented in Table 9.1.

The furnace depicted in Fig. 9.12(c) utilizes externally-cooled water jackets for the hearth and bosh walls. The belly and stack are cooled by internal copper cooler elements or plates installed in horizontal rows around the stack. It should be noted that cooler plate row spacing and horizontal spacing should be designed to optimize refractory performance as described in Section 4.4.

Refractory wear in the bosh, belly, and stack usually follows a similar pattern from furnace to furnace. The most significant area of wear occurs between the middle to upper bosh and the lower to middle stack. The most severe wear in this range occurs in the upper bosh and belly. Historical furnace *wear lines* can be studied to determine a course of corrective action, which may include improvements to geometry, configuration, operating practices, cooling or refractory types. Often, the solution requires modifications in all of these factors. It is not uncommon in North America to experience severe bosh and stack wear before the hearth lining is worn significantly. This situation makes it possible to reuse hearth linings for two or more bosh and stack campaigns. The ideal situation, however, is to maximize the lifetime of all components by providing a capable initial cooling/refractory system and by utilizing maintenance practices such as grouting or gunite application to the bosh and stack to

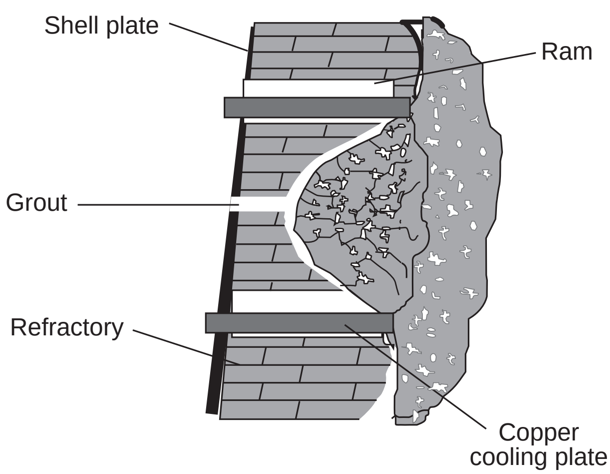


Fig. 9.13 Typical example of a grout repair.

Table 9.1 Furnace Line Dimensions for a Typical, Mantle-Supported Blast Furnace in North America

Dimension	Designation[a]	Measurement	
Working volume		2195.1 m^3	77,520 ft^3
Volume below tuyeres		341.6 m^3	12,064 ft^3
Total volume		2536.7 m^3	89,584 ft^3
Hearth area		74.7 m^2	804 ft^2
Hearth diameter	a	9754 mm	32’-0”
Straight section diameter	b	11,735 mm	38’-6”
Stockline diameter	c	8306 mm	27’-3”
Throat diameter	d	3135 mm	10’-3 7/16”
Overall height—centerline iron notch to top ring	e	35,181 mm	115’-9”
Working height—centerline tuyeres to stockline	f	25,908 mm	85’-0”
Top ring thickness	g	203 mm	0’-8”
Top cone height	h	3396 mm	11’-1 11/16”
Top ring to stockline	i	4801 mm	15’-9”
Protective brick height	j	3810 mm	12’-6”
Stack height	k	17,983 mm	59’-0”
Straight section height	l	3048 mm	10’-0”
Bosh height	m	4267 mm	14’-0”
Crucible height	n	6401 mm	21’-0”
Centerline notch to hearth floor	o	1219 mm	4’-0”
Bottom block depth	p	2743 mm	9’-0”
Lumnite thickness	q	229 mm	0’-9”
Bottom block diameter	r	10,973 mm	36’-0”
Steel shell ID	s	11,125 mm	36’-6”
Stack lining brick	t	914 mm	3’-0”
Castable packing	u	76 mm	0’-3”
Bosh lining	v	457 mm	1’-6”
Hearth wall	w	686 mm	2’-3”
Bosh angle	θ	1.3449 rad	76°55’51”
Stack angle	ϕ	1.4760 rad	84°34’12”
Top cone angle	ψ	0.7850 rad	45°

[a] Refer to Fig. 9.12(c) for location of each designation.

avoid major relines. Grout injection involves drilling into the residual refractories to enable a type of castable refractory to be pumped to the refractory hot face. Here, the grout encounters and intermixes with burden materials and is cured by process heat to form a hard mass, Fig. 9.13. This mass of material is comprised of a matrix of burden materials and refractory binder (the grout), which adheres to the residual refractory. However, this technique is much more effective if it can utilize the holding and supporting capability of inserted copper coolers or other types of cooled anchor. Otherwise, the force of burden descent often dislodges these injection masses. Grouting, once started, is effective only if it is periodically renewed by subsequent injections.

Another method of extending stack campaign life is to spray a coating of refractory, called gunite, on the hot face of the residual lining. This technique requires that the residual lining be completely exposed by blowing-down the furnace, an operating practice that consumes burden and continues to produce iron, while stopping burden material filling. This permits the burden materials to be totally consumed until they reach the desired level (maximum is to tuyere level), exposing the

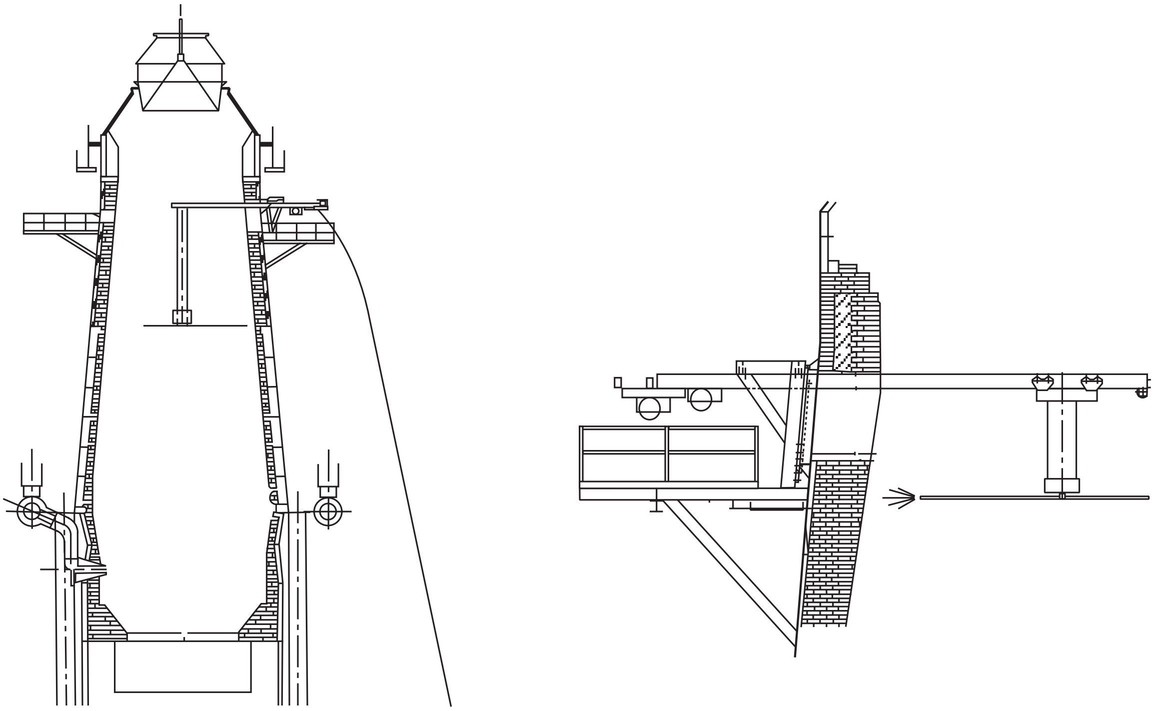


Fig. 9.14 Platform and gantry installation for gunning the blast furnace

residual refractories or cooled surfaces. Following blowing down, high pressure water sprays or other methods are used to clean residual materials from the application surface. Usually robotic devices are utilized for this work, although sometimes manual labor is utilized. After the application surfaces are cleaned of debris and buildups, a refractory lining is sprayed to the desired thickness, Fig. 9.14. Various types and qualities of gunning materials are available, many with proprietary ingredients; see Section 4.5. As with grout, gunite application works best when there are cooler plate or other types of anchors to support the gunite. The spray application of such materials does result in some product rebound, which results from the impact of the sprayed stream onto the application surface. The quantity of rebound is a function of the material being sprayed and the application technique and quality. Improper spray techniques can result in a heavy layer of ceramic rebound material that collects on the hot burden below. This rebound material can severely restrict or choke off the gas flow patterns in the furnace when it is restarted and cause quite serious problems. Gunite repairs, if properly done however, can extend the refractory life approximately one to two years. Periodic gunning can indefinitely extend the campaign of the stack, providing the cooling capability and supporting systems are capable of sustained operation.

The uppermost part of the stack, where the charged burden materials are deposited, is called the stockline. Some type of stockline armor must protect the part of the refractory wall that can be impacted by charged materials. The armor is often in the form of L-shaped or Z-shaped sections, either cast or fabricated, and is placed between rows of bricks or cast in place in refractory castable. The intent for placement is to completely cover the face of the refractories with the armor. In some blast furnaces this fixed armor is replaced with hanging armor, which consists of overlapping, heavy steel panels that are rolled to the diameter of the wall. This armor is suspended on chains or other hanging devices in front of the brick wall. The charged material then impacts the armor plates, rather than refractories. Fig. 9.15 depicts these types of armor.

Another type of armor provides the capability of throat diameter adjustment by moving the individual armor segments, see Fig. 9.25. This allows the operator the capability of diverting charged materials to fall in specific patterns. This becomes a very important tool to enable the operator to control burden distribution patterns and thus control gas flow and wall temperatures. Other furnace

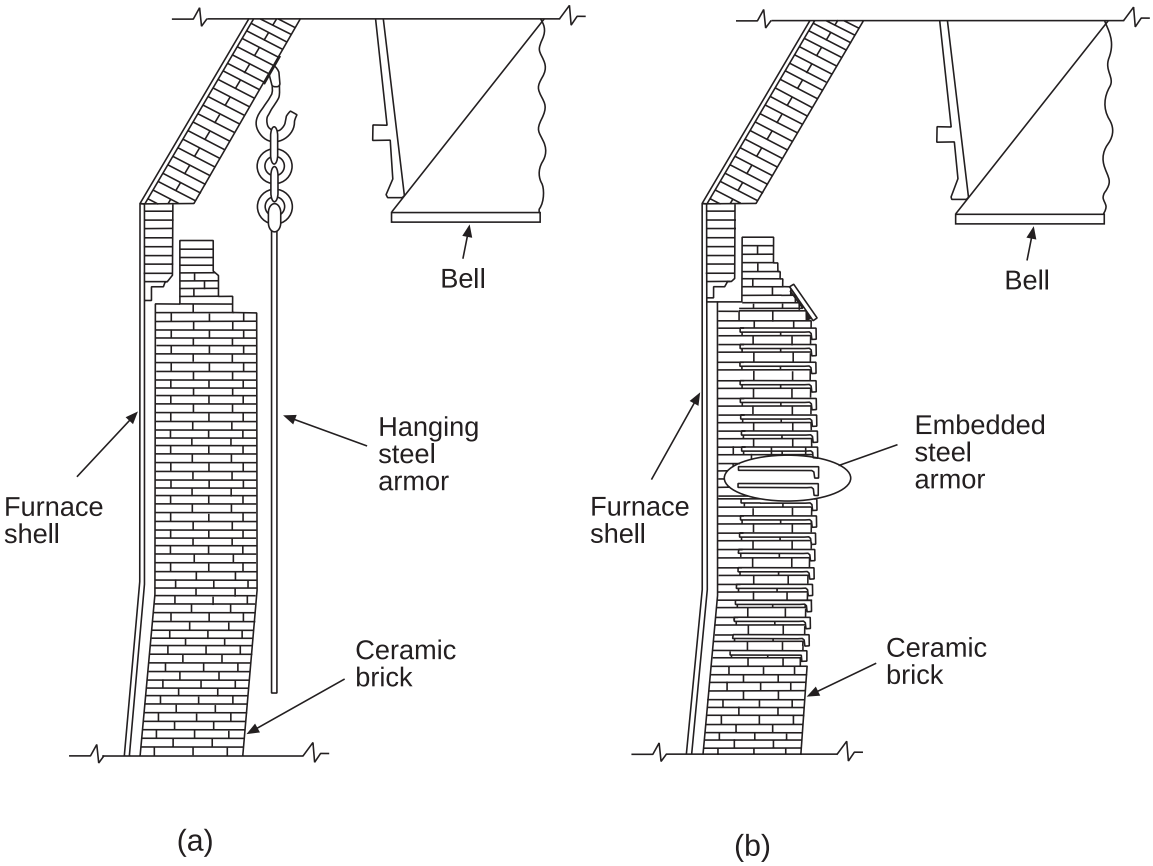


Fig. 9.15 Schematic of stockline armor: (a) hanging armor, (b) fixed armor.

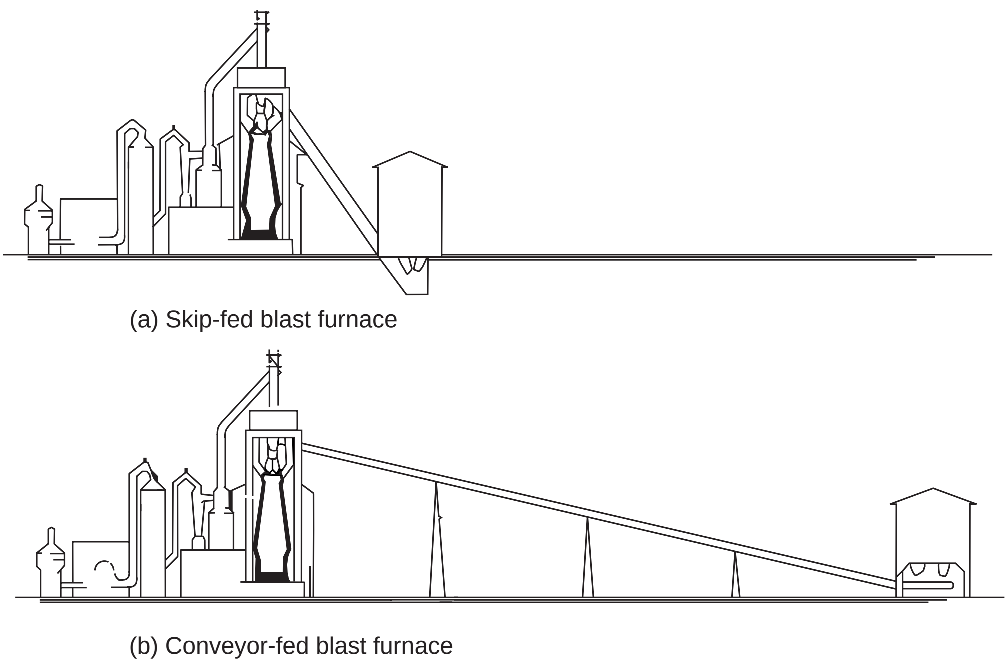


Fig. 9.16 Methods for delivering raw materials to the furnace top.

filling systems, such as the bell-less top, provide exceptional burden distribution capability and can prevent excessive wall impact by directing the material stream away from the wall. Furnaces with this type of charging system can utilize a lighter protective armor or no armor, because wall impingement is reduced considerably. A more detailed discussion of the types of burden distribution equipment can be found in Section 9.3.2.

9.3 Charging System

The blast furnace charging system consists of two main areas, the stockhouse system and the top charging equipment. The function of the stockhouse system is the weighing, batching and delivering of the recipe of raw materials to the top charging equipment. The top charging equipment serves the function of delivering blast furnace raw materials to the furnace top and distributing these materials into the furnace. Weighed raw materials are gathered in a batch mode governed by a charge program and are delivered to the furnace top either by skip car or by a conveyor belt. The size of the blast furnace, productivity requirements and available site plan have an impact on determining whether a skip car or conveyor belt system is the means for getting the raw materials to the top of the blast furnace, Fig. 9.16. The raw materials are then placed into the furnace by the top charging equipment (either a two-bell type or a bell-less type system) which is also controlled by the charge program.

9.3.1 Stockhouse

The stockhouse is the area where the individual raw material types are stored and then measured out in the prescribed order for delivery to the top of the blast furnace. The typical blast furnace stockhouse in the early 1900s was built as a deep pit in the ground and rail cars were moved over it and discharged the raw materials into these storage bins. The stockhouse is grouped into three sections of storage bins, usually comprised of coke, iron-bearing and miscellaneous materials. Typically each of these material types is divided into symmetrical sections on either side of furnace centerline. In the 1920s and through the 1950s, the stockhouse increased in size and was built as a structure partially above and partially below ground to accommodate more material types and larger quantities.

9.3.1.1 Scale Car Stockhouse

Since the early 1900s the method of measuring the raw materials and delivering them to the skip car was by means of a mobile scale car that moved below the material bins. A person would manually open the bin door and weigh the ordered amount of raw material, then proceed to the next bin for gathering the appropriate amount of the next material. As the production demand on the blast furnaces increased in the 1980s the existing scale car stockhouse was usually upgraded to decrease the time required for gathering the materials. The bin gate operators were mechanized and in many cases the scale cars were linked to a computer system which tracked the materials by weight, giving improved control and accuracy and eliminating much of the physical labor. The addition of holding hopper bins between the scale car and the skip cars enabled the scale car operator more time to gather the different materials without delaying the movement of the skip cars. A typical scale car stockhouse is shown in Fig. 9.17. In some cases the demand on productivity and furnace size required a fully automated stockhouse.

9.3.1.2 Automated Stockhouse

The automated stockhouse can be of two distinct and different forms. The first is the replacement of the scale car under the raw material bins with a feeder and conveyor belt system. Separate conveyors are provided for each type of raw material (coke, sinter, pellets, miscellaneous, flux, etc.) over which rows of storage bins are mounted, with vibrating feeders to discharge burden from storage bins to conveyors. For the coke, pellets and sinter, a single vibrating screen is located at the discharge of each conveyor to screen the material and feed this material into weigh hoppers. This

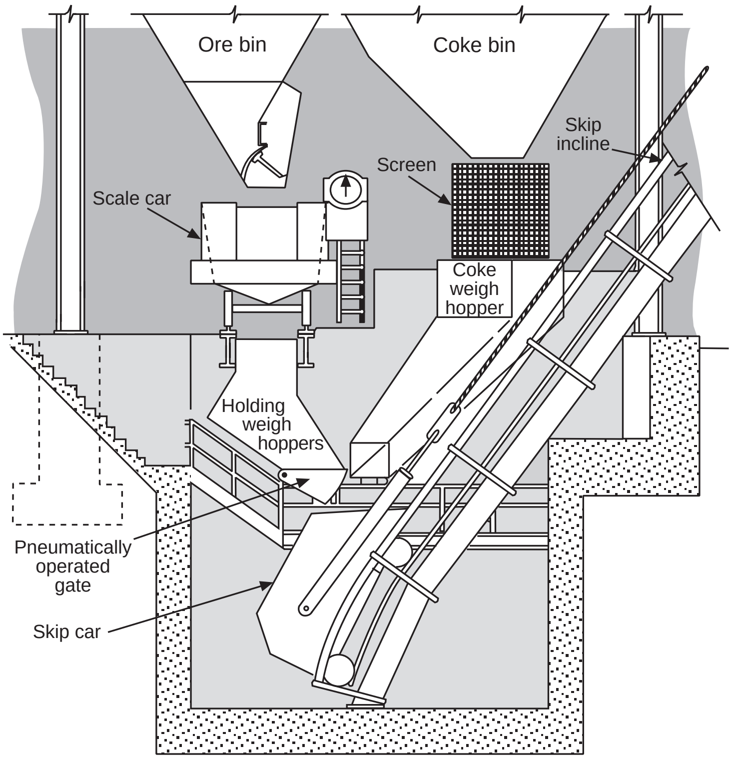


Fig. 9.17 Typical scale car stockhouse.

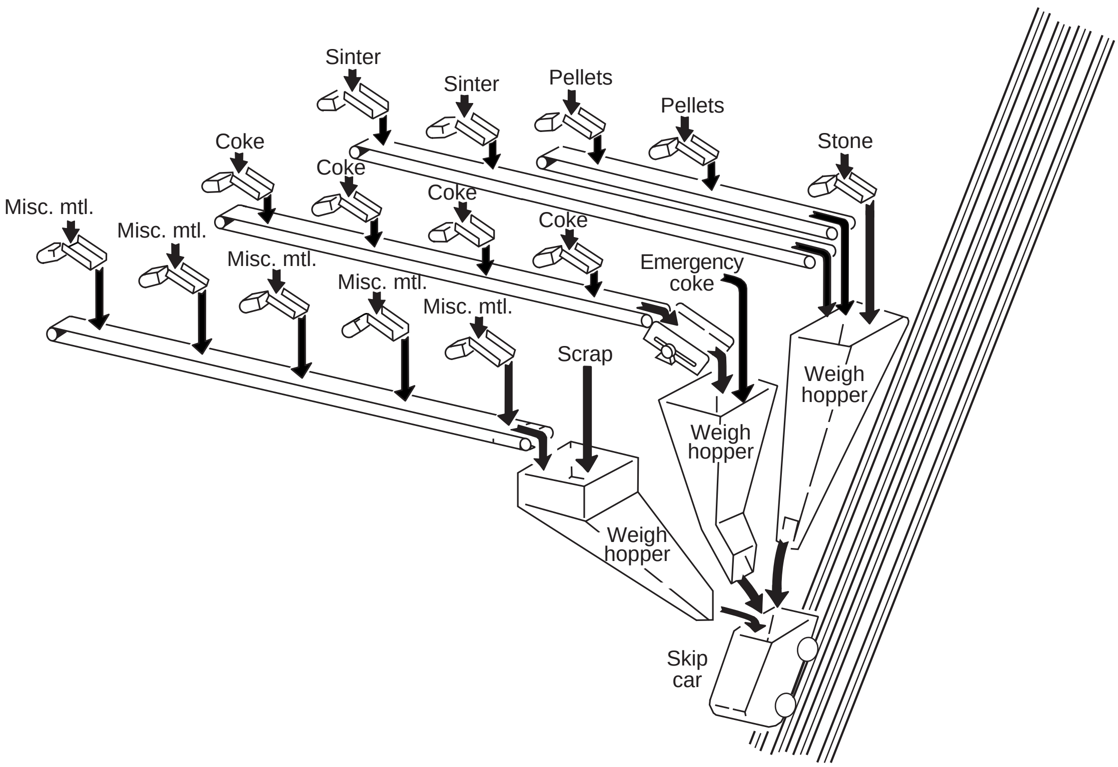


Fig. 9.18 Simplified schematic of an automated stockhouse for a skip-fed furnace.

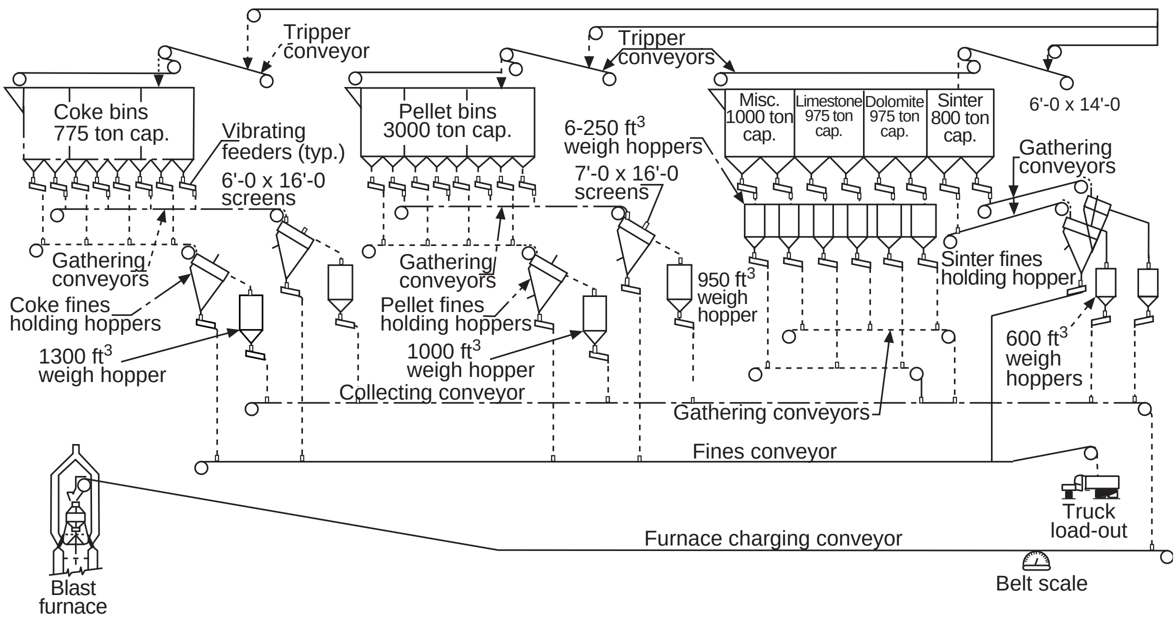


Fig. 9.19 Automated stockhouse for a conveyor belt-fed blast furnace.

type of system continues to feed weigh hoppers ahead of the skip cars. A simplified automated stockhouse for a skip-fed furnace is shown in Fig. 9.18.

The other automated stockhouse is a large structure of storage bins built entirely above ground and more remote to the blast furnace. This is possible by replacing the skip cars with a belt conveyor to the top of the furnace. The method of filling the storage bins is usually by a conveyor belt system instead of by railroad cars. The raw materials are drawn from the storage bins by vibrating feeders and belt conveyors into weighing hoppers. The weigh hoppers in turn discharge the material onto the main conveyor by means of a collecting conveyor. The weighing hoppers are programmed to meter the raw materials in a correct order onto the main conveyor belt to the top of the furnace. Automation of a stockhouse significantly increases production capability, improves operating efficiency, and eliminates operating variances caused by personnel and equipment. In practice a modern, automated stockhouse can be quite complex. The stockhouse itself may be fed by conveyors, which in turn discharge onto tripping conveyors to distribute materials to various bins. The layout of conveyors and equipment in the stockhouse can be arranged in numerous ways. One type of arrangement is shown in 9.19.

Both iron-bearing materials and coke are typically screened and another conveyor removes the fines. The materials can be sampled, analyzed and tracked by a computer, enabling the operator to precisely control chemical variation in furnace input materials. Coke moisture is monitored and weighing corrections are made to assure the desired dry weight in the charge. This monitoring of both the iron-bearing and carbon-bearing raw materials has enabled greater control of the thermal condition of the blast furnace and lowered overall fuel rates.

9.3.2 Top Charging Equipment

In early ironmaking, the blast furnace tops were open and the gas from the furnace was allowed to escape into the atmosphere and burn, Fig. 9.20 and Fig. 9.21. Aside from the environmental issue, this practice wasted considerable energy that could be recovered. The first attempts to recover the sensible heat from the offgas were made in 1829, when tubes were placed around the inwall of the furnace and blast air was passed through these tubes to absorb some of the heat before it was blown into the furnace through tuyeres. In 1845, a plan was devised for using a separate stove to transfer the heat from the top gas to the air blast. This was accomplished by using suction created by a

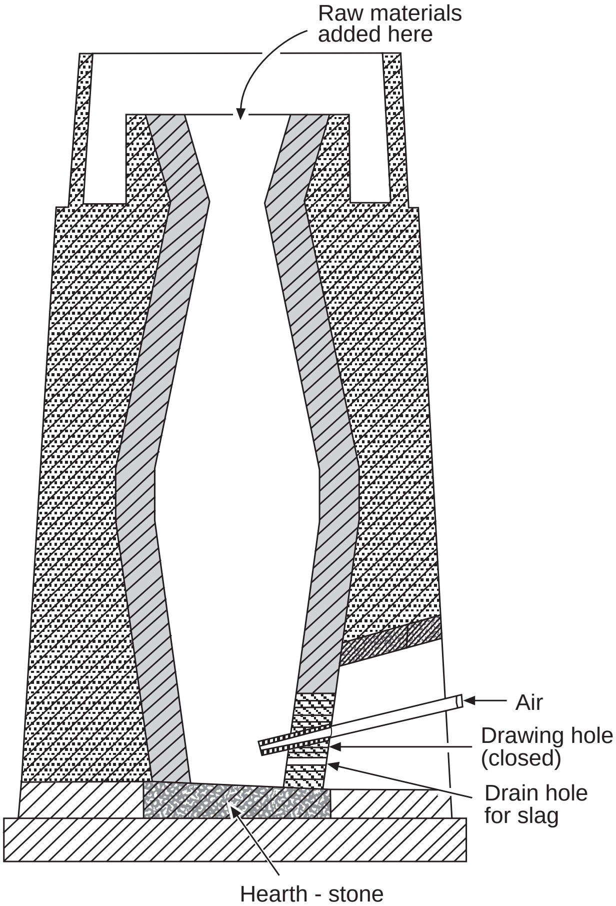


Fig. 9.20 Schematic cross-section of a Stuckofen with an open top.

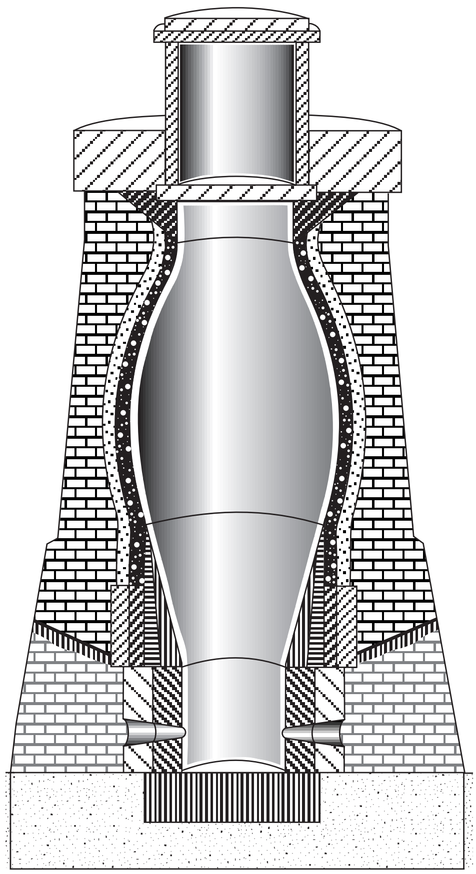


Fig. 9.21 Mid-19th century blast furnace.

chimney attached to the stove to draw the hot burning gas through the stove. At first, the blast furnace gas was drawn out of the furnace just below the stock line so that the top could be left open for raw material charging. However, in 1850, as the size of the furnaces increased it was found that the furnace top could be enclosed so that the furnace gas could be drawn off above the stock level. A single bell and hopper arrangement could be used for charging the furnace that kept the top of the furnace closed and sealed. While the furnace was being charged, the bell kept the bottom of the hopper closed so that gases could not escape. The raw material charge was placed in the hopper while the bell was closed and it was opened only long enough for these materials to be dumped into the furnace. This bell system also gave the advantage of larger size burden materials rolling to the center of the furnace shaft. This placement of larger materials in the center of the furnace reduced the resistance to gas flow and permitted higher wind rates and augmented the increased production rates. The single bell and hopper system permitted large quantities of gas to escape every time the bell was opened. It was not long before it was realized that by using a second bell and hopper above the first that a gas-tight space could be provided between the two bells to prevent the blast furnace process gas from escaping when the small bell was opened. The upper bell and hopper did not have to be as large as the lower one because several loads could be deposited through it onto the lower bell and the upper bell could be closed before the lower bell was opened. This two-bell system provided a more consistent flow of blast furnace gas for the stove system and reduced significantly the amount of offgas lost to the atmosphere.

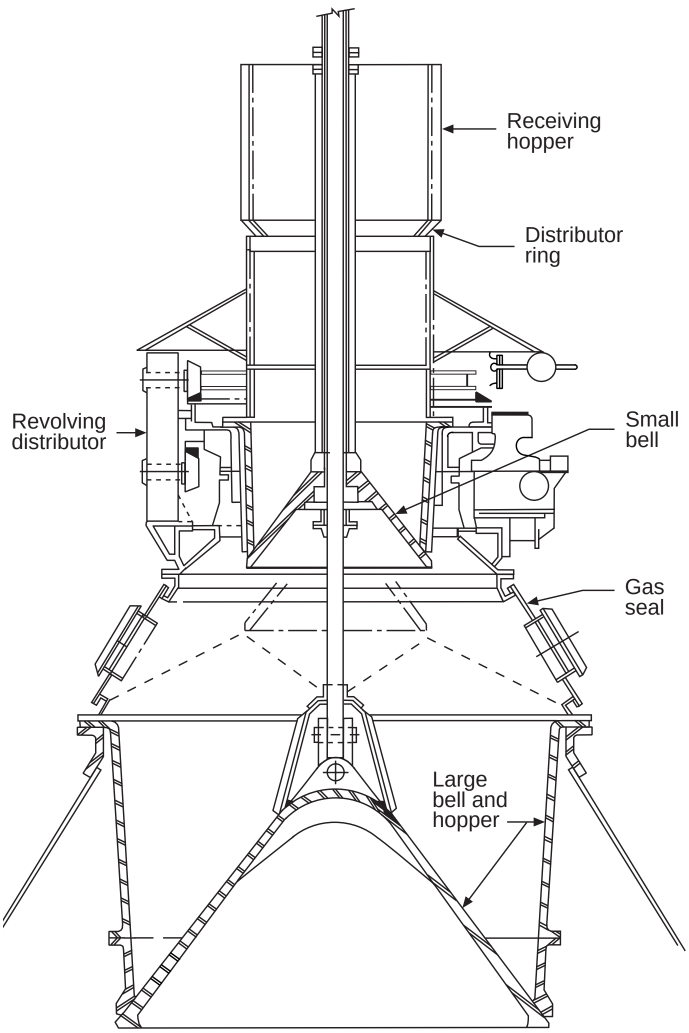


Fig. 9.22 Schematic of a typical two-bell top.

9.3.2.1 Two-Bell Top

The conventional top charging unit consists of a material distributor, a small bell and a large bell as shown in the Fig. 9.22. The large bell diameter is usually 1.5–1.8 m (5–6 ft) smaller than the stockline diameter. The lower edge of the upper face of the bell forms a seal against the bottom edge of the large bell hopper. The bells are connected by a rod and move in the vertical direction by means of air cylinders. As shown in the Fig. 9.23, the materials can be delivered to the furnace top by skip car and hoist or a conveyor belt and are dumped into the upper hopper or small bell receiving hopper. With the large bell closed, the small bell is lowered and the charge material is dropped onto the large bell. This procedure is repeated several times and then, with the small bell held closed, the large bell is lowered and the material is discharged into the furnace without allowing any of the process gases to escape. By using this charging method, the large bell, the small bell and hopper are subjected to heavy impact and severe abrasion and require replacement two or three times during the campaign of the furnace lining.

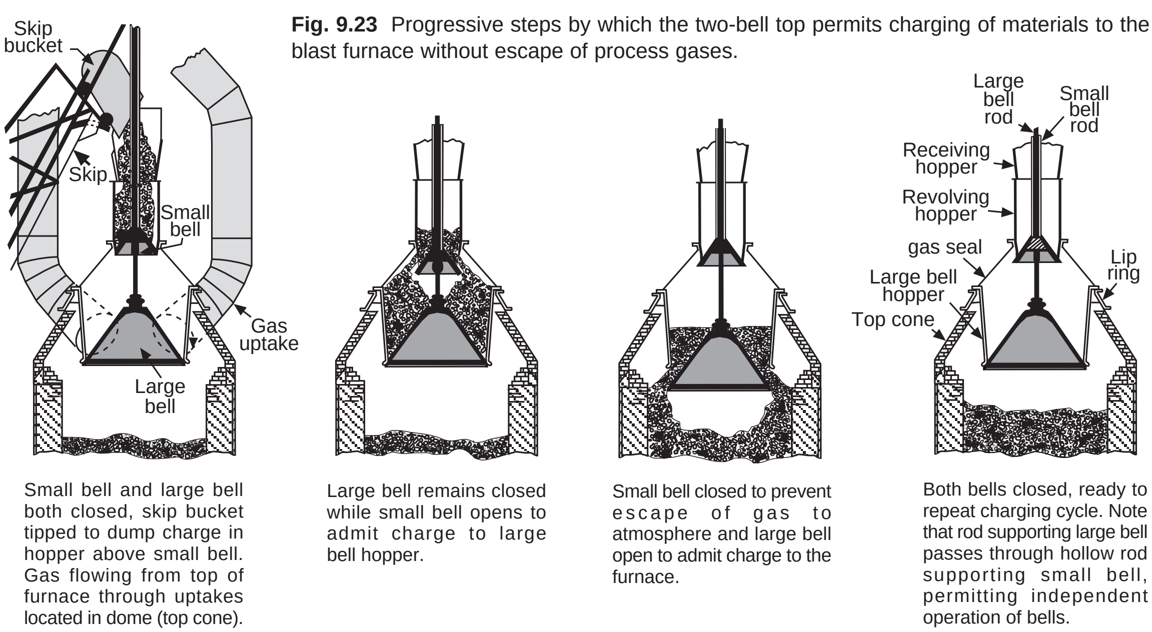


Fig. 9.23 Progressive steps by which the two-bell top permits charging of materials to the blast furnace without escape of process gases.

Most two-bell tops are equipped with a revolving distributor. The small bell and hopper, small bell rod and wearing plates are part of distributor. As each skip car of material is discharged on the small bell, the small bell and hopper rotate to a selected position and dump. This provides an improved distribution of material onto the large bell by placing the larger materials more evenly around the perimeter of the large bell. The bells are usually hard-surfaced in the area where they are subjected to the most severe wear from the impact of charging materials. Hard surfacing is also applied to the seating surfaces of the bells and hoppers. The bells are supported by bell rods, which are attached to counterbalances through a lever arrangement that restrict their motion to a vertical direction only. The small rod is hollow and the large-bell rod passes through it. Packing materials are used between the bell rods to prevent the escape of the gas.

With the use of high top pressure, particularly in excess of 100 kPa (1.02 kg/cm^2 or 14.5 psig), it is extremely difficult to maintain a gas-tight seal with the conventional bell and hopper arrangement. Also, the recent increase in productivity requirements in the past two decades required the subsequent increase in the quantities of materials being handled by the top equipment. Blast furnace operators and designers realized the importance of burden distribution flexibility to enable better furnace performance and the modification of top charging equipment to achieve this. The different kinds of top charging units that have been developed to meet this requirement are described below.

The two-bell system requires less height than other systems and it is a comparatively simple device. The drawback is that the large bell seal and the large bell hopper gas seal are difficult to maintain at higher top pressure. A good seal can not be held at the periphery of the large bell or the small bell as these areas are in the raw material flow. Because of the large size and heavy weight of the components, fabrication and maintenance is difficult, slow, and expensive and requires significant furnace downtime to replace.

The solution to this problem was to develop top charging equipment that would drastically reduce or overcome the problem of effective sealing associated with bell and hopper deterioration. Basically, two other types of top charging units were developed and are in operation on high-pressure blast furnaces today. One is a two-bell system with seal valves and a revolving chute above the small bell. The other is a bell-less system that incorporates a revolving chute.

9.3.2.2 Two-Bell Top with Seal Valves and Revolving Chute

This system consists of a large bell, a small bell, and a seal chamber with a revolving chute added above the small bell as shown in Fig. 9.24. Material is introduced onto the small bell through two openings, each equipped with a seal valve. These seal valves are smaller than the small bell and the sealing surfaces are out of material flow, leading to effective sealing. The revolving chute consists of one or two openings, which direct the material flow evenly onto the small bell. The small bell hopper is fixed and the small bell has only vertical movement. The large bell and hopper are the same as in the two-bell type.

The advantage of this system is that it overcomes the deficiencies of the standard two-bell system. By placing gas seal valves above the upper bell, this arrangement ensures that the large bell always sees the same pressure. The large bell functions as only a burden distribution device and has no gas sealing requirement. The pressure-containing components are the seal valves and the small bell. Both of these are significantly smaller and easier to maintain during shorter duration blast furnace scheduled outages.

9.3.2.3 Bell-type with adjustable armor

A disadvantage of the bell-type charging system is the lack of burden distribution capability. This is generally defined as the ability to modify the coke and ore layer thickness across the radius of the stockline of the furnace. With bell-type charging equipment the placement of the burden material becomes more difficult with increasing blast furnace dimension. The bell-type furnace top, which discharges the material into the furnace from the lip of the large bell, does not permit control over

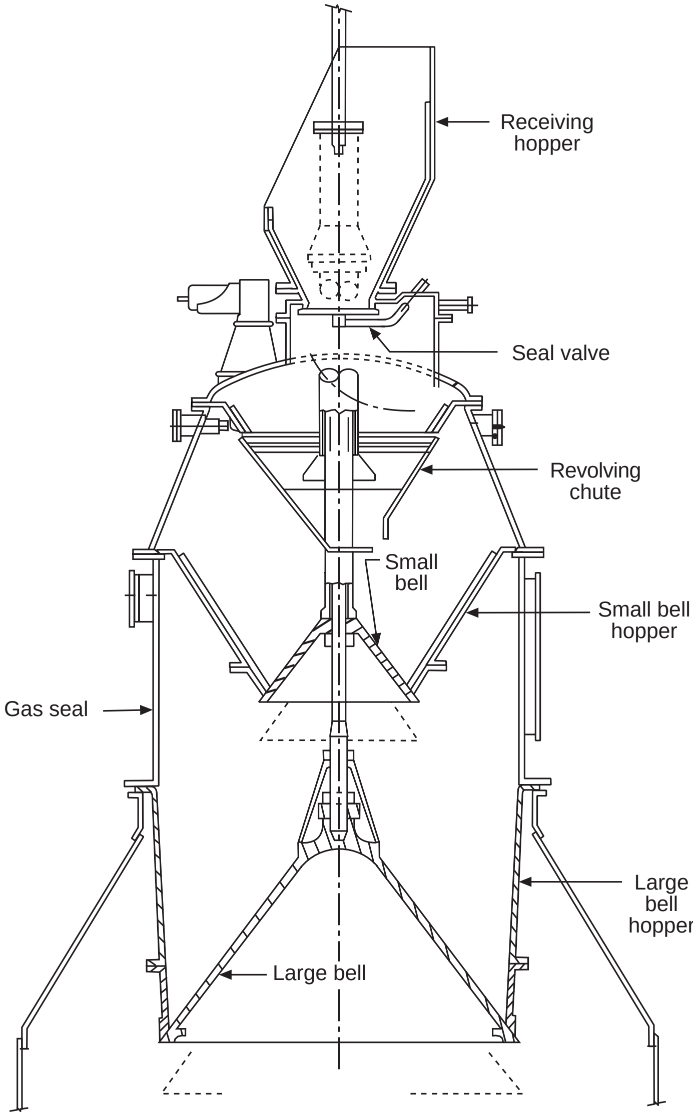


Fig. 9.24 Schematic of two-bell top with seal valves and a revolving chute.

the burden distribution. Operators have tried to vary the speed of the bell to change the distribution, but this had very little effect. An adjustable throat armor system, used in connection with bell-type top charging equipment, was developed (see Fig. 9.25) to control and vary the burden distribution so that optimum permeability in the blast furnace stack could be achieved.

Adjustable throat armor varies the diameter at the furnace top and in some cases changes the slope of the armor as well. Material falling from the bell impacts against the armor and finds its position at the stockline level dependent upon the set position of the armor. Adjustments are totally circumferential, but there is a limit to how much adjustment can be attained.

There are several types of movable armor design. One of the adjustable armor designs in Germany consists of cast-steel plates arranged to form a cylinder, the diameter of which can be increased or decreased by the furnace operator while charging, see Fig. 9.23(a). The cast-steel plates are separated and suspended so as to overlap each other. Movement is permitted under impact of the falling charge and part of the impact energy is converted into kinetic energy, which reduces abrasive wear. Each

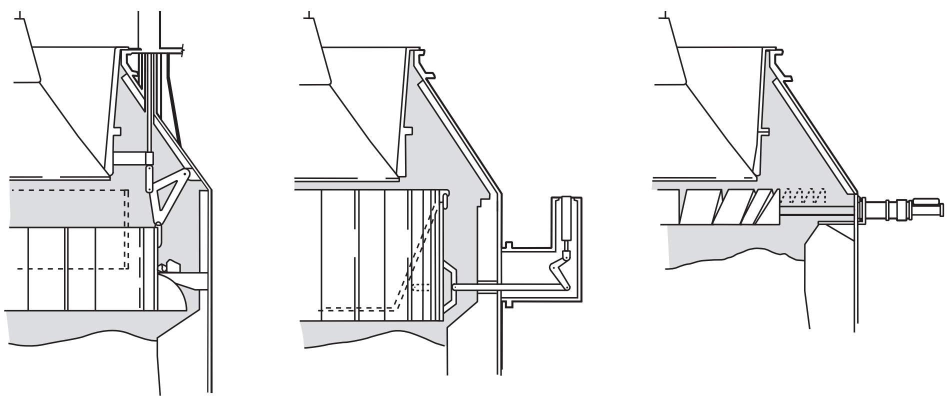


Fig. 9.25 Types of adjustable throat armor used to control burden distribution.

plate is hooked to a triangular lever. The triangular levers are pivoted in brackets attached to the furnace top shell, and are connected to the draw ring by links.

A second type of armor developed in Germany also adopted hanging plates, Fig. 9.23(b). The plates are suspended from a fixed circular support and the drive linkage is attached to the bottom of each plate, allowing a range of settings from a vertical cylinder to a conical chute.

Another form of adjustable throat armor is a deflector-type, developed in Japan, which is actuated by hydraulic cylinders as shown in Fig. 9.23(c). Compared to the conical chute armor, this system requires much less vertical space between the bell and the stockline within the furnace.

Adjustable armor systems will continue to be used, especially in large furnaces, as long as bell charging systems are in use. Experience on very large furnaces has shown that proper burden distribution from a bell with a diameter greater than 7 m (23 ft) becomes increasingly difficult. In such cases, a bell-less type charging equipment may be a very good alternative.

9.3.2.4 Bell-Less Top

One development in top charging equipment that appears to be a quantum jump in technology is the bell-less top, Fig. 9.26, which was invented by S.A. Paul Wurth in Luxembourg in 1972. This design has rapidly gained in popularity, especially in Europe, North America and Asia.

This top charging unit was developed to solve the problem of gas sealing under a high-pressure operation, to provide flexibility for the most advantageous distribution of burden, and to reduce maintenance time and frequency for the equipment. This top charging system can be part of a skip car or a conveyor belt system. The required height of the bell-less top is slightly higher than that of bell-type top. The system consists of the following main component parts:

(1) a movable receiving chute or hopper,

(2) one, two or three lockhoppers equipped with upper and lower seal valves and a material flow control gate,

(3) a central vertical feeding spout,

(4) a rotating adjustable-angle distribution chute,

(5) and a rotational and tilting drive mechanism.

In operation the skip or conveyor belt fills the lockhopper with the raw material. The lockhopper is then sealed and pressurized to the furnace top operating pressure. Each lockhopper is equipped with an upper and lower seal valve and a material flow control gate. The lockhoppers are used alternately; one is being filled while the other is being emptied. By design the seal valves are always out of the path of material flow to prevent material abrasion, which reduces the probability of a sealing problem. The flow control gate opens to predetermined positions for the various types of raw materials to control the rate of discharge. Lockhoppers are lined with replaceable wear plates. The lower seal valves and material flow control gates are in a common gas-tight housing with the material flow chutes, which direct the material through a central discharge spout located in the main gear housing.

When the furnace stockline has descended to the desired level, the lower seal valve opens and allows the charge to flow at a controlled rate onto the distribution chute. The distribution chute rotates around the vertical axis of the furnace and changes to predetermined angles with respect to the horizontal plane. This system has the flexibility of charging the materials in distinctive rings, in spiraling rings of smaller diameter, or of point/spot area filling. In addition, the quantity of material in each discharge area can be precisely controlled if desired.

Refinements to the design of the bell-less top system have focused on two areas: (1) the elimination or reduction of the segregation of finer particles in the lockhoppers ahead of the rotating chute, and (2) the development of a smaller unit for installation on the many smaller blast furnaces already in operation. To address the first condition of small fines concentration, a design that incorporates

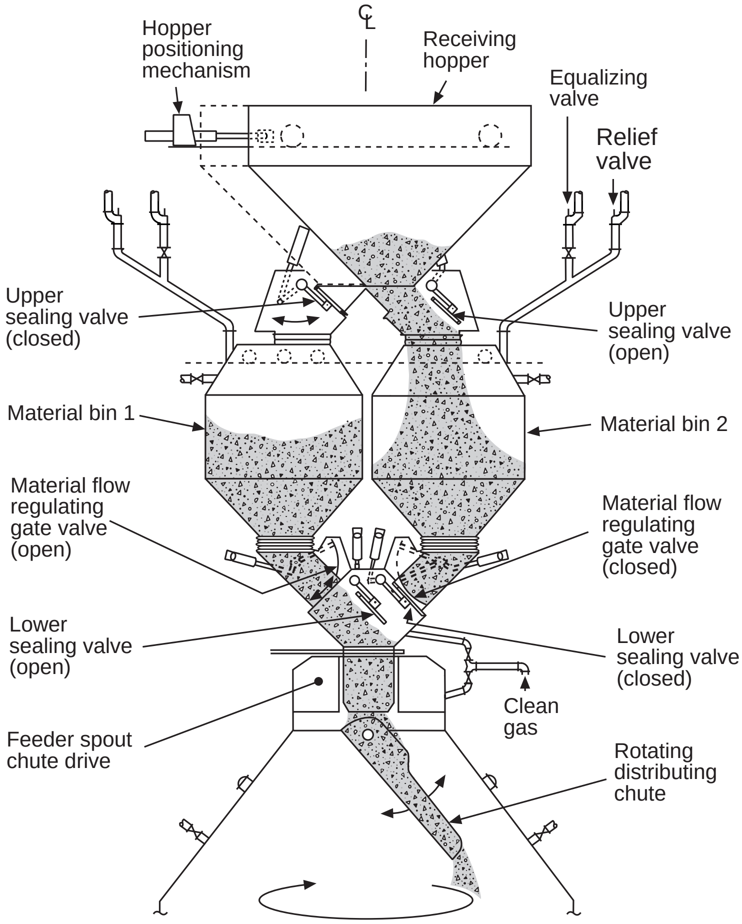
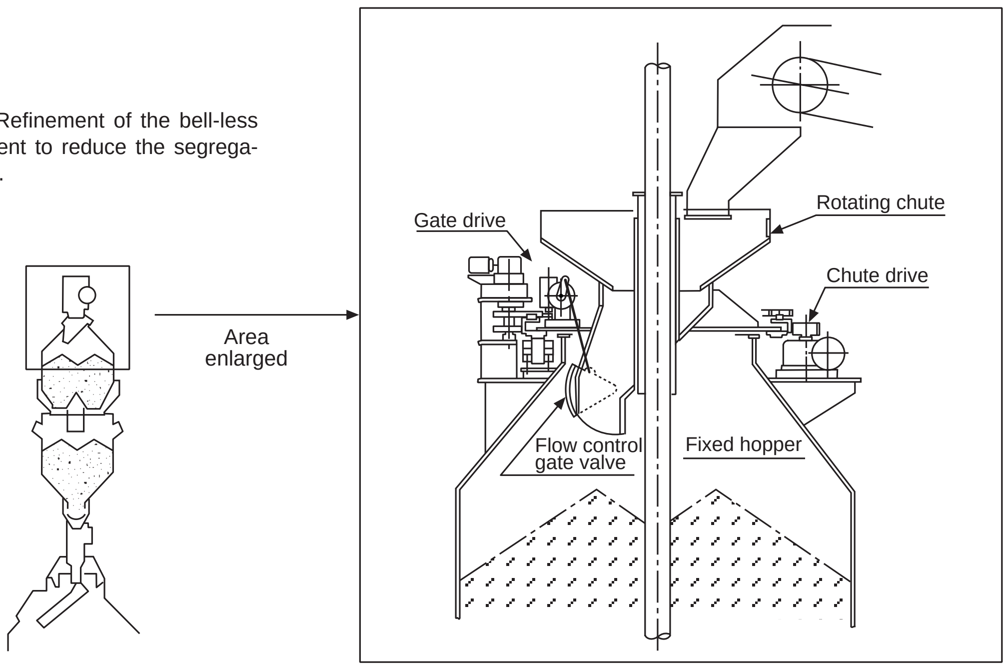


Fig. 9.26 Schematic of a bell-less top with pressurized hoppers and a rotating distributing chute.



(a) Multiple - port vertical two-hopper type

(b) Flow control gate valve of rotating chute

Fig. 9.27 Refinement of the bell-less top equipment to reduce the segregation of fines.

a rotating chute into a large receiving hopper that is positioned above the single large lockhopper yields the desired result of dispersing the finer material evenly throughout the burden, Fig. 9.27.

The problem of installing a bell-less system on the existing smaller furnaces has been addressed with the development of the Paul Wurth compact top. This design employs a distribution chute that can be changed by means of a door installation and a design that permits access through the main gear unit. Additionally, the overall height of the lockhopper has been reduced by a different flow gate design and a double actuating seal valve design, Fig. 9.28.

In conclusion, bell-less top equipment has the following features.

(1) Nearly-continuous furnace charging is possible. While the rotating chute is distributing the contents of one lockhopper bin, the other can be filled.

(2) The operator has different choices of distribution patterns: point, segment, ring or spiral.

(3) The top equipment is of light and compact construction compared to other high-pressure top charging systems.

(4) The chute can be replaced within a short period of time as opposed to that of bell-type top equipment.

All of the types of top charging equipment discussed have their place and application. All have been proven in service. For modern furnaces, the bell-less top is the best proven solution.

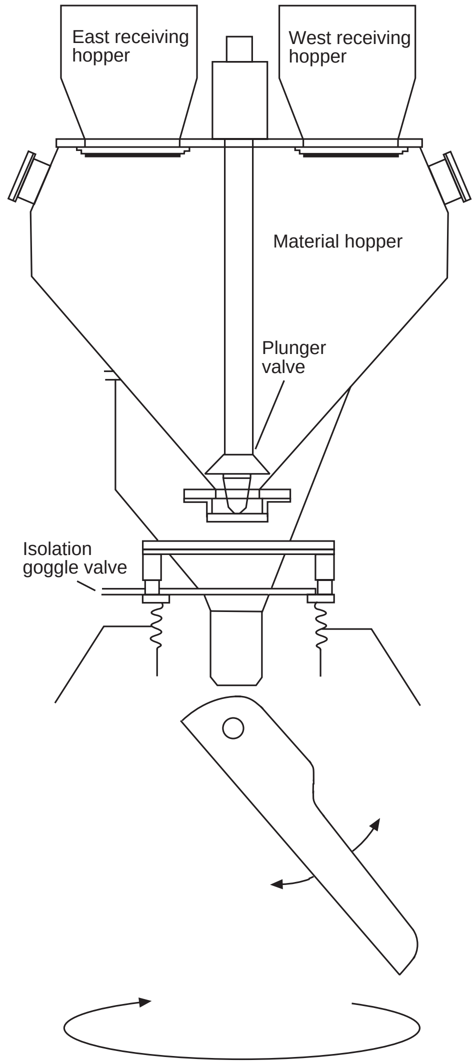


Fig. 9.28 Schematic of the Paul Wurth compact top.

9.4 Blast Furnace Gas System

9.4.1 Top Openings

In addition to the opening in the blast furnace top through which the burden materials are charged, there are generally four openings for large vertical pipes called *uptakes* through which the top gas is withdrawn. The large diameter and the vertical height of these uptakes prevent excessive amounts of charge material from blowing over into the gas cleaning system. The uptakes are lined with 114–152 mm (4.5–6 in.) of refractory brick or with 79–114 mm (3–4 in.) of monolithic castable cement that is anchored to the inner surface of the metal of the uptakes. The tops of the uptakes join together in pairs, and each pair is connected to a large duct called a downcomer that descends into the dustcatcher. The ducts connecting the uptakes to the downcomer are called *off-takes*. The total cross-sectional area of the downcomer is usually slightly less than that of the four uptakes, Fig. 9.29.

Each of the pairs of uptakes that are joined together into a single duct is equipped at its uppermost point with a valve called a bleeder valve. There are two general types of bleeder valves, those that

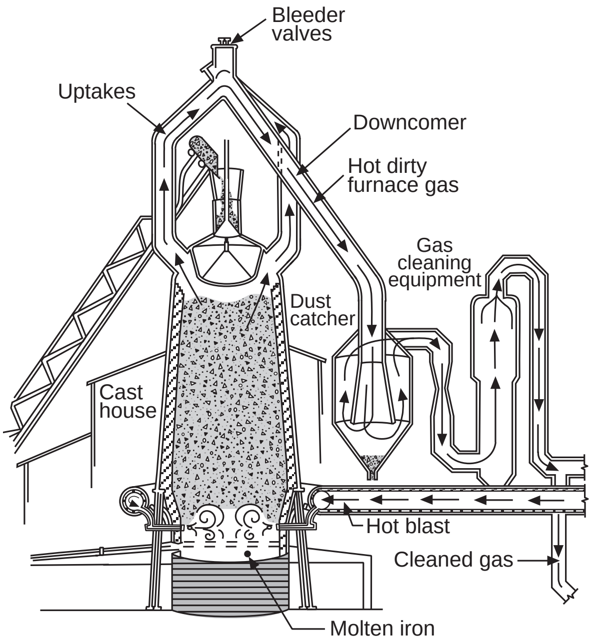


Fig. 9.29 General arrangement of blast furnace gas equipment.

open out and those that open in. The open-in valves are operated by air or hydraulic cylinders and their movement is actuated by pressure impulse lines that cause the valves to open to relieve the pressure when it becomes too high. Manual switches are also provided to open these valves when the furnace has to be shut down and it is necessary to create a draft through the furnace stack. The open-out bleeders are usually counterweighted so that they will open without the need of another source of power when the pressure in the furnace significantly exceeds the planned operating pressure. This is to prevent serious damage to the furnace top in the case of an explosion or a bad burden slip.

9.4.2 Gas Cleaning Equipment

As the blast furnace gas leaves the top of the furnace, it contains dust particles varying in size from about 6 mm (about 1/4 in.) to only a few microns (1.0 micron = 0.001 mm ≈ 0.00004 in.). In some instances where the *burden slips* in the furnace, relatively large lumps of coke (up to about 51 mm or 2 in. in size) and burden materials have blown out with the gas. The dust that is carried out of the top of the blast furnace in the gas stream is generally referred to as *flue dust*. The flue dust is made up of fine particles of coke and burden material and also extremely fine particles of chemical compounds that are formed from the reactions within the blast furnace that are condensed from their vapor phase. Before the blast furnace gas can be burned in either the hot blast stoves or the boiler house, it must be cleaned to remove most of this particulate to prevent plugging and damaging of the checkers or burners and to keep the dust from being discharged into the atmosphere with the products of combustion.

For the first step in the cleaning process, the gas is usually always passed through a dry dustcatcher where almost all of the particles coarser than 0.8 mm (0.03 in.) are removed. The dustcatcher is a large, cylindrical structure about 10–12 m (33–39 ft) in diameter and 20–30 m (66–98 ft) high. It is typically lined with brick or gunite to insulate it and prevent condensation of the moisture in the gas. To operate effectively the dust must remain relatively dry so that it will not ball up, but rather will flow freely into the conical-shaped section at the bottom of the dustcatcher.

The gas is conveyed to the dustcatcher by a single downcomer and enters through the top by a vertical pipe that carries the gas downward inside the dustcatcher, Fig. 9.30. This pipe flares outward at its lower extremity like an inverted funnel, so that as the gas passes downward its velocity (and thus its dust carrying potential) decreases. Most of the dust coarser than 0.8 mm (0.03 in.) drops out of the gas stream and is deposited in the cone at the bottom of the dustcatcher. Because the bottom of the dustcatcher is closed, and the gas outlet is near the top, the direction of travel of the gas must reverse 180°. This sudden reversal in the direction of flow causes more of the dust to drop out of the gas stream. In a dry dustcatcher of this type, the efficiency of dust removal depends on the size of the dust particles and the ratio of the gas velocity to the size of the dustcatcher.

The dust that accumulates in the dustcatcher is generally removed through a pug mill or some type of wetting device attached to the bottom cone below a shutoff valve. Water is added to the dust as it passes through the pug mill or wetting device to moisten it and prevent it from blowing into the atmosphere as it is discharged. On some installations, the dust is discharged directly into trucks or railroad cars as it leaves the wetting device and in others it is dumped onto the ground and removed with excavating equipment.

After the gas has passed through the dry dustcatcher, it generally goes to a wet cleaning system where the very fine particles of dust are literally scrubbed out of the gas with water. Prior to the 1960s, blast furnaces had two stages of relatively low pressure wet gas cleaning systems. These systems were usually large vessels equipped with many types of water sprays, gas deflectors, spin vanes and banks of refractory tile all for the purpose of intimate mixing of the solid particulate in the gas with the water. In the late 1950s, experimentation showed that as dirty gas is put through a pressure drop via an orifice, or restriction in the gas main, and cleaning water is introduced at this same point that the cleanliness of the gas is improved. Work by Campbell and Fullerton[1] showed that as the pressure drop is increased to 25 kPa (200 mm or 3.9 psi) the resulting gas cleanliness will improve to 10 mg/m^3 (0.004 gr./scf). The first application of this idea to blast furnace gas cleaning was the venturi type gas cleaner as shown in Fig. 9.31. In the venturi washer, the gas from the dust catcher enters from the top and passes downward through the venturi throat. As the gas passes through the narrow throat of the venturi, it is sprayed with water. There are usually two sets of water sprays, one operating at low pressure and entering the unit at right angles to the gas flow, and the other operating at high pressure and directed upward at an angle of 110° to the gas flow. The washer is lined with a suitable abrasion-resistant material to withstand the erosive effect of dust laden gas and water. The initial washers of this type were a design with a fixed throat opening. As productivity requirements increased, one of the improvements was to design moveable throat openings into the venturi washer. This gave the advantage of maintaining a more constant pressure drop across the washer as well as a means of controlling top pressure on the furnace.

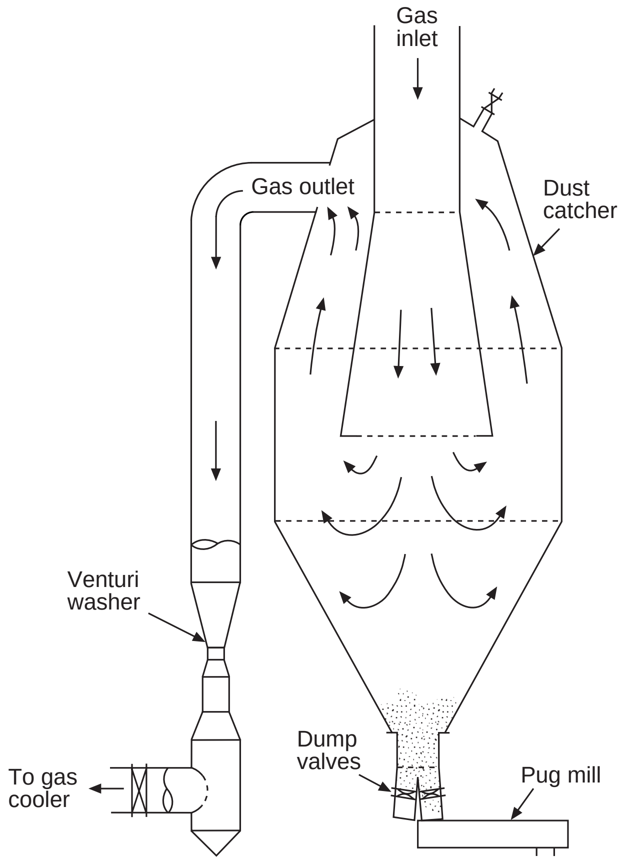


Fig. 9.30 Schematic of a dustcatcher and a venturi washer.

In some blast furnaces which operate with an elevated top pressure as high as 207 kPa (about 2.1 kg/cm^2 or about 30 psig), a relatively new type of two-stage venturi gas washer and cooler is used that automatically controls the top pressure. With this washer the dirty gas enters at the top and passes through a relatively low pressure drop fixed venturi that is flooded with water. After the first stage venturi the primary cleaned gas makes a 180° directional change and then passes vertically downward through a high pressure drop movable venturi throat. The diagram of this washer is shown in Fig. 9.32. A conical plug valve actuated by pressure impulse lines from the blast furnace top controls the desired pressure drop through the bottom unit. The secondary cleaned gas impinges on rotary spin vanes and again reverses its direction of flow 180°. This final reversal of flow and the centrifugal force of the spin vanes remove the remaining entrained water. The gas passes from the venturi washer into a water separator directly beneath it and then to a cooling tower where its temperature is lowered by passing through water sprays. The cooled gas then passes through a moisture eliminator before going to the secondary cleaning system. This type of high energy, high efficiency scrubber has the ability to clean the gas to a dust content of less than 6 mg/m^3 (0.002 gr./scf) in one operation.

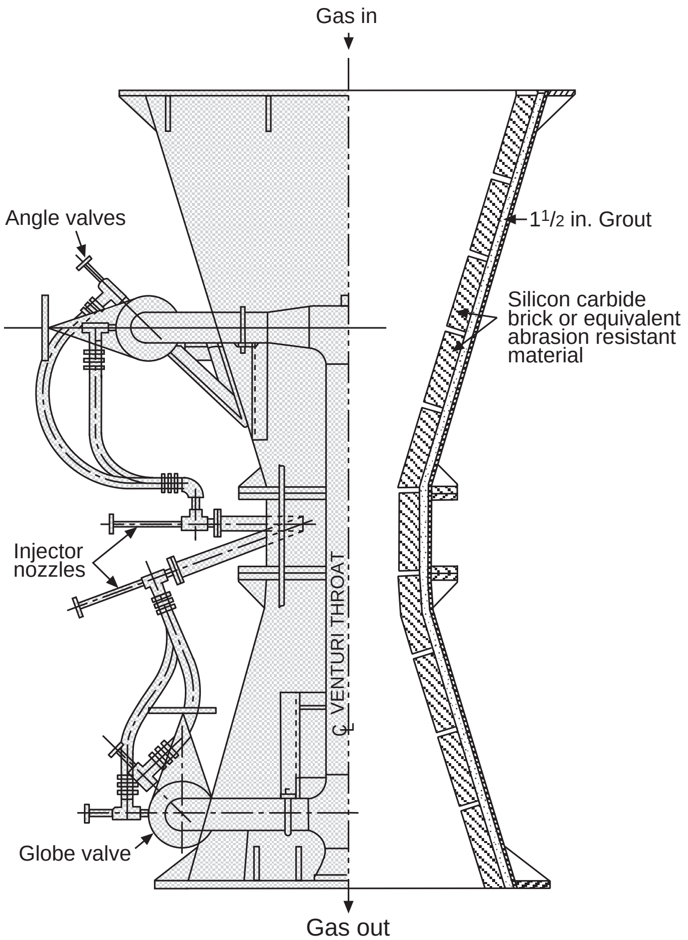


Fig. 9.31 Schematic arrangement of a venturi-type unit for washing blast furnace gas; at right is a cut-away drawing to show the lining.

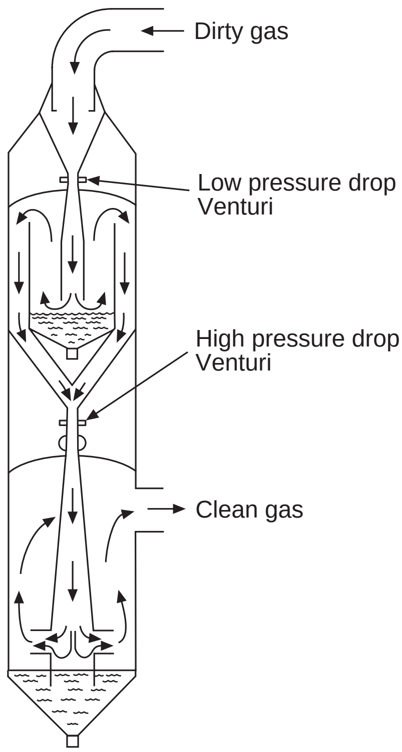


Fig. 9.32 Schematic of an automatic two-stage venturi gas washer that controls blast furnace top pressure.

The water used in the wet gas cleaning systems contains 30–50% of the total dust removed from the gas as it leaves the gas washer. Consequently, the suspended particles of dust must be removed from the water before it can be reused or discharged from the system. In many older plants, settling basins were used where the dirty water entered at one end and the clear water flowed out over a weir at the other end. These units were usually in pairs, so that when one was full it could be drained for removal of the solids while the other one was in use. In most plants today, closed-circuits water systems with thickeners are used to remove the solids from the water because they require less space than the settling basins formerly used, Fig. 9.33.

A typical thickener consists of a circular reinforced concrete tank, which may contain one or several compartments in each of which one or several arms revolve. The arms are driven from a central vertical shaft. Water enters at the center of the thickener and leaves over a continuous weir, which follows the circumference of the compartment. Each arm carries a series of rakes or vanes set at such an angle that the solids, which settle out, are gently pushed toward the center of the compartment. The thickened solids, containing about 60% water, are pumped out and delivered either pneumatically or by a pump to a filter for further processing. The thickener may be built with either an open or a closed top. Two types of filters are in general use, the cylindrical or drum type and the disc type. Both operate upon the underflow from the thickener, discharged into a basin into which an arc of the slowly rotating filter dips. The drum or disc consists of a framework over which canvas is stretched, and a partial vacuum is applied on the inside of that part which dips in the basin,

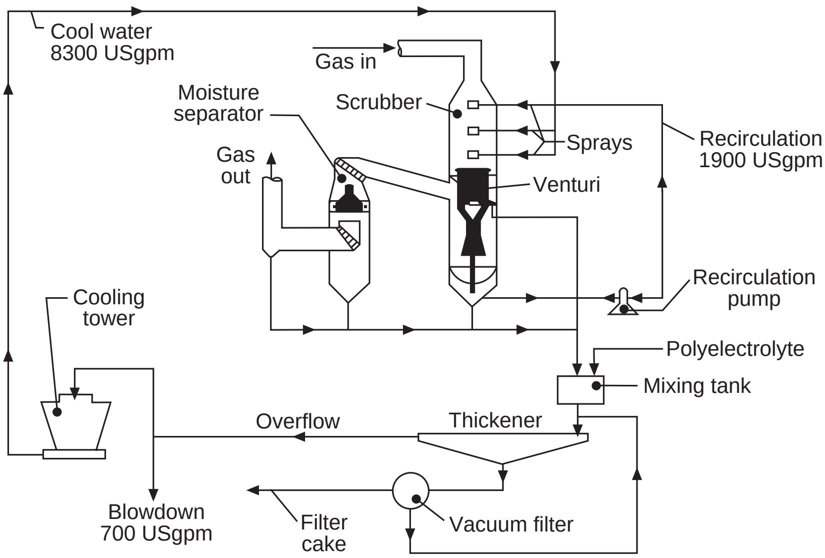


Fig. 9.33 Schematic of a modern closed-circuit water system for gas cleaning.

thereby drawing liquid through the canvas while the solids are retained by the canvas. When the drum or disc reaches another point in its rotation, a slight air pressure is applied on the inside of the canvas thereby bulging it and causing some of the filter cake to crack and drop off into a chute, the balance being scraped off by a scraper. The filtrate returns to the thickener. The filter cake, containing about 25% of moisture, is delivered by railroad car to a sintering plant or recycled with other waste oxides All of the contact water in the gas cleaning systems is recycled, cooled and reused. None of the water is permitted to be released into the local water table unless properly treated.

9.5 Hot Blast Generation

9.5.1 Stoves

Before the blast air is delivered to the blast furnace tuyeres, it is preheated by passing it through regenerative stoves that are heated primarily by combustion of the blast furnace offgas. In this way, some of the energy of the offgas that would otherwise have been lost from the process is returned to the blast furnace in the form of sensible heat. This additional thermal energy returned to the blast furnace as heat decreases the amount of fuel that has to be burned for each unit of hot metal and thus improves the efficiency of the process. An additional benefit resulting from the lower fuel requirement is an increase in the hot metal production rate.

The blast furnace process offgas is not high enough in BTU value to achieve the high flame temperature required for the higher hot blast temperatures of 1100°C (2012°F). Therefore the blast furnace gas for the stoves is enriched by the addition of a fuel of much higher calorific value, such as natural gas or coke oven gas, to obtain the high flame temperature.

Most blast furnaces are equipped with three hot blast stoves, although in a few instances there are four. The stoves are tall, cylindrical steel structures lined with insulation and almost completely filled with checker brick where heat is stored and then transferred to the blast air. Each stove is about as large in diameter as the blast furnace, and the height of the column of checkers is about 1.5 times as tall as the working height of the blast furnace. At the newer furnaces, the relation of the stove size to the furnace size is even larger. For example, one typical American blast furnace, which has a hearth diameter of 9.75 m (32 ft) and a working height of 25.9 m (85 ft), is equipped with three stoves. Each stove has an inside diameter of 10.36 m (34 ft) and a checker height of 40 m (131 ft).

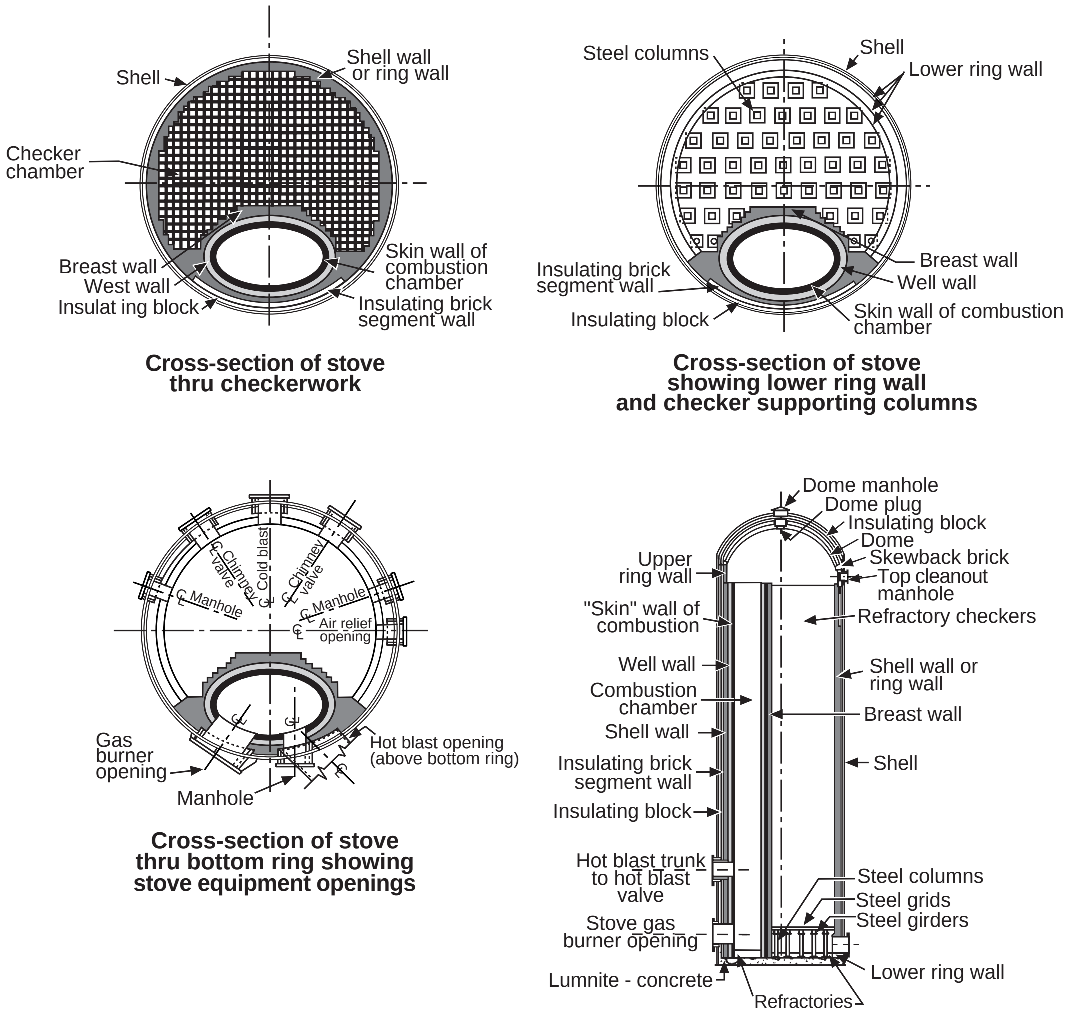


Fig. 9.34 Vertical section through a stove with cross-sectional views at several elevations.

Fig. 9.34 shows the construction of a conventional two-pass hot blast stove. In this type of stove, the oval shaped combustion chamber occupies about 10% of the total cross-sectional area of the stove and extends from the bottom of the stove to within about 4 m (13 ft) of the top of the stove dome. A sturdy brick breast wall separates the combustion chamber from the balance of the stove, which is filled with checker brick resting on a steel grid supported by steel columns.

Just inside the steel shell is an insulating lining and this is usually very thick on the side near the combustion chamber. The combustion chamber is completely surrounded by a brick well wall, which is lined with superduty brick containing 50–60% of alumina. For very high hot blast temperatures in excess of 1200°C (2192°F), the entire combustion chamber and the dome are lined with this type of brick: also, the top 8–10 m (26.3–32.8 ft) of checkers are superduty brick. However, in many hot blast stoves where the temperatures are only about 1000°C (1832°F), the upper portions of the combustion chamber, the dome lining and the upper checkers are made of semi-silica refractory.

In erecting the dome lining, arch bricks are used and a space is provided between the brick and the dome to allow for expansion of the ring wall from which it is supported. In some stoves, there is an offset in the steelwork at the top of the ring wall so that the dome brick can be supported independently.

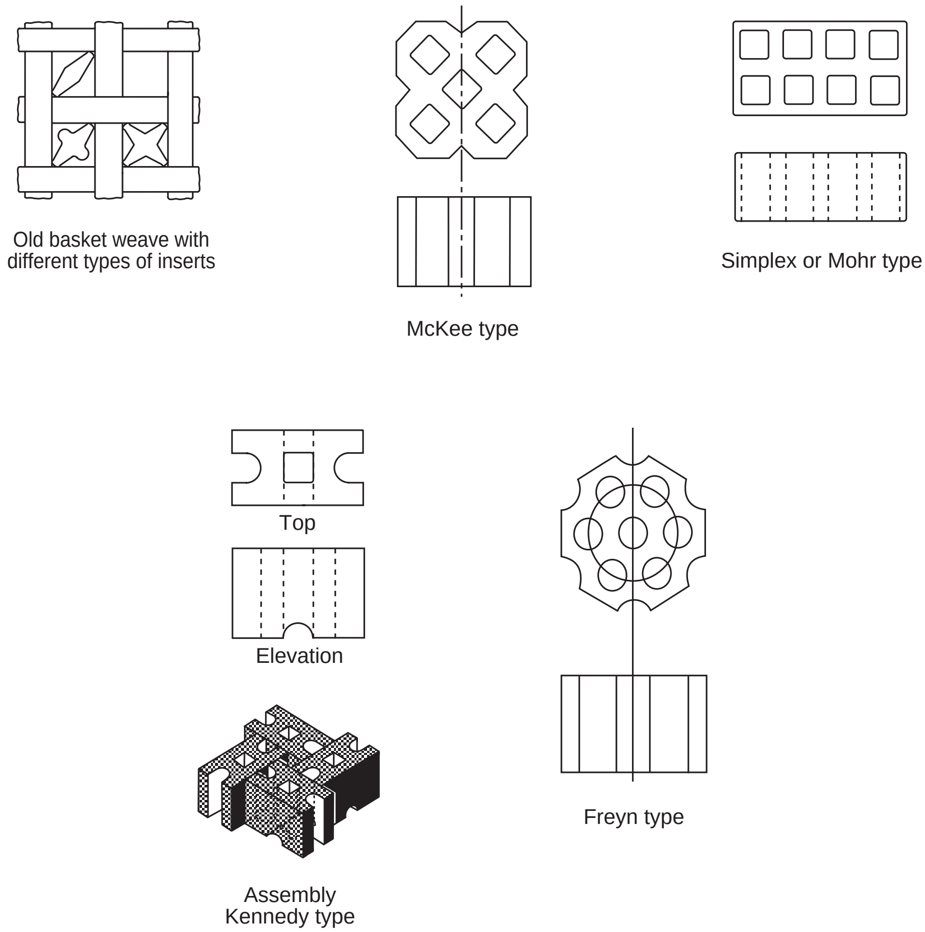


Fig. 9.35 Different checker designs employed in blast furnace stoves. The basket weave design with inserts is no longer used.

Many older hot blast stoves that were built before gas cleaning was very efficient were equipped with basket weave checkers with very large flue openings, as large as 140×140 mm (5.5×5.5 in.). However, with better gas cleaning facilities, it became possible to use checkers with smaller flue openings without as much danger from plugging the flues with dirt. With smaller flues, heat transfer rates could be increased because the ratio of heating surface to checker weight increased and more checker weight could be installed in the available space. However, with the smaller flue openings, it became very important to lay up the checkers so that the flues matched perfectly. Misaligned flues would increase the pressure drop through the stoves significantly and would prevent effective use of all the heat storage capacity. Several of the types of checkers used presently are shown in Fig. 9.35.

The burner for the blast furnace stove is located near the bottom of the combustion chamber, as shown in Fig. 9.34. On the majority of hot blast stoves in the United States, the burners are external to the combustion chamber. There is a burner shutoff valve between the burner and the stove that is closed to isolate the burner when the stove is on blast but open when the stove is being fired. The gas and combustion air are partially mixed in the metallic burner but, because of their high velocity through the burner, actual ignition probably does not occur until inside the stove. The mixture of gas and air impinges on the target wall directly opposite the burner port and then makes a 90° turn. Combustion continues while the gas ascends up the combustion chamber as shown in Fig. 9.36(a). When a stove is to be heated from the cold condition, an igniter must be used to start combustion but, during normal operation, the residual heat in the target wall is sufficient to cause ignition.

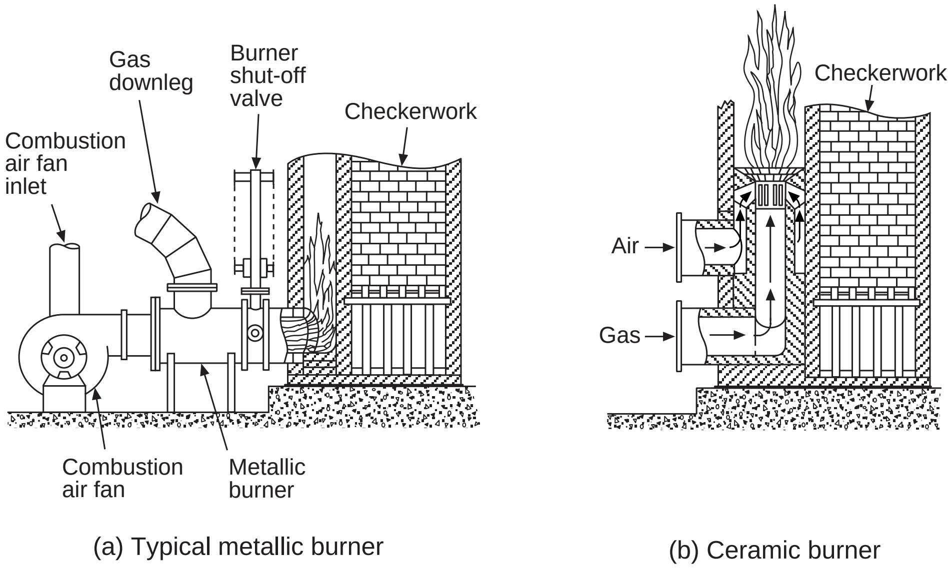


Fig. 9.36 Schematic of hot blast stove burners.

In several modern hot blast stoves, ceramic burners are used. These burners, with their mixing chamber, are installed inside the combustion chamber and the firing is upward in a vertical direction instead of a horizontal direction as with the conventional metallic burner. A diagram of a ceramic burner is shown in Fig. 9.34(b). With this type of burner, shutoff valves are required in both the gas main and the combustion air duct; these valves must be capable of withstanding the force of the blast pressure. Schick and Palz[2] described the benefits of ceramic burners and the special design features required for their successful use.

The port through which the hot blast air exits from the stove is located on the side of the combustion chamber 4–7 m (13–23 ft) above the burner. Between the stove and the hot blast main is a water-cooled hot blast valve that prevents the high pressure air in the main from entering the stove during the heating process. The hot blast valve is usually located a short distance away from the stove to reduce the amount of radiation it receives from the combustion gases. In many installations, the cold mixer air that is used for controlling the temperature of the hot blast is mixed with the hot air from the stove on the stove side of the valve. This is to prevent the valve from being exposed to air at the maximum temperature obtained in the stove dome. Some blast furnaces have a central single cold blast mixer opening that is located in the hot main between the closest stove and the furnace itself. This central system has the advantage of fewer thermal cyclings of the hot main with the higher temperature systems. Most of the hot blast valves are of the gate type shown in Fig. 9.37(a) or of the mushroom type shown in Fig. 9.37(b) and are 1.2–2.0 m (4–6.5 ft) in diameter.

The reheating of the stove requires instrumentation in the dome area, the checker refractory and the waste gas exit area at a minimum. There is an opening in the dome of the hot blast stove through which a thermocouple or a radiation-type temperature detector can be inserted. This instrument is used to control the amount of gas and air during the firing process. The temperature monitoring instruments in the dome, checkers and waste gas area are also used to protect the refractories from an overheating condition.

In the plenum chamber below the grid that supports the checkers are the openings to the chimney and to the cold blast main. In most modern stoves, there are two chimney valves, ranging in size from 1.5–2.0 m (5–6.5 ft) in diameter, which are opened when the stove is being heated so that the products of combustion will be drawn out to the stove stack. When the stove is on blast (heating the blast air), the chimney valves must be closed. Fig. 9.38(a) shows a diagram of a typical chimney valve. The seats of the valve are arranged so that when the stove is on blast, the pressure in the stove holds the seats together to prevent leakage. When the stove is to be taken off blast and put on

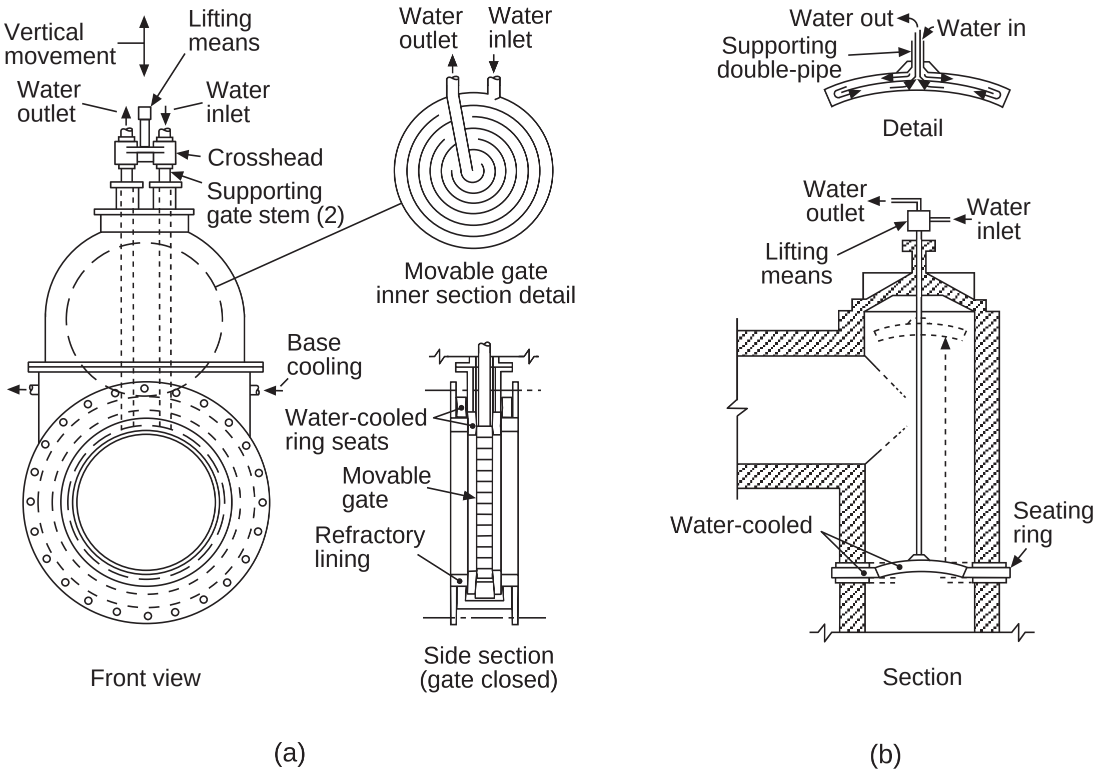


Fig. 9.37 Hot blast valves.

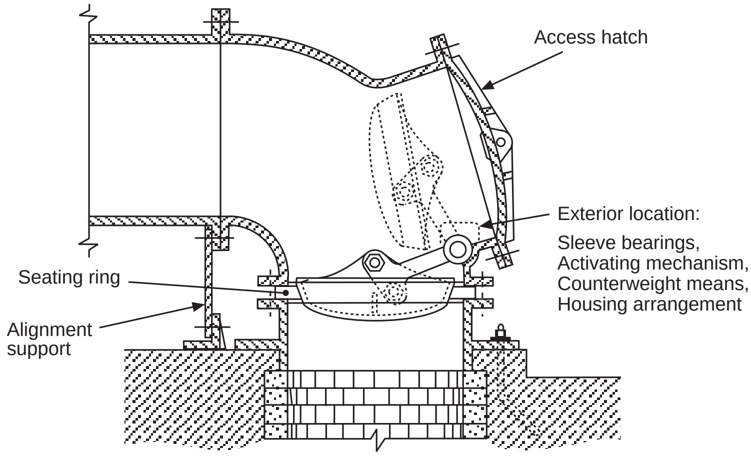
heating, there is a blow-off valve that must be opened to relieve the pressure. Because of the need to depressurize the stove rapidly, the air must exit at a very high velocity. Consequently, the blow-off valves must be equipped with mufflers to keep the noise level within tolerable limits.

The cold blast valve is the type that is held closed by the pressure in the cold blast main. A diagram of a cold blast valve is shown in Fig. 9.36(b). Before this valve can be opened, the small ports in the valve disc must be opened to pressurize the stove and equalize the pressure on each side of the valve.

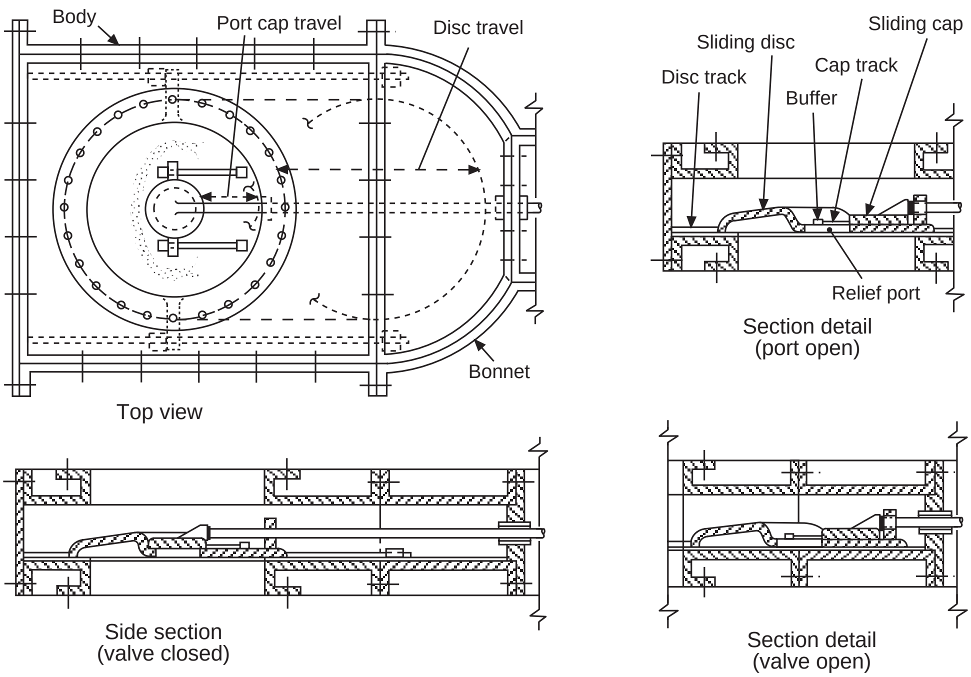
At several very modern blast furnaces, particularly in Europe and Japan, the stoves are equipped with combustion chambers completely external to the stove shell, Fig. 9.39. The advantage of this design is that the entire stove shell can be filled with checkers. Furthermore, the thermal pattern in the stove is much more symmetrical and there are far fewer stresses that tend to distort and rupture the brickwork. However, there have been many stress-induced problems that have caused rupturing in the steelwork of the junction section between the combustion chamber and the stove. As a result, frequent repairs to the steelwork are required in this location.

9.5.2 Air System

Between the hot blast stoves and the blast furnace blower is the cold blast main. It is unlined because the temperature of the cold blast is usually 150–250°C (302–482°F), which is the temperature resulting from the heat of compression at the blower. At the stove end of the main are the cold blast valves for the stoves and the mixer line equipped with a butterfly valve. To maintain a constant hot blast temperature to the blast furnace, a thermocouple in the hot blast main controls this butterfly valve in the mixer line and proportions the amount of air delivered to the stove and the amount bypassing it, Fig. 9.40. When a heated stove first goes on blast, the temperature of the heated air is much higher than the desired hot blast temperature, so a significant portion of the air must bypass the stove. As heat is removed from the stove and the temperature decreases, the mixer



a) Chimney valve



b) Cold blast valve

Fig. 9.38 Blast furnace stove valves.

line butterfly valve must gradually close and force more of the air through the stove. In some automatic stove changing systems, the position of the regulating valve is used as the signal that initiates a stove change.

The cold blast main is also equipped with a snort valve, usually located near the blast furnace, that is opened when it is necessary to decrease the blast pressure rapidly. This discharges the cold blast air to the atmosphere and keeps a positive pressure on the cold blast line so that gas from the furnace cannot travel back to the blower. Because of the rapid discharge of air when the snort valve is opened, it also must be equipped with a muffler.

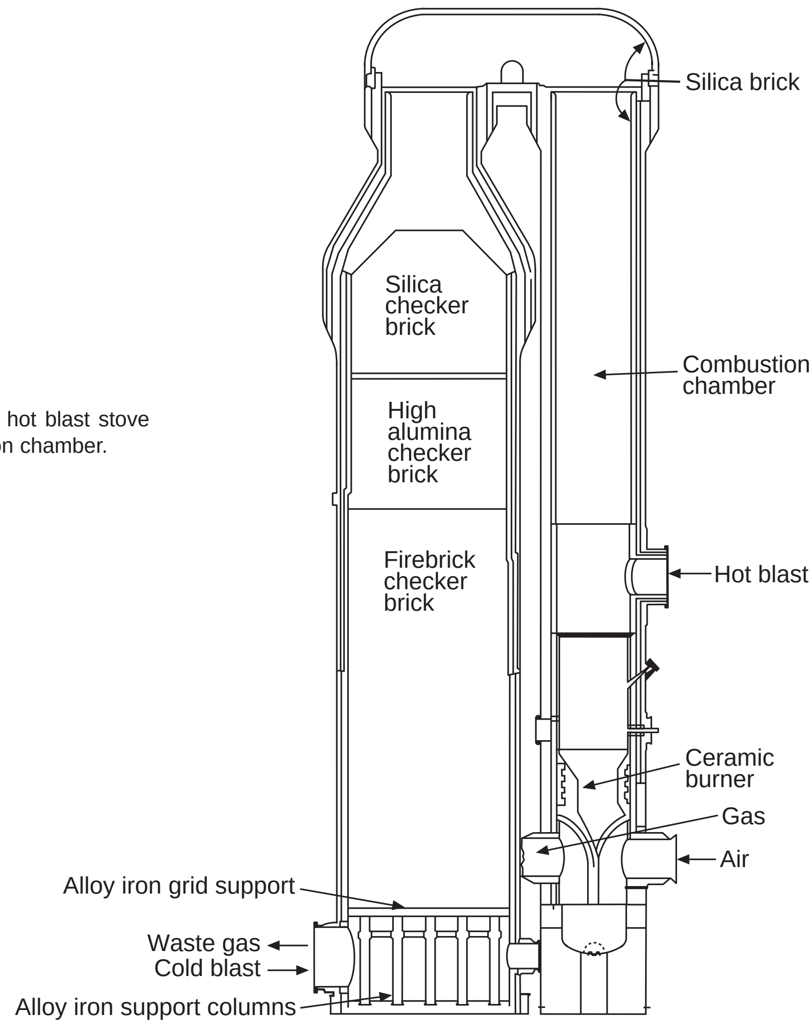


Fig. 9.39 Schematic of a hot blast stove with an external combustion chamber.

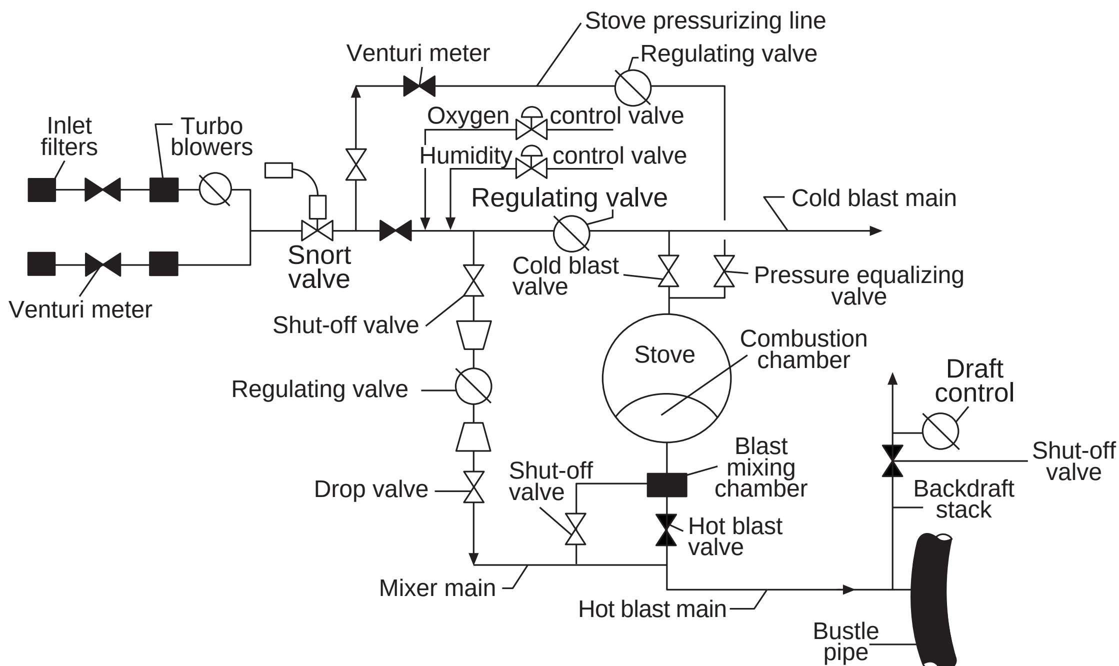


Fig. 9.40 Schematic of a typical cold and hot blast air system.

For generating the blast air, most blast furnaces are equipped with centrifugal turbo-blowers provided with three or four stages. For some of the very large blast furnaces, two blowers will operate in parallel. However, with very large blast furnaces an axial blower can be used more efficiently. At plants where the blast is enriched with oxygen, the oxygen can be added at atmospheric pressure to the inlet of the turbo-blower or it can be added under pressure in the cold blast main. Moisture is added in the cold blast main when it is required for blast moisture control.

The blowpipe, which connects the hot blast system to the tuyere, fits into a machined spherical seat at the base of the tuyere. The tuyere cooler and the tuyere are water cooled. On modern blast furnaces utilizing hot blast temperatures near 1150°C (2100°F), the tuyere body water passages are designed to keep the water velocity above 20 m/sec (65.6 ft/sec). And the tuyere nose water passages are designed to keep the water velocity above 27.5 m/sec (90 ft/sec) to improve the rate of heat transfer. In the example shown in Fig. 9.41, the nose of the blowpipe is also water cooled, although in most of the older furnaces this is not the case. The fuel injection lance enters through the wall of the blowpipe and usually discharges the fuel slightly off the centerline and about 50 mm (2 in.) back from the nose of the blowpipe. Some blast furnaces are equipped with dual injection systems that have two openings in the blowpipe to facilitate multiple tuyere fuels. With the increased use of fine coal as a tuyere fuel, the injection lance placement is more critical to deter impingement on the inside of the tuyere and for better combustion of the coal.

The blowpipe is held tightly against the tuyere by tension in the bridle rod, which connects the tuyere stock to the hearth jacket. The bridle spring on the end of the bridle rod allows limited motion as the blowpipe expands and contracts with changes in hot blast temperature. The blowpipe itself is an alloy steel tube lined with refractory material to prevent the metal from becoming too hot.

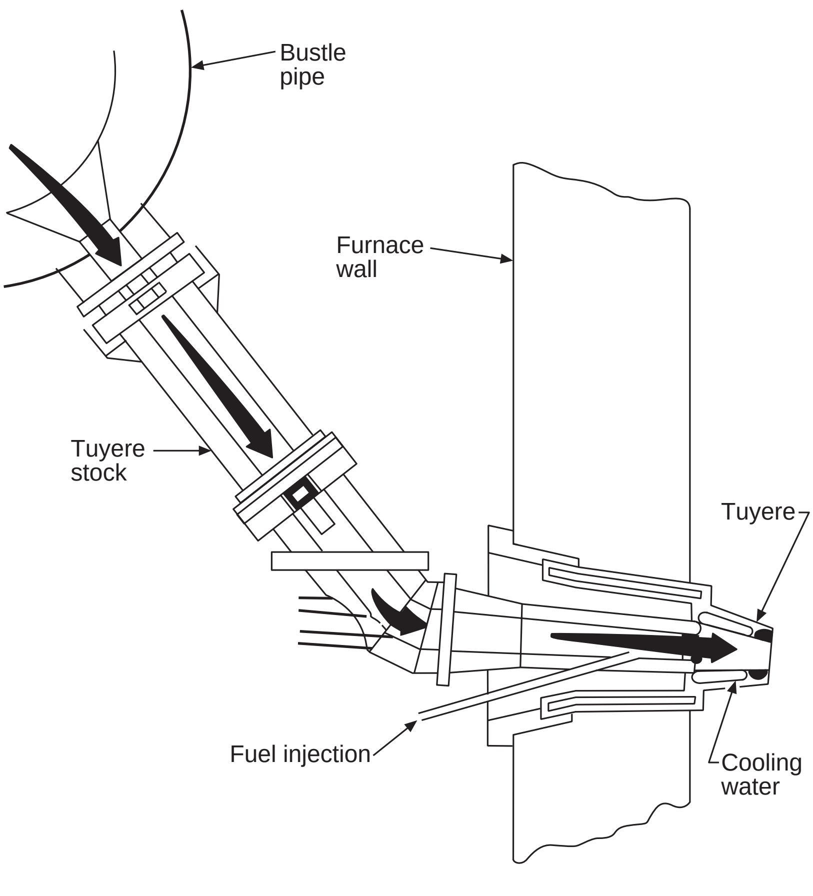


Fig. 9.41 Schematic of a typical tuyere stock arrangement.

At the back of the tuyere stock on the centerline of the blowpipe and tuyere is a small opening through which a rod can be inserted for cleaning material out of the blowpipe. The opening is closed by a cap that can be opened when necessary but is gas tight when closed. In this cap, called a tuyere cap or wicket, there is a glass-covered peep sight that permits the operator to inspect the interior of the furnace directly in front of the tuyere. The upper part of the stock is connected by a swivel joint to the refractory lined nozzle of the gooseneck to which it is clamped by lugs and keys that fit into seats of hanging bars. Each gooseneck in turn is connected by flanges and bolts to a neck extending radial from the inside diameter of the bustle pipe. The bustle pipe is a large, circular, refractory lined and insulated pipe that encircles the furnace at above mantle level and distributes the heated blast from the hot blast main to each tuyere connection. The general arrangement of the bustle pipe, tuyere stocks and blowpipe can be seen in Fig. 9.41.

9.5.3 Tuyere Injectants

In the late 1970s operators began to experiment and increase the amount of fuel that was injected into the blast air at each tuyere. This practice was due to the short supply and rising cost of coke. The improvement in hot blast capability of the stove system has permitted increased amounts of tuyere fuels to be used. The fuels used for injection into the blast furnace are natural gas, coke oven gas, fuel oil, tar, fine coal and shredded plastics. All of these fuels serve the same purpose as a partial replacement of the coke required for the smelting process. The liquid and gaseous fuels of natural gas, coke oven gas, fuel oil and tar are typically pressure-injected via a lance pipe through the blowpipe assembly as shown in Fig. 9.41. The solid fuels of fine coal and plastics are typically pneumatically conveyed with air or nitrogen in a similar lance arrangement as the other fuels.

The selection of what fuel is appropriate for blast furnace injection is dependent on supply, hot blast capability, furnace design and installation costs. Most blast furnaces are operating with 15–20% of their fuel requirement being supplied by the tuyere injectants. Some furnace operations are as high as 33% of the fuel requirement being supplied by the tuyere injectants. Enrichment of the oxygen content of the blast air to the furnace is often required to enhance combustion of the tuyere fuels. The trend toward higher tuyere fuel usage will continue with the diminishing supply and increasing cost of coke.

9.6 Raw Material Receiving

9.6.1 Receipt of Blast Furnace Raw Materials

The iron-bearing materials, ore and pellets, generally come from a considerable distance and must be transported either by rail or water or a combination of both. Coke is often received by rail and is consumed as rapidly as it is received. However, in the case of ore and pellets, weather conditions are often such as to prevent mining and transportation during the colder months, so during the warm months it is necessary to store approximately a six month supply adjacent to the furnaces. Because many of the furnaces in the United States receive their iron-bearing material from the Lake Superior District, as discussed at length in Chapter 8, the transportation of ore from there to the lower lake plants is described very briefly here as being typical of water transportation of iron bearing materials. At the head of Lake Superior, ore is loaded by gravity, from overhead bins arranged on long piers extending into the harbor, into specially constructed ore boats. Most of the ore boats are self unloading and require no equipment at the plant site. The hold of these boats is divided in into compartments or bins that are equipped with feeders that can discharge the contents of the bins onto a conveyor belt that runs along the bottom of the ship’s hold. This conveyor discharges onto a series of inclined conveyors that raise the cargo out of the hold. A long conveyor mounted on the boom of the ship’s crane can be swung out from the side of the ship in any direction and discharge the cargo directly into the ore trench.

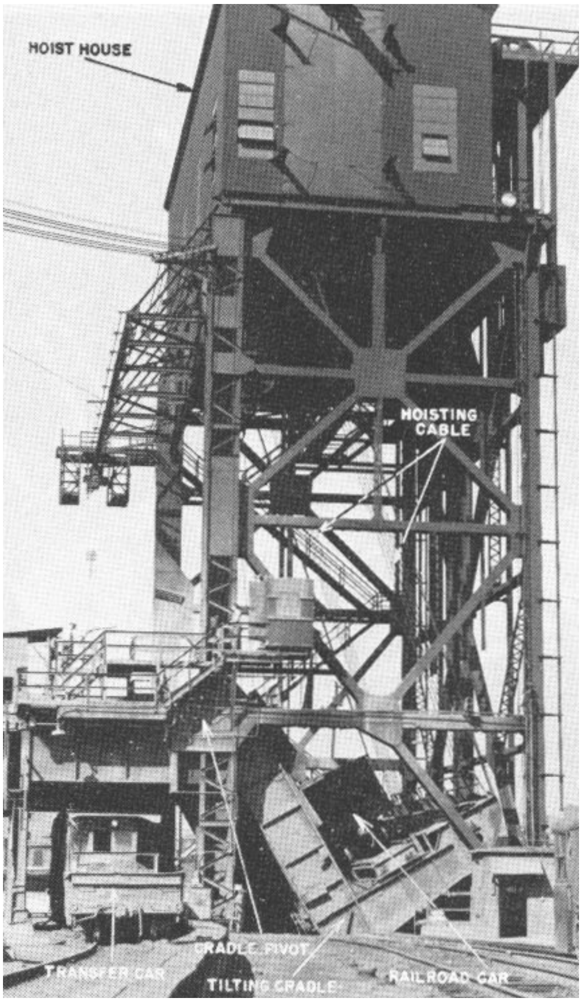


Fig. 9.42 Car dumper discharging iron ore from a railroad car into a transfer car.

9.6.2 Car Dumper

For those plants located some distance from the point of vessel unloading, or where ore and pellets are received directly from the mines by railroad, a car dumper is the usual means to unload them. The material, arriving at the plant in trainload lots, is switched to a siding ahead of the car dumper and the cars are unloaded one-by-one in rapid succession.

In one type of dumper, illustrated in Fig. 9.42, a car is pulled up an incline to the platform of the dumper by a steel cable of a *mule* or *barney*. There it is lifted bodily and turned over so as to empty its contents into a large transfer car which, in turn, discharges into an unloading trough at the designated location in the stockyard for that particular grade. The dumper then resumes its former position and the empty car is pushed off the platform, by the next car of ore or pellets, to an incline, down which the empty cars move to a siding. The transfer cars are usually designed to hold two railroad cars of ore or pellets.

Another type of car dumper shown in Fig. 9.43 is the rotary dumper in which the car is held in position on the track with clamps and the entire supporting structure rotates the car about its longitudinal axis. Many of the modern dumpers discharge the materials into bins from which they are fed onto conveyor belts and taken either to storage space or directly to the highline bins.

9.6.3 Ore Yard and Ore Bridges

The ore yard, Fig. 9.44, is a large space, sometimes with concrete bottom and sides, which parallels the furnace bin structure and serves as storage for approximately a six month supply of burden material.

Its width is determined by the practical maximum span of the ore bridge, which for a bridge supported at each end amounts to about 107 m (350 ft). Other types of bridges are supported by two legs which run on tracks that run longitudinally through the ore yard (dividing the yard into three separate piles); such bridges have cantilevers on the outer sides of the two supporting legs. This type gives a longer trolley travel but does not necessarily store more ore per running foot because of the space occupied by the supporting structures. A trolley running on the bridge proper carries a grab bucket of about 15 tonnes (16.5 net tons) capacity which lifts the ore from the dumping trough and distributes it on the pile. The reverse action removes the ore from the pile and deposits it either directly into the bins or into a bin car or transfer car, Fig. 9.45, which in turn distributes the ore. Some bridges are equipped with a bin mounted on the bridge into which the bucket dumps, permitting the bridge to keep working while the bin car is dumping its load. In order to obtain the maximum blending, the ore is stocked in horizontal layers and removed in vertical slices. For this reason, the use of ore direct from hopper cars unloaded from the trestle into the bins is undesirable. The details of the ore handling system will vary considerably but the general scheme is essentially as stated.

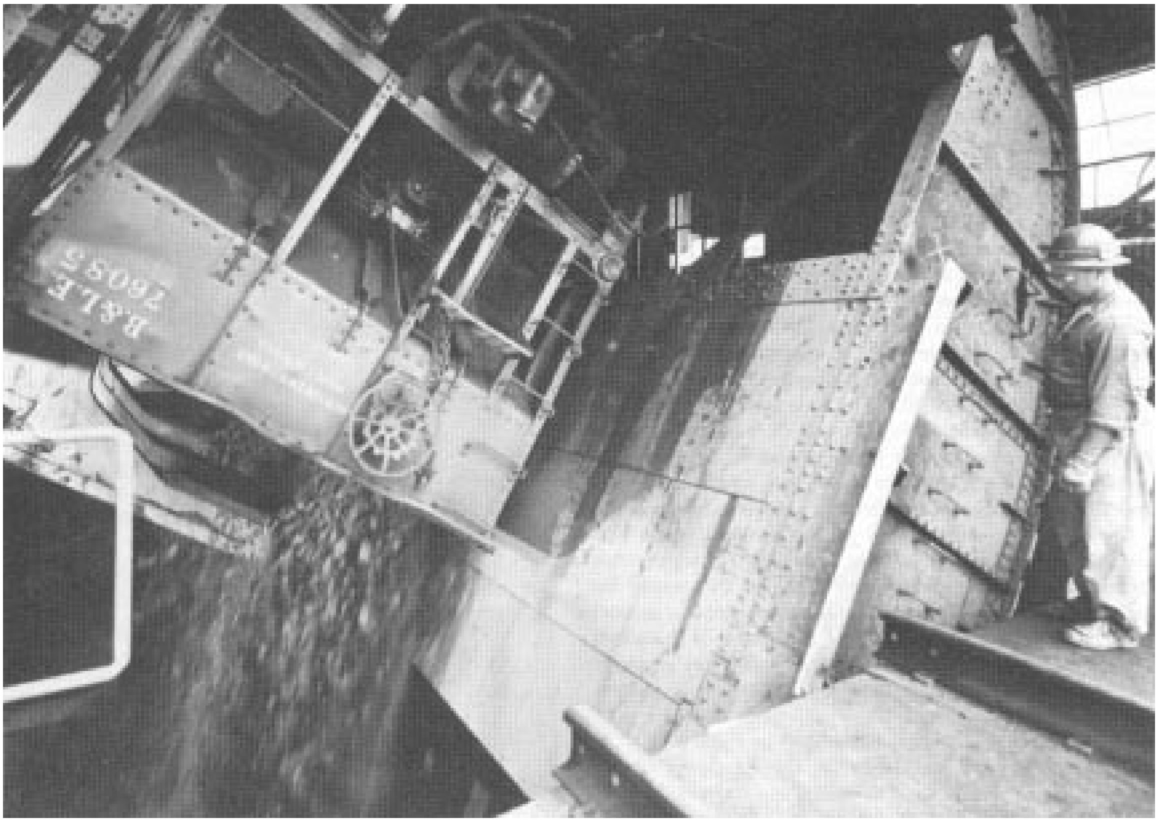


Fig. 9.43 Rotary car dumper with the railroad car in the inverted position.

Fig. 9.44 View of an ore yard servicing the blast furnaces in the background.

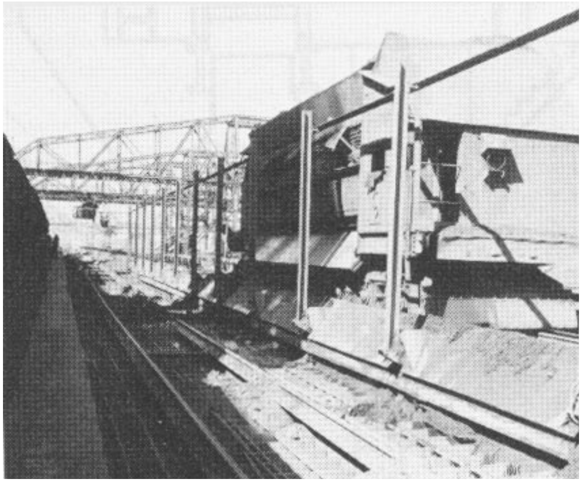


Fig. 9.45 Transfer or bin car of the side-discharge type shown in position to discharge a load of ore into the stockhouse bins. The ore must pass through the gratings shown, which effectively prevent oversize material from entering the bins.

9.6.4 Trestle and Stockhouse

The function of the trestle and stockhouse is to deliver the correct quantities of iron-bearing materials, flux and coke to the furnace as expeditiously as possible to keep the blast furnace at top operating performance.

The constructional details of the trestle differ considerably from plant to plant. A trestle of modern design consists of a reinforced concrete wall on the stockyard side and steel columns on the furnace side, between which is a pattern of transverse and longitudinal girders. On the top, these girders support three or four railroad tracks, and on the bottom, they support the bins. The track nearest the stockyard carries a side dump bin car, the next track carries railroad cars containing such materials as limestone, dolomite, scale, scrap, etc., which are unloaded by manual operation of the hopper gates of the cars, and the next one or two tracks carry coke cars. When there are more than six furnaces in a line, it is desirable to have two coke tracks so that the coke cars not fully unloaded may be bypassed. Where a belt conveyor fills the coke bins, one coke track for emergency use is sufficient. This construction results in two lines of bins in the stockhouse with one line containing ore, flux and miscellaneous materials and the other containing coke.

9.7 Casthouse

9.7.1 Tapping the Furnace

The operation of a blast furnace is a continuous process, and the furnace continues to produce liquid iron and slag as long as it is in operation. The iron and slag accumulate in the hearth, but because there is a limit to the amount that can be tolerated before it interferes with the furnace operation, the slag and iron must be removed from the furnace at regular intervals. The iron notch, which is used for tapping the hot metal from the furnace, is located slightly above the floor of the hearth. Most modern furnaces are equipped with more than one iron notch. There is also a cinder notch for removing slag from the furnace, and it is located in a plane typically 1–2 m (3.3–6.6 ft) above the iron notch.

Before the blast furnace burdens were improved to today's current standards, the weight of slag produced in the blast furnace was more than half the weight of the hot metal. The lower density of the slag caused it to fill up the space in the hearth above the metal, and it would interfere with the penetration of the blast air and the combustion process at the tuyeres long before the accumulation of iron had reached the desired amount for casting. Consequently, it was necessary to remove the excess slag through the cinder notch (generally referred to as the monkey) once or twice between casts. However, in recent years, since better prepared burdens have been used, the slag volumes have decreased to 200–300 kg/tonne (400–600 lb/net ton). Therefore the monkey is seldom used and the slag is typically only removed via the iron notch during the casting process.

Until 1962, all of the blast furnaces in the United States were equipped with only one iron notch, Fig. 9.46; however, all of the new large blast furnaces built since then have been provided with two or more iron notches, Fig. 9.47 and Fig. 9.48. When the furnace is in operation, the iron notch is completely filled with a refractory material called taphole clay, see Section 4.6. To cast the hot

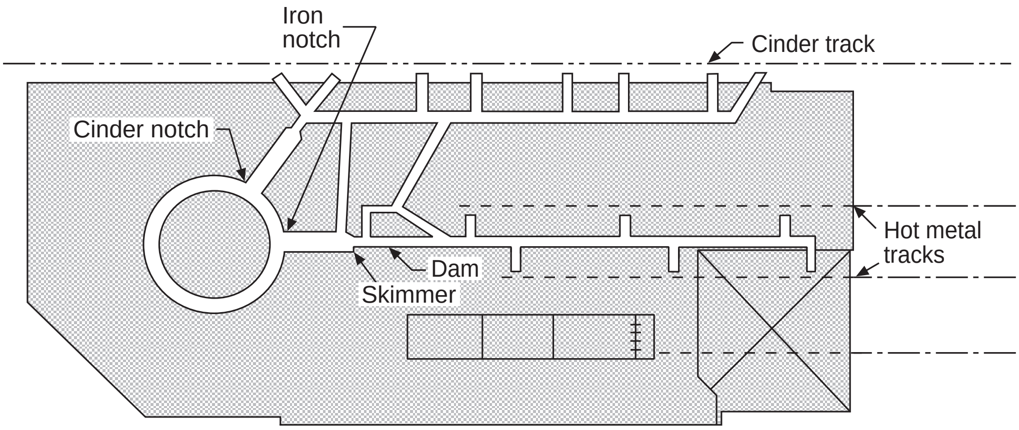


Fig. 9.46 Layout of a single taphole casthouse.

metal from the furnace, a taphole is drilled through this material, Fig. 9.49, and after the cast has been completed, the hole is plugged again with fresh clay that is extruded into the hole from a mud gun, Fig. 9.50. The mud gun consists of a hollow, cylindrical barrel and a plunger that pushes the clay out through a nozzle into the taphole. The plunger is operated either electrically or hydraulically . Formerly, only water-based bloating clays were used in the taphole, but this type of clay erodes too rapidly and the hole enlarges so much during tapping that it is difficult to control the cast. Consequently, at most large blast furnaces this type of clay has been replaced by carbonaceous material and resin materials, which perform better. Fig. 9.51 is a photograph taken in a casthouse facing the blast furnace and shows the mud gun inserted into the taphole in the position used for stopping (plugging) the hole. To the left side of the mud gun is the tapping drill in its retracted position. For tapping, the mud gun swings away to the right and the drill swings into position so that the hole is drilled at the desired angle.

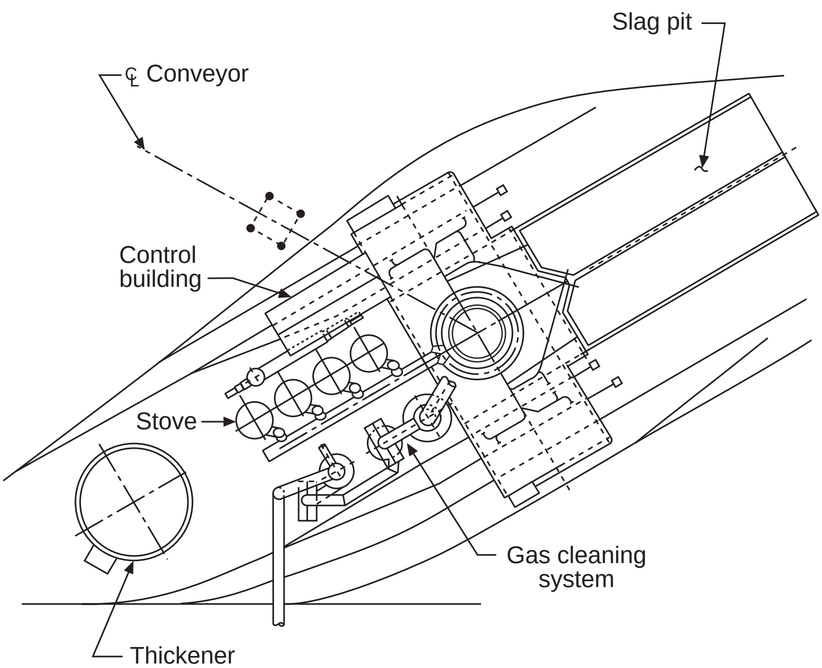


Fig. 9.47 Layout of a casthouse arrangement with two tapholes.

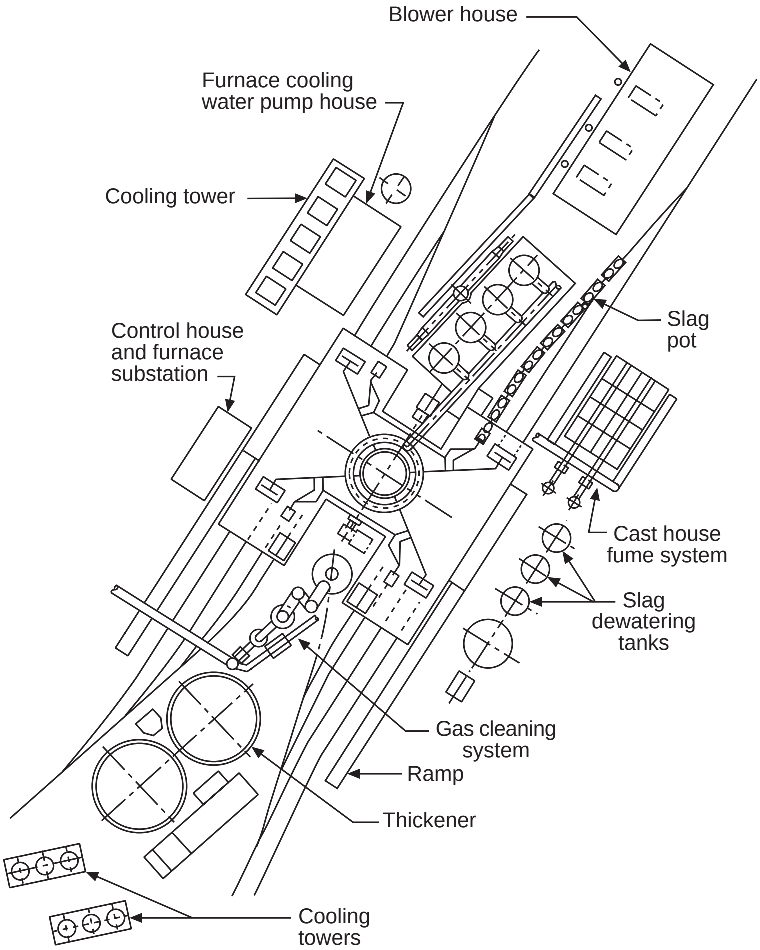


Fig. 9.48 Layout of a casthouse arrangement with four tapholes.

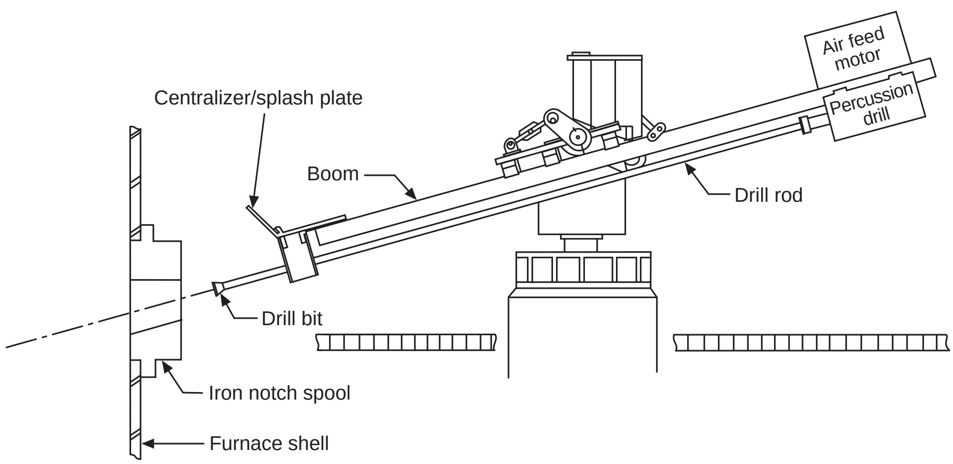
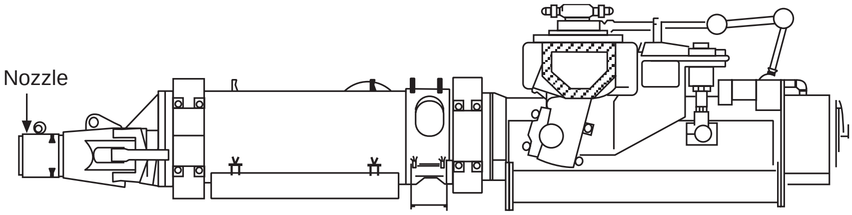
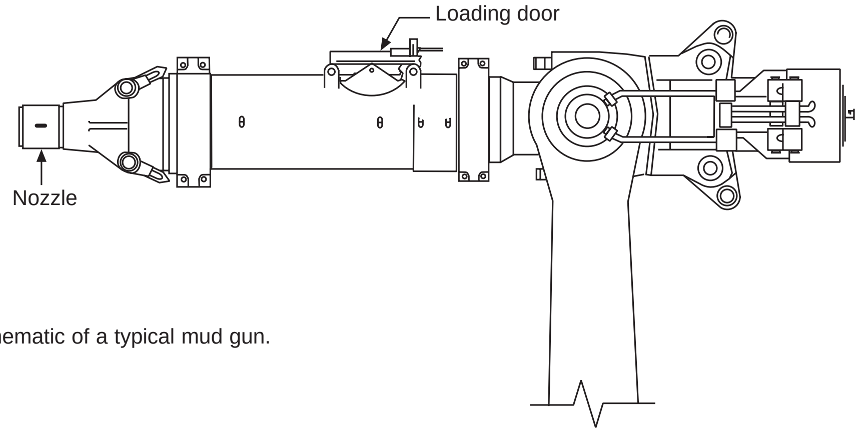


Fig. 9.49 Schematic of a typical taphole drill.



(a) Elevation view



(b) Plan view

Fig. 9.50 Schematic of a typical mud gun.

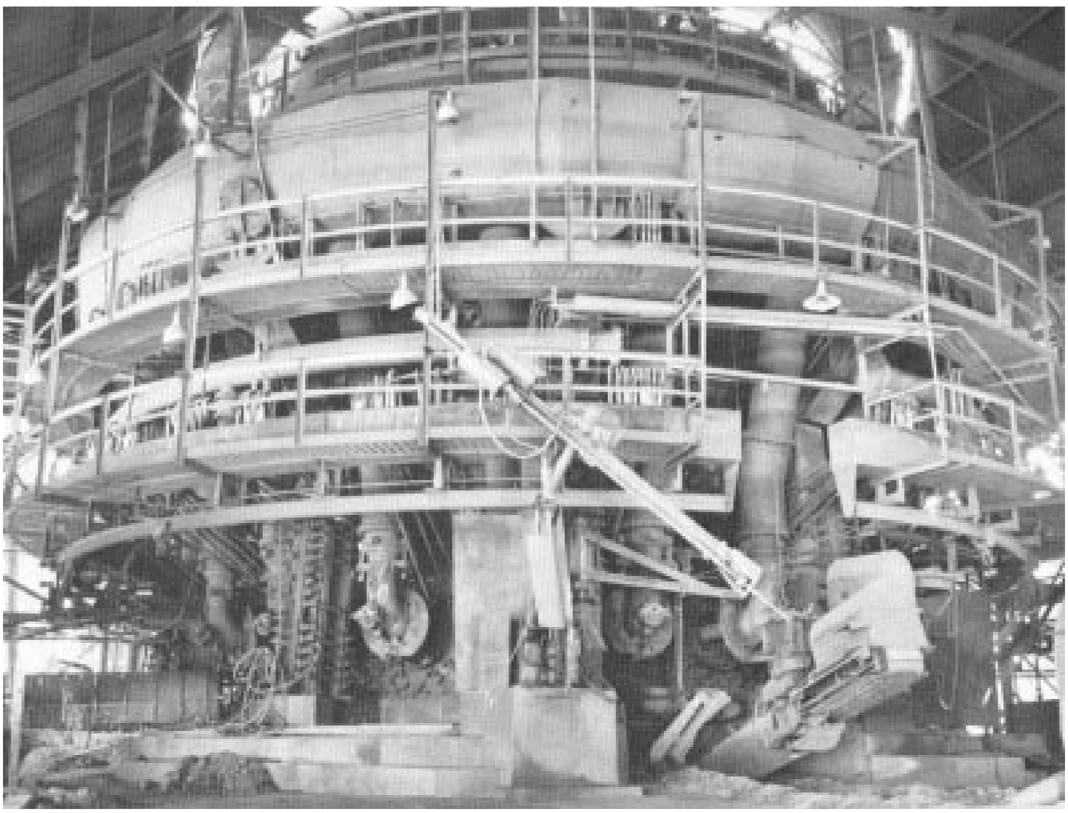


Fig. 9.51 Photograph of a blast furnace at the end of a tap with the mud gun in position at the taphole. The taphole drill is retracted and ready to be swung into position for use for the next tap.

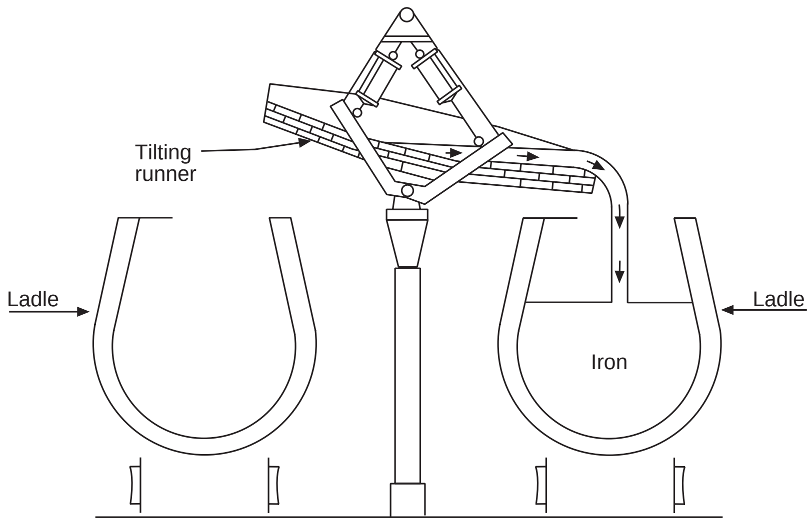


Fig. 9.52 Typical tilting runner arrangement.

As the hot metal leaves the taphole it is discharged into the trough which is a long, narrow basin 1–1.5 m (3–5 ft) wide and 8–12 m (26.5–39.5 ft) long. The trough generally has a slightly sloping bottom inclining 1.5–2 mm per metre (0.018–0.024 in. per foot) away from the furnace. At the far end of the trough there is a dam to hold back the hot metal until the depth of metal in the trough is sufficient (about 300 mm or 12 in.) to contact the bottom of a refractory skimmer block. The skimmer holds back the slag and diverts it into the slag runners. The hot metal flows over the dam and down the iron runner where, by a series of gates, it is directed in sequence to the train of ladles positioned under stationary spouts along the runner. At several large blast furnaces, a tilting spout is positioned between two hot metal tracks, Fig. 9.52. The spout is first tilted to fill the ladle on one track and then tilted to back to fill the ladle on the other track. While the second ladle is being filled, the first one can be replaced with an empty so that the cast can be continued uninterrupted while several ladles are filled.

Most of the blast furnaces hold the hot metal in the trough at the end of casting to permit frequent casting which is required by the increased production demands. This has become possible due to improved trough refractories, installation machinery and procedures. At several modern blast furnaces the iron troughs are removable. Removable iron troughs minimize the time required to maintain the casting refractories and the end result is greater furnace production capability.

9.7.2 Casthouse Emissions

Fumes from the casting process are no longer permitted to freely escape into the atmosphere. The basic methods of controlling or reducing the emissions to acceptable levels vary according to the furnace design and regional requirements. One method is to enclose the entire casthouse structure and evacuate the casthouse atmosphere to a capture facility. This approach is expensive to install and operate and it creates an environment that is less than desirable for employees on the casthouse. A second method is a system of covered iron and slag runners and point capture hoods where the fume generation is the greatest during casting (i.e. taphole, iron spouts) with evacuation from these collection devices to a baghouse filter system. A third method is to cover the entire trough and runner system to reduce the contact with the atmosphere, and a fourth method is to suppress fume formation by the blanketing of the iron with an inert atmosphere such as burning natural gas or nitrogen. The last two methods minimize the fume generation by reducing the contact between the molten iron and air, which can generate a brown iron oxide fume.

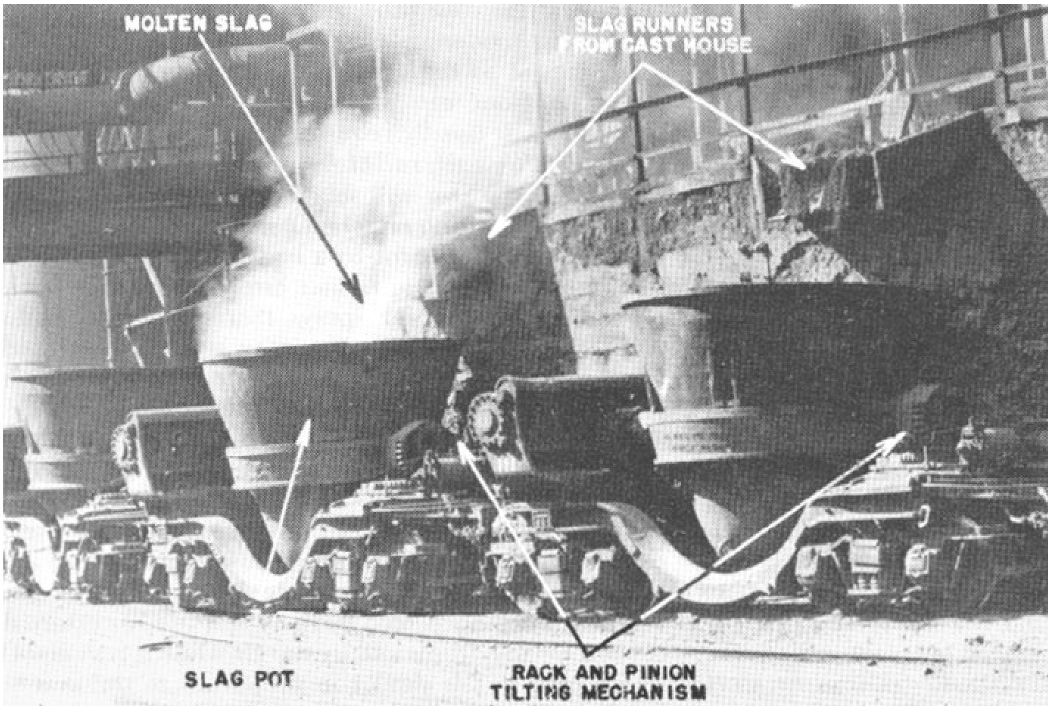


Fig. 9.53 Molten slag filling a slag pot.

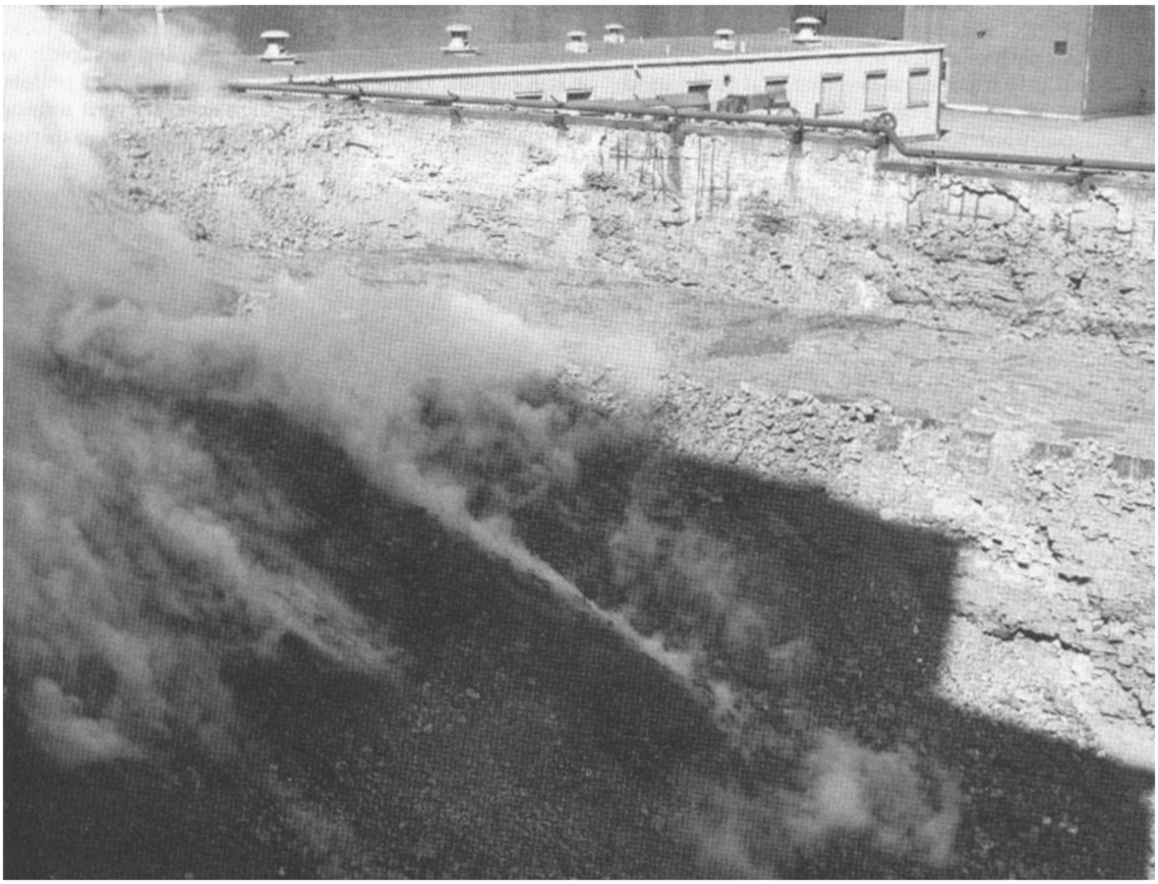


Fig. 9.54 Slag pit adjacent to a blast furnace.

9.7.3 Slag Disposal

Blast furnace slag is handled in many different ways, depending upon the amount of space available around the furnace and on the type of product that is to be made from the slag. At most of the older blast furnaces, the slag was run into cinder pots mounted on railroad cars and transported outside the plant to a slag dump. The cinder pots (also called slag pots) are unlined, thimble shaped, cast iron or steel castings mounted on railroad cars. The pot fits into a bracket with trunnion mountings set on a rack and pinion so that it they can be rotated and dumped by a compressed air operated cylinder mounted on the railroad car. The slag from the pots can be dumped over a bank into pits and later excavated, crushed and screened to be used as ballast or aggregate. Or the slag can be poured into the path of a high pressure stream of water that expands it into popcorn like material to be used as lightweight aggregate. Fig. 9.53 shows a train of slag pots positioned under the spouts of the slag runners of the blast furnace casthouse.

At many modern blast furnaces, the slag is run into pits adjacent to the casthouse. There are usually two pits so that one can be excavated while the other is being filled. It usually requires two or three days to fill a pit, and after each run of slag water sprays are used to assure that the slag will solidify rapidly enough to be ready for excavating on schedule. Fig. 9.54 shows a hard slag pit adjacent to a blast furnace. At several blast furnaces, the slag runner directs the slag in front of high pressure water sprays that granulate it into small pieces and then wash it into a wet pit. The rapid cooling of the slag gives it a glassy structure, and when it is finely ground, it has hydraulic bonding properties and can be used in cement. Similarly, a few furnaces have been equipped with machines to form pelletized, lightweight slag granules. In these installations, the molten slag is diverted from the slag runner to water-cooled, rotating drums which throw the slag through the air onto a pile a short distance from the machines. The slag is rapidly cooled by the water used as external coolant for the drums and by the air while it is in flight. The cooled slag is similar in properties to the granulated slag except the particles are more spherical in shape.

9.7.4 Hot Metal Transportation

The hot metal is transported from the blast furnace to the steelmaking shop in refractory-lined ladles that have a course of insulating material between the lining and the steel shell. The Pugh-type ladle, shown in Fig. 9.55, is shaped a little like a submarine and for that reason these ladles are often referred to as submarine ladles or subs. They are also sometimes called torpedo ladles because they have somewhat the shape of a torpedo. These ladles have a relatively small opening in relation to their capacity which is usually 200–250 tonnes (220–275 net tons) although some have been built much larger. The ladle itself is an integral part of the railroad car and, to empty it, it is rotated about its longitudinal axis by a motor built on the railroad car. Because of its large capacity in relation to its small opening, the torpedo or submarine ladle loses very little heat through radiation from the opening and in many instances it may be used to hold hot metal for the steelmaking process and the hot metal mixer is eliminated.

In merchant iron plants where the hot metal is not converted into steel, it is taken to a pig machine and cast into small molds that are moved consecutively and continuously under a pouring spout. The molds are attached to an endless chain. In some designs, the chains are attached to wheels that ride on the track, while in others the chain forms a track that rides on stationary rollers. The chain passes over a head and a tail sprocket wheel so that the molds are upside down on the return side. The molten iron is poured into the molds near the tail sprocket, and it solidifies and is cooled by water as the chain carries it to the head sprocket. As it passes over the head sprocket, the iron falls from the mold into a railroad car. On the return travel, the molds are sprayed with a lime wash to prevent the iron from sticking to them. Many years ago, most blast furnace plants were equipped with pig machines that were used for disposing of hot metal that did not meet the specifications of the steelmaking shop. However, the cost of maintaining such expensive equipment just for standby purposes was not economical. Most plants handle out of specification iron by pouring relatively thin layers into dry pits. The solidified iron is then broken into pieces that can be used as cold iron in the steelmaking shop. Operation of a pig machine is illustrated in Fig. 9.56.

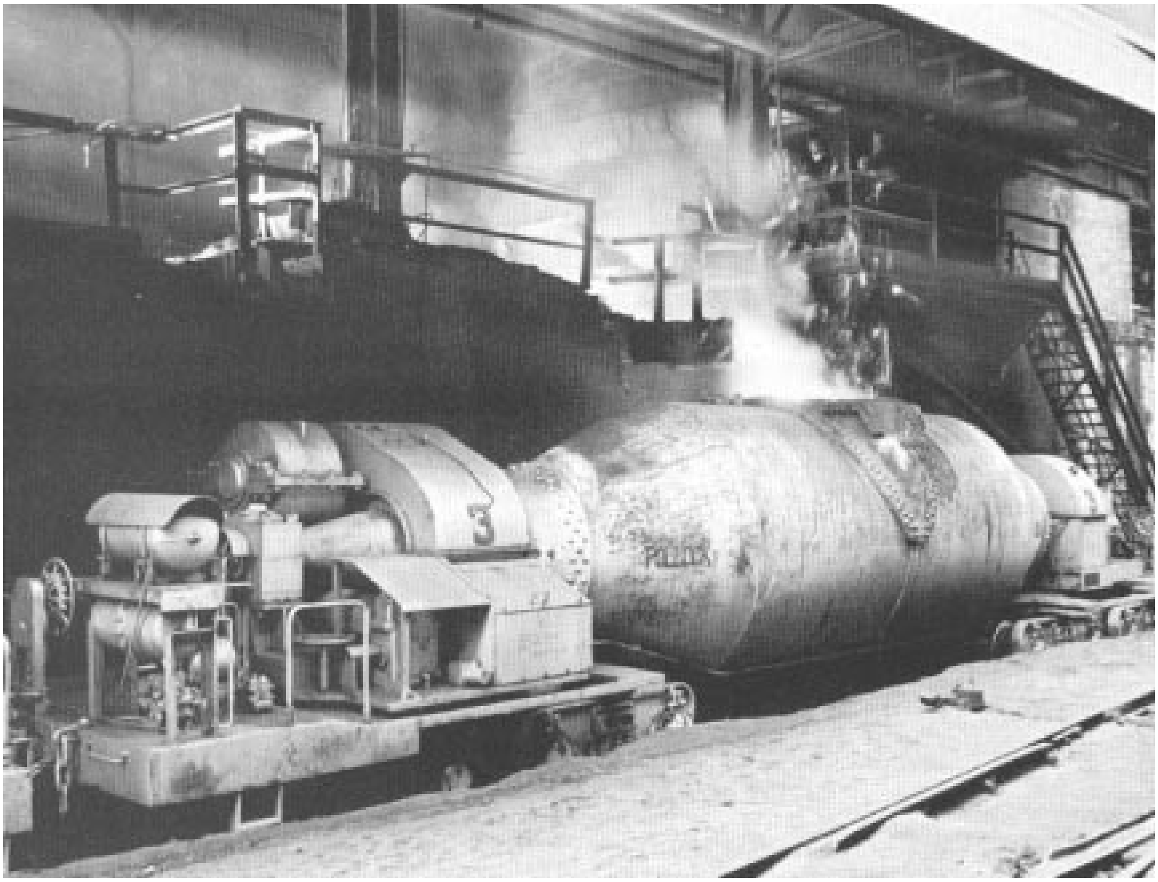


Fig. 9.55 View of hot metal filling a submarine or torpedo ladle.

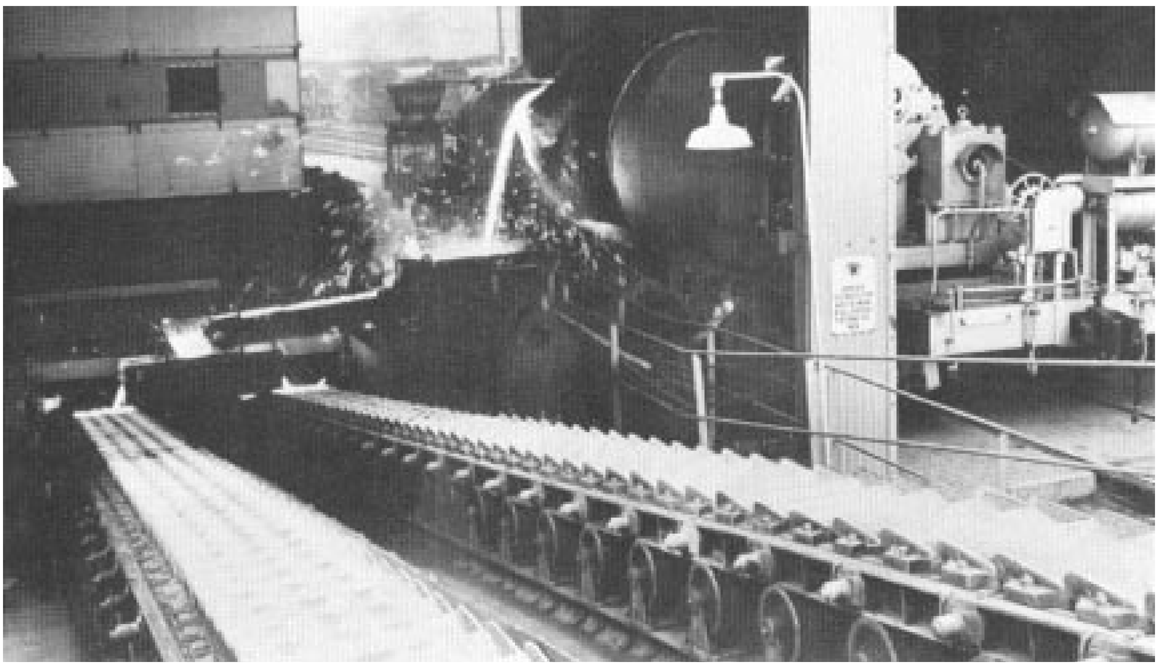


Fig. 9.56 View of a pig casting machine in operation, showing hot metal being divided into two streams by the split runner to simultaneously fill the molds in each of the two strands.

9.8 Instrumentation and Control

9.8.1 Evolution of Process Control

It is not the objective of this section to describe in great detail all the complexities of a sophisticated process control system for a blast furnace operation. Rather, the objective is to give an understanding of how the technology has evolved and how the technology is a useful tool to give the operator more information about the process to enable better control.

Blast furnace instrumentation has advanced dramatically in the past forty years and exponentially over the last five to ten years. For example, the blast furnaces in the 1950s were operated with the barest of instrumentation by today's standards. A typical instrumentation package on a blast furnace of that era would have consisted of a single pressure gauge for monitoring the wind pressure on the furnace. A mechanical weight lowered into the furnace top monitored burden descent. A thermocouple in the hot blast main monitored the blast air temperature. A total of two temperature thermocouples in each stove, one in the dome and one in the waste gas flue, informed the stovetender as to the heat capacity in the stoves. The blast furnace operator had very minimal instrumentation to monitor and control the process. Consequently the blast furnaces were operated at a high fuel rate and moderately low production rates. Communication with ancillary facilities such as the powerhouse, the turbo-blower, the stockyard and the trestle were via intercom and or telephone, which were adequate for the level of the operation at that time.

As productivity demands on blast furnaces increased, and associated fuel rates decreased, it became critical to monitor and understand more data for the process. New and improved instrumentation devices were invented and installed on blast furnaces throughout the industry. The knowledge gained from this instrumentation and monitoring has been shared throughout the industry. This shared knowledge has enabled blast furnace operators and engineers to accomplish dramatic production increases, to lower fuel rates, to introduce new types of fuels, and ultimately to effect better designs and control of the blast furnace process. This trend of acquiring and sharing new information will continue to advance the understanding of the blast furnace process and its control.

9.8.2 Typical Computer Process Control System Architecture

The modern blast furnace control system can be divided into several discrete layers to effect information and control of the blast furnace process as depicted in Fig. 9.57.

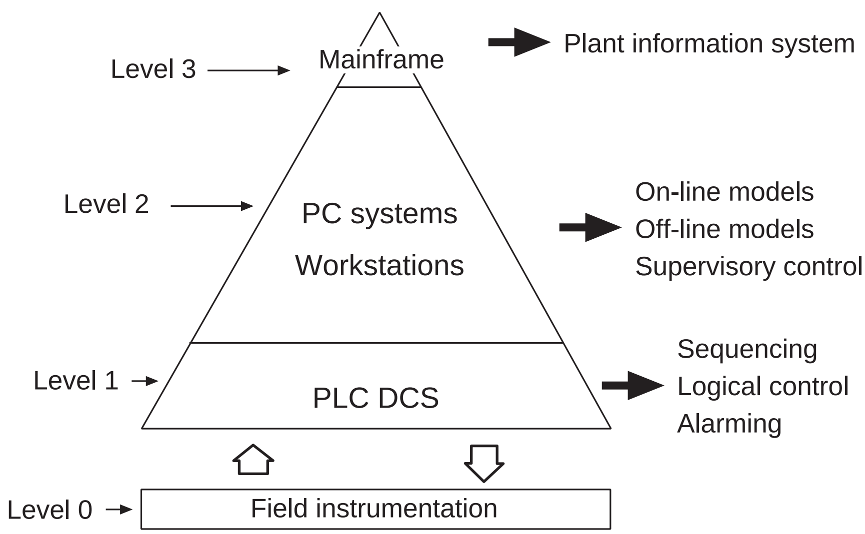


Fig. 9.57 Typical architecture for a modern process control system

The first layer of the architecture depicted in Fig. 9.57 comprises the field devices, sometimes referred to as Level 0. In simple terms these are the actual instruments, valves, motors, etc. that are measuring and controlling the pressures, flows, temperatures, positions and analyses of the process.

The second layer is the programmable logic controller (PLC) and/or distributed control system (DCS). This layer is commonly referred to as Level 1 because it is where the raw field data is initially processed. The information to and from the field devices is interfaced with this area where sequencing, logical control, instrumentation monitoring, alarming, first level diagnostics and operation of the different areas of the blast furnace process are accomplished. Examples of sequencing functions are the controlling the cooling water flows to the furnace, stove heating and changeover control, and charging of the furnace with the raw materials. An example of instrumentation monitoring would be the recording and displaying of refractory thermocouples in the lining of the blast furnace. The control in this area is generally capable of stand-alone sequencing that will continue in a repetitious pattern until new setpoints or parameters are transmitted from higher layer systems or models. This stand-alone functionality assures that disruptions in one part of the system do not cascade or interfere with critical process subsystems and possibly causing safety and property damage issues.

The operators communicate with Level 1 via man-machine interfaces (MMI) which are typically personal computers (PCs) and/or control panels. MMIs are sometimes referred to as Level 1.5 as they could interface with both the Level 1 (the PLC and/or DCS) and Level 2 (process model) systems. With PC-based MMIs, the operators can access all areas of the blast furnace plant via graphic screens that allow the starting and stopping of motors, opening and closing of valves and process monitoring from remote control rooms, Fig. 9.58.

The next layer, commonly referred to as Level 2, is where the basic knowledge of the process is located. Models for controlling and optimizing the process through rule-based algorithms and parameter changes are located in this area. Data is generated and stored in this area and downloaded or

Fig. 9.58 View of a modern control room with many MMIs for operating the blast furnace. *(Courtesy of Kvaerner Metals.)*

transmitted to lower level control systems as the process conditions change. Communication to higher-level plant information systems for use in larger plant-wide coordination also occurs in this level.

Typical process models found in Level 2 systems in blast furnaces include burden distribution, burden charging calculations, silicon prediction, hearth iron level prediction, refractory wear analysis, stove optimization, heat and mass balances, etc.

This level of control has been the most recent area of development with the introduction of advanced computer models that are approaching *artificial intelligence* for various subsystems in the blast furnace process. Knowledge-based algorithms control parts of the process without operator intervention and additionally monitor input parameters to alarm if conditions are out of range or are suspect.

The highest level associated with the blast furnace is Level 3, which forms part of the entire plant information system. This level is usually structured in such a manner that changes in this level do not affect the other levels of the system. The primary function is for *business functions* such as record keeping, order entry, quality requirements, order status and management functions such as overall plant coordination and process change analysis.

An example of a well-instrumented, modern blast furnace is depicted in Fig. 9.59; the specific instruments illustrated are referred to here by number. Thermocouples (1) are installed in the refractories at various locations to monitor the condition of the refractory. Pressure taps (2) are located in the bustle pipe to monitor blast pressure and at different elevations of the furnace shaft to aid in monitoring the permeability of the burden and the location of the cohesive or melting zone. A retractable below-burden probe (3) is inserted for monitoring the temperature and composition of the gas in the shaft of the furnace. This data is used for modifying burden distribution

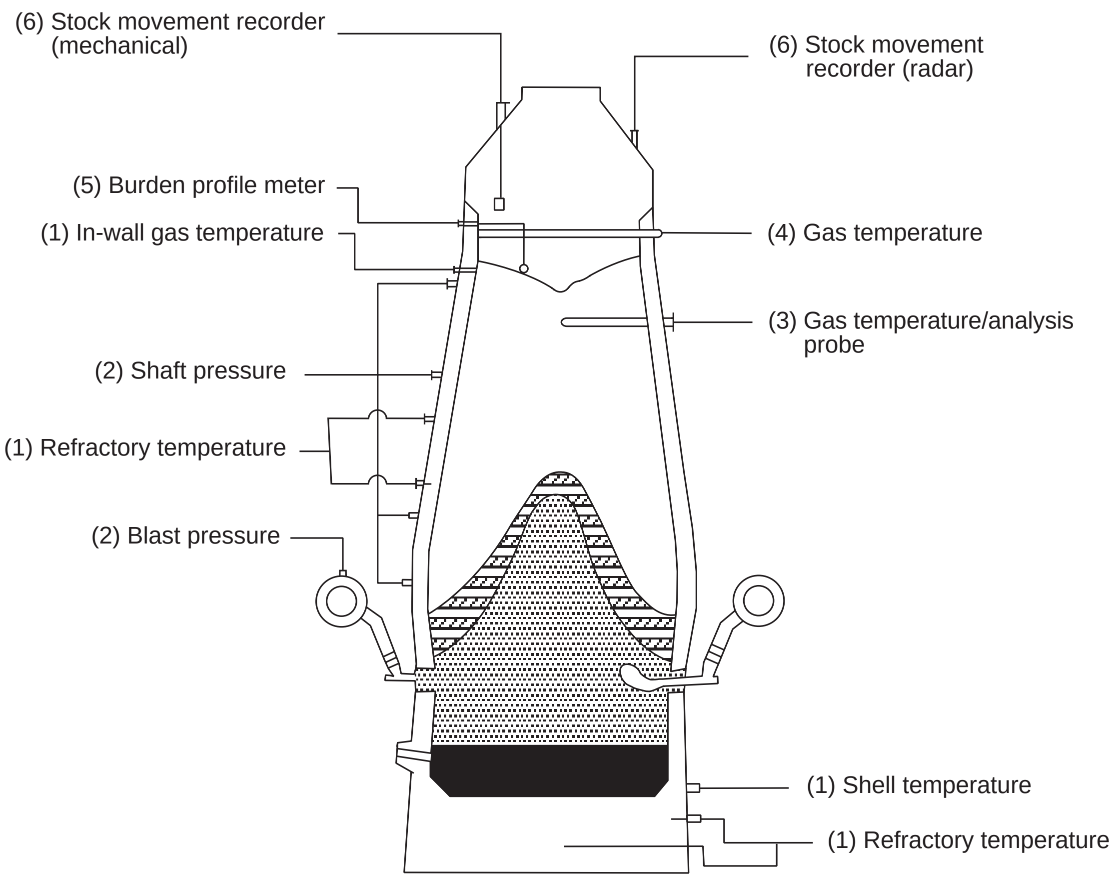


Fig. 9.59 Schematic of a well-instrumented, modern blast furnace.

changes and monitoring furnace efficiency. Fixed above-burden probe(s) (4) are employed to measure gas temperature to monitor gas patterns through the burden. A transverse radial profile meter (5) measures the top surface of the burden material after initial charging into the top of the furnace. This instrument is used to monitor the proper placement of different types of materials into the furnace. Stock movement sensors (6), either mechanical weights or radio wave type sensors, monitor the descent of the burden and essentially give the permissive for charging additional material into the furnace.

A blast furnace plant is a collection of somewhat unique subsystems: the raw material handling and charging system; the furnace refractory condition and cooling system; the stove system; the cold blast and hot blast system; the gas cleaning and distribution system; the casting system; and the smelting process system.

Each of the above subsystems has it's own array of instrumentation and control schemes for sequencing and/or monitoring to insure proper functioning. Some are quite autonomous; for example, the cooling system has little need for data linking or sharing of information to properly perform it's main function. Other subsystems are fundamentally linked and others can be programmed to share information and/or setpoint changes to optimize the process. These interconnections can be as simple as halting or suspending an operation when a sensor or signal from another subsystem reaches a specific value and then prompting for operator intervention to continue. Interconnections can also be a more complex routine where new parameters or settings are calculated, transmitted and used in adjusting and fine tuning an operation to reduce costs or to have greater control and less process variability.

The advance of technology, coupled with the increasing acceptance of the reliability of the instrumentation and control logistics, is moving the process control of ironmaking to greater and greater levels of systems. These advanced systems not only monitor the process, but also change parameters, alert operators to undesirable conditions, recommend changes to the process, and alert the operator to potential problem areas for inspection.

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