Ferrous Extractive metallurgy

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Blast Furnace Process (BF)

- The iron blast furnace is a tall, vertical shaft furnace which uses carbon, mainly in the form of coke to reduce iron ores.
- **The principal objective of the** (BF) is to produce hot metal at a higher rate.
- The produced hot metal which is impure iron, is suitable as feed material for steelmaking.

* It is circular in cross section and around **30–40m in height**.

* The outer shell of BF is made of steel plates, and refractory lining is at the inside of shell.

* The tall structure has been made free standing, i.e., the only support is provided by the foundation.

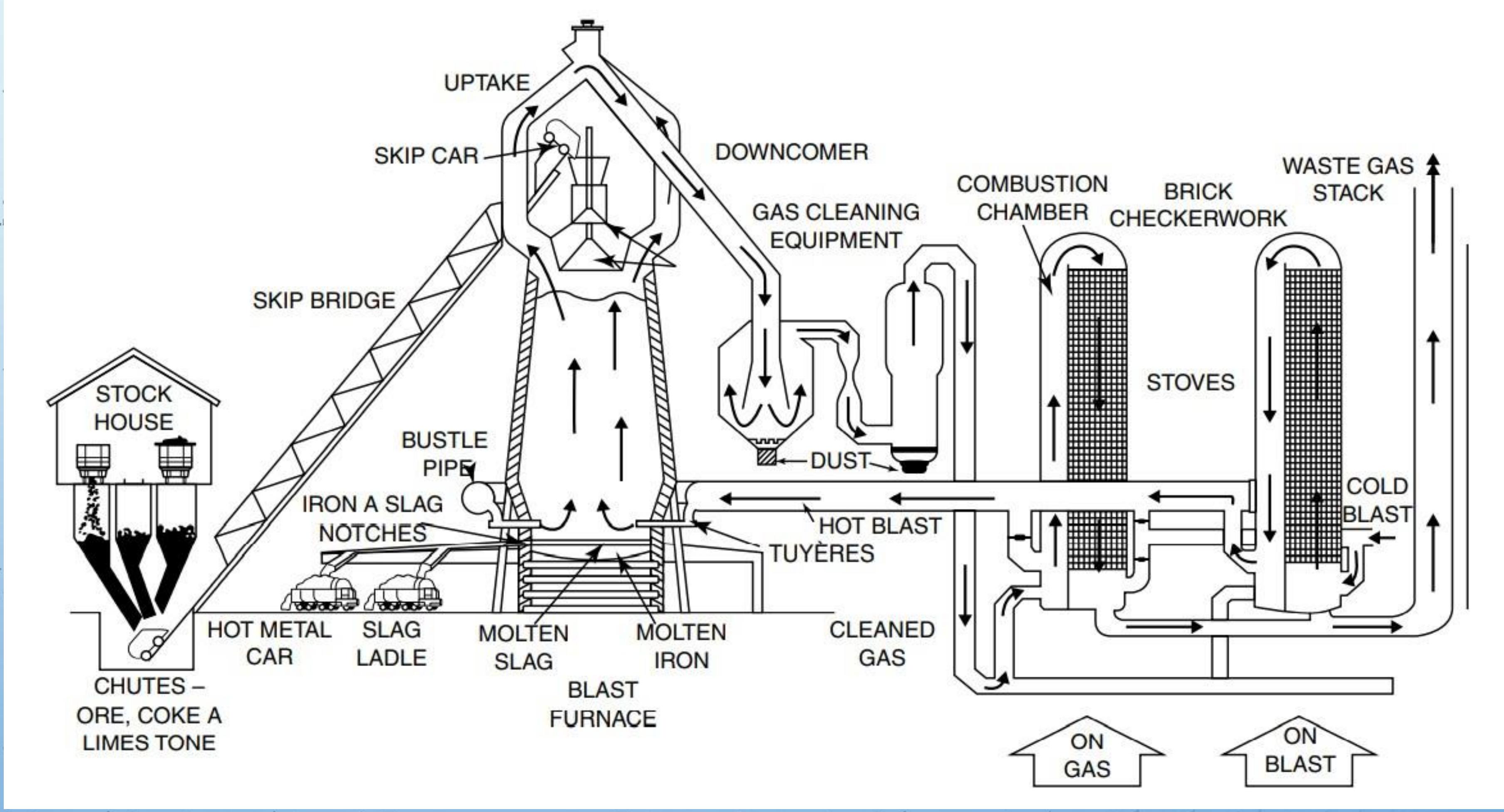


Fig. 1: A schematic view of a typical blast furnace plant.

Constructional Features of BF

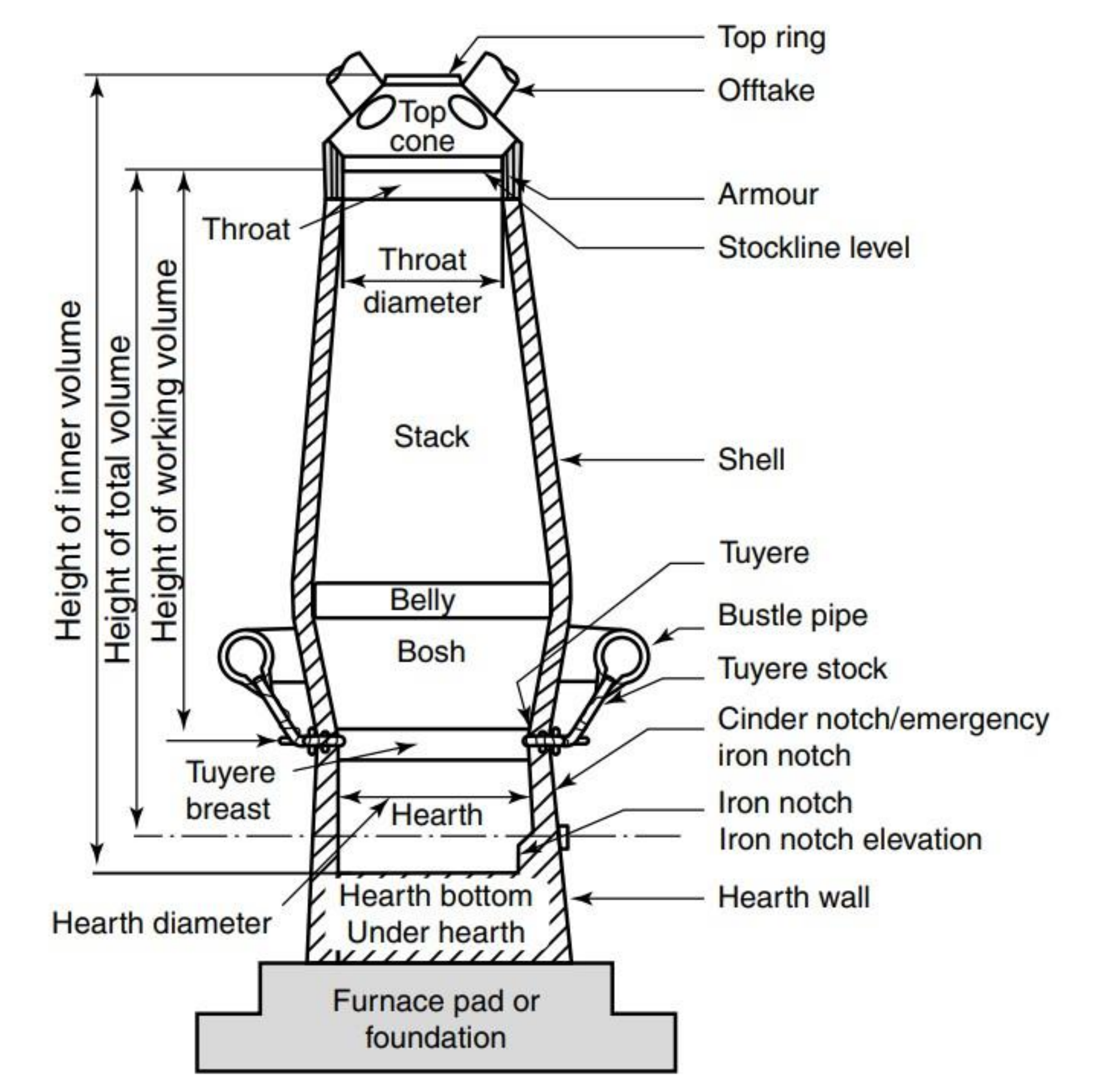


Fig. 2: Schematic sketch of a blast furnace indicating different sections.

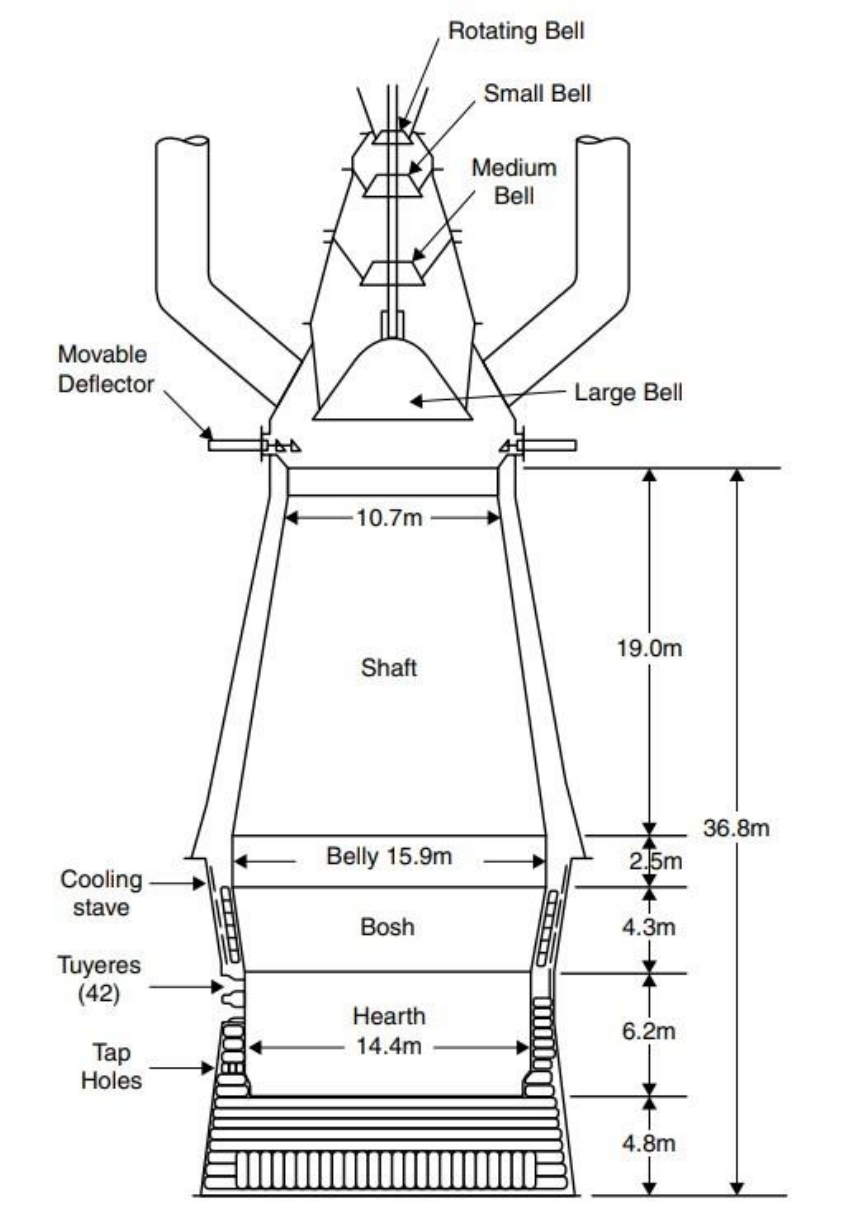


Fig. 3: Typical profiles of blast furnace with four-bell system and movable deflectors.

- **The only critical operating parameter is the temperature of the hot metal and slag which must be greater than 1425°C for these products to be tapped from the furnace in the molten state.**

- **The raw materials of the blast furnace:-**
- **(i) solids:** (ore, coke, flux) which are charged from the top of the furnace,
- **(ii) pre-heated air:** (hot blast) which is passed through tuyeres near the bottom of the furnace.

- **Metallurgical coke:-** supplies most of the reducing gas and heat for ore reduction and smelting operation.

- **Air** is preheated between **925-1325°C** by hot stoves and in some cases enriched with oxygen to give blast containing up to 25 vol% O_2.
- **The hot blast** burns the descent **coke** in front of the tuyeres at **1525°C** to provide heat for (i) reduction reactions and (ii) heating and melting of the charge materials and produce hot metal and slag.

- **The products of BF hot metal and slag are in molten conditions.**

- Pre-heated blast enters the tuyeres through the refractory lined **bustle pipe**, which is like a horizontal circular ring around the furnace.

- **Iron notch** is the tap hole for hot metal. It is kept sealed by refractory clay. For tapping, the clay seal is opened by a mechanical device. After tapping, the iron notch is again sealed by clay material using the same device.

- **Slag notch** is the hole for tapping molten slag. It is above the iron notch, since the slag has a lower density compared to molten iron and floats above the hot metal in the hearth.

- **The hot metal** is tapped through the tap hole several times a day (or continuously in the case of very large furnaces) into **ladles**, is the intermediate form through which almost all iron must pass in the production of steel.

- The hot metal is transferred to the steelmaking shop by **metal mixer** for further refining.

- The **ladles** are lined with refractory. Excess **hot metal** is cast into pig iron in a pig iron casting machine for further use as feedstock in **foundries** or in other **steelmaking shops** for a wide variety of castings.

- **The molten slag** is tapped from time to time through the slag notch into the slag ladle and is used as feedstock for the manufacture of slag cement, etc.

- **The top gas** is known as blast furnace gas. It has a considerable caloric value since it contains carbon monoxide gas.

- **The dust** must be removed first in a gas-cleaning unit.

- **The gas** is stored and then mostly utilized in the blast furnace shop itself for pre-heating of air in **stove** and running turbines to drive air blowers.

* The furnace interior is broadly divided into different sections:-

Stack:-

* It is the upper portion of the BF, whose wall slopes going outwards as goes downwards.

* It is the zone in which the burden is completely solid.

* The charge materials are heated by descending from 200°C at the stock line level to nearly 1100–1200°C at the bottom of the stack. To ensure free fall of the charge material, as it expands progressively with the progressive rise in temperature, the cross section of the furnace is uniformly increased to almost double the size from the stock line to the bottom of the stack.

* Since most of the iron oxide reduction occurs in the stack region, The success of the blast furnace process depends on the efficiency of the counter-current gas–solid reaction in the stack.

Belly:-

It is the cylindrical portion below the stack and above the bosh region. The furnace walls are parallel (to some extent) in this region.

- **Bosh:-**

* It is below the belly and sloping inwards going downwards.

* The charge materials (except coke) begin to soften and fuse as they come down into the bottom of the stack.

* The gangue of iron ore, ash of coke and flux combine to form the slag.

* The furnace walls in this region tapered down to reduce the sectional area by about **20–25%** in harmony with the resultant decrease in the apparent volume of the charge.

* The burden permeability in this region is mainly maintained by the presence of solid coke. Therefore, this dictates that coke should have adequate strength and proper size for efficient operation. Any degradation of coke leads to decrease permeability in the bosh region, and that adversely affects the operation of the blast furnace.

Tuyeres:-

* Tuyere and combustion zone are located below bosh and above hearth zone.

* By the time the charge descends into the area near the tuyeres, except the central column of coke (which is solid), the entire charge is molten.

* The oxygen of the blast burns coke to form reducing gas, CO in front of each tuyere. Thus, there is **a raceway** in front of each tuyere, which is first horizontal and then smoothly changes its direction to vertical while expanding over the entire cross section of the furnace.

* Hot blast is blown into the blast furnace via tuyeres.

* A tuyere is a cooled copper conical pipe numbering up to 12 for smaller furnaces, and up to 42 for bigger furnaces through which pre-heated air (up to more than 1200°C) is blown into the furnace.

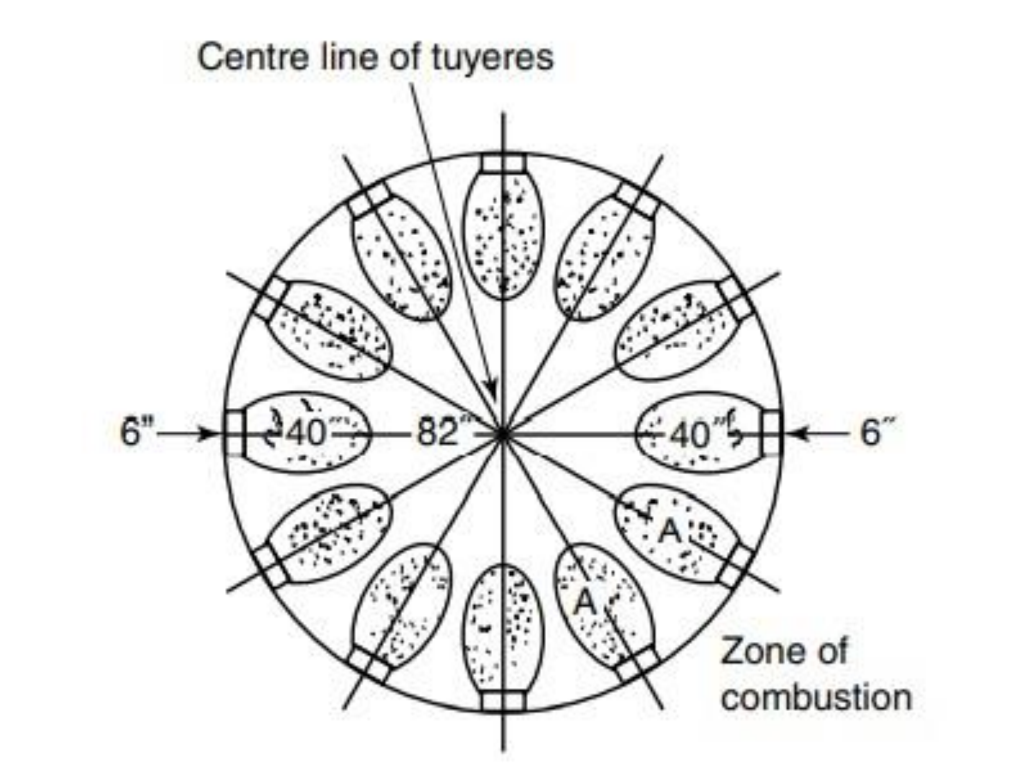


Fig. 4: Horizontal cross-sectional view of tuyere zone

Hearth:-

* It is the bottom cylindrical portion of the BF, below the bosh and tuyere regions.

* Although most of the coke burns at the tuyere level, a small fraction descends even into the hearth (to form the **dead man zone**, which is undissolved solid coke particles either sits on the hearth or floats just above it).

* Carbon is dissolved in the metal to its near saturation limit.

* The entire charge (except dead man zone which is in solid form) is molten and tends to stratify into slag and metal layers in the hearth from where these are tapped separately.

* The cross section of the furnace below the tuyeres decreases since the liquids are dense without pores and voids, thus leading to decrease in volume.

* The walls of the hearth are parallel, and the hearth is the smallest cross section of the BF.

Temperature Profile of BF

* Exothermic combustion of coke by oxygen from air gasifies carbon into reducing gas, CO, and also generates the heat.
* The highest temperature zone of the furnace (1900–2000°C) is at the level of tuyeres.
* As the hot reducing gas travels upwards, it heats up the downward solid charges as well as participates in various reactions at different zones of the furnace.
* It is shown that the softening/melting zone is in an area where temperatures are between 1100 and 1450 °C.

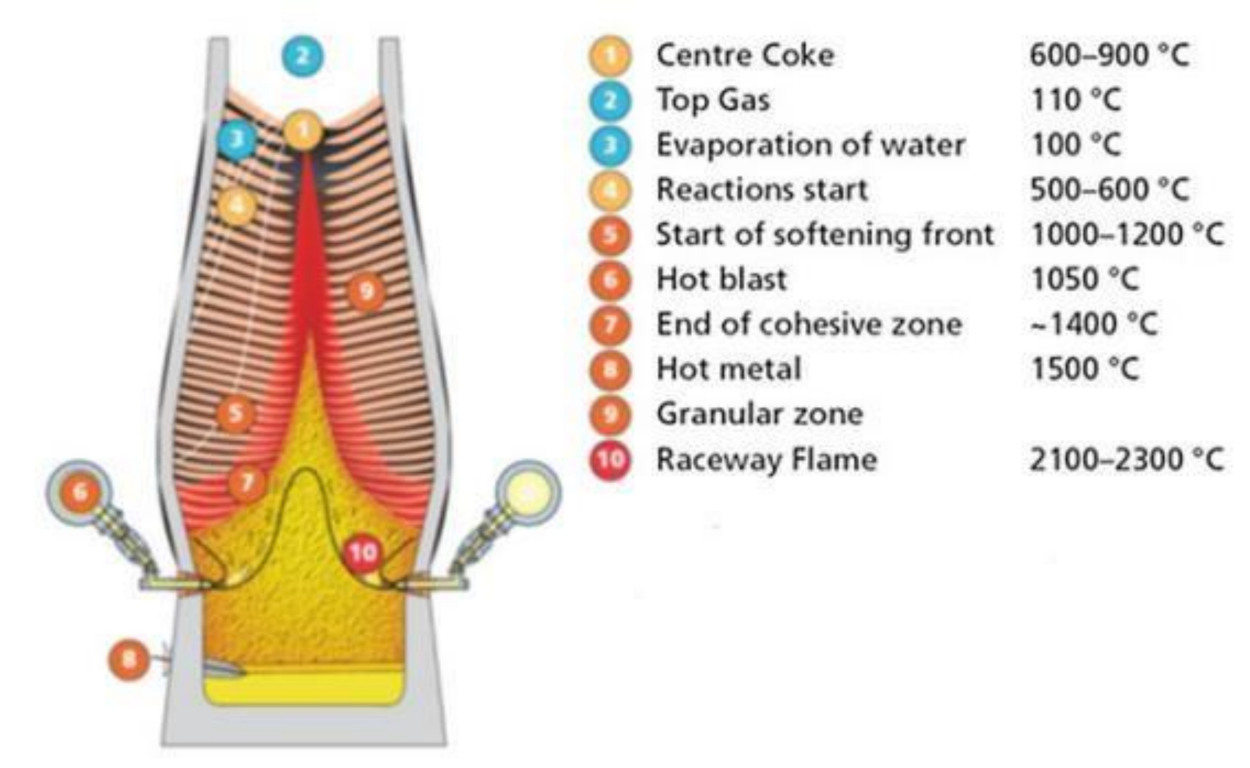


Fig. 5: Temperature profile in a BF (iron ore starts melting at 1100–1150 °C and slag become fully liquid at (1350–1400 °C).

The major reactions of BF are classified as following:

- Removal of moisture from the raw materials,
- Reduction of iron oxides by CO (i.e., indirect reduction),
- Gasification of carbon by CO_2,
- Dissociation of $CaCO_3$,
- Reduction of FeO by carbon (i.e., direct reduction),
- Reduction of some other oxides present as gangue in the ore by carbon,
- Combustion of coke in front of tuyeres.

The outputs from the BF are as follows:

- Molten impure iron (i.e., hot metal),
- Molten slag,
- Gas containing CO, CO_2, N_2, moisture and some dust particles at a temperature of around 200 °C.

Function of Charged Materials in BF

(i) Iron-bearing materials:-

The iron-bearing materials supply the iron, which represents about 93.5–95% of the hot metal.

(ii) Coke:-

Coke has three major functions inside the BF:

(1) as a fuel to supply the heat,
(2) as a reducer to produce reducing gas CO,
(3) as a spacer to maintain permeable charge which allows the gases to pass through it smoothly,
(4) as a source of carbon that dissolves in the hot metal (about **30–45 kg** of carbon for every tonne of hot metal).

(iii) Fluxes:-

The function of the limestone and dolomite is as follow:

(a) to supply calcined lime,
(b) to form a fluid slag with the coke ash, gangue of iron ore and any other impurities of the charged materials,
(c) to form a slag of such chemical composition that will provide a degree of control of sulphur content in the hot metal.

(iv) Air:-

The air blast helps to burn part of the fuel to produce heat for the chemical reactions involved and for smelting the iron, while the balance of the fuel and part of the gas from the combustion remove the oxygen combined with the metal.

Charging System of BF:-

In the blast furnace process, iron-bearing materials, coke and flux are charged by the skip car or belt conveyor from the top of the furnace.

The materials are charged in the sequence OCSOCC (i.e., ore-coke-stone-ore-coke-coke).

Hot blast is blown from the tuyeres, along with hydro-carbon gas, and oil or powder coal is injected to the tuyeres.

The blast furnace is working on the counter-current principle. Descending solid charge meets an opposite current of ascending gases; due to that progressively heating and reduction of iron ore take place.

The production rate of a BF depends on:-

(i) The rate of reduction of iron ore,

(ii) The rate of heating of the burden.

- These two factors are not independent but are related to (a) the quantity of blast and (b) permeability of burden, (c) the degree and time of contact of gases with the burden.

So, the burden inside the furnace should have uniform and good bulk permeability. A proper charging mechanism is required for more uniform permeable burden distribution.

Earlier double-bell charging system had long been a familiar feature of the BF. Nowadays, large BFs (>3500 m^3) are used. Large BFs have significant advantages in terms of productivity, raw material transportation, performance and maintenance requirements and environmental friendliness. Furnaces have working volume of up to 4500 m^3 and employ the rather different charging mechanism.

The reasons for dissatisfaction with the traditional two-bell charging method for large furnace:-

(i) uniform burden distribution is not easily achieved with two bells,

(ii) accelerated wear and consequent gas leakage occur when a furnace is operated with high top pressure.

Bell-less top (BLT) charging systems are the new development of charging devices.

Two-Bell Charging System

The two-bell charging system consists of a revolving material distribution, a small bell and a large bell. The diameter of large bell is usually smaller than the stock line diameter. The bells are connected by a rod and move in the vertical direction by means of air cylinders.

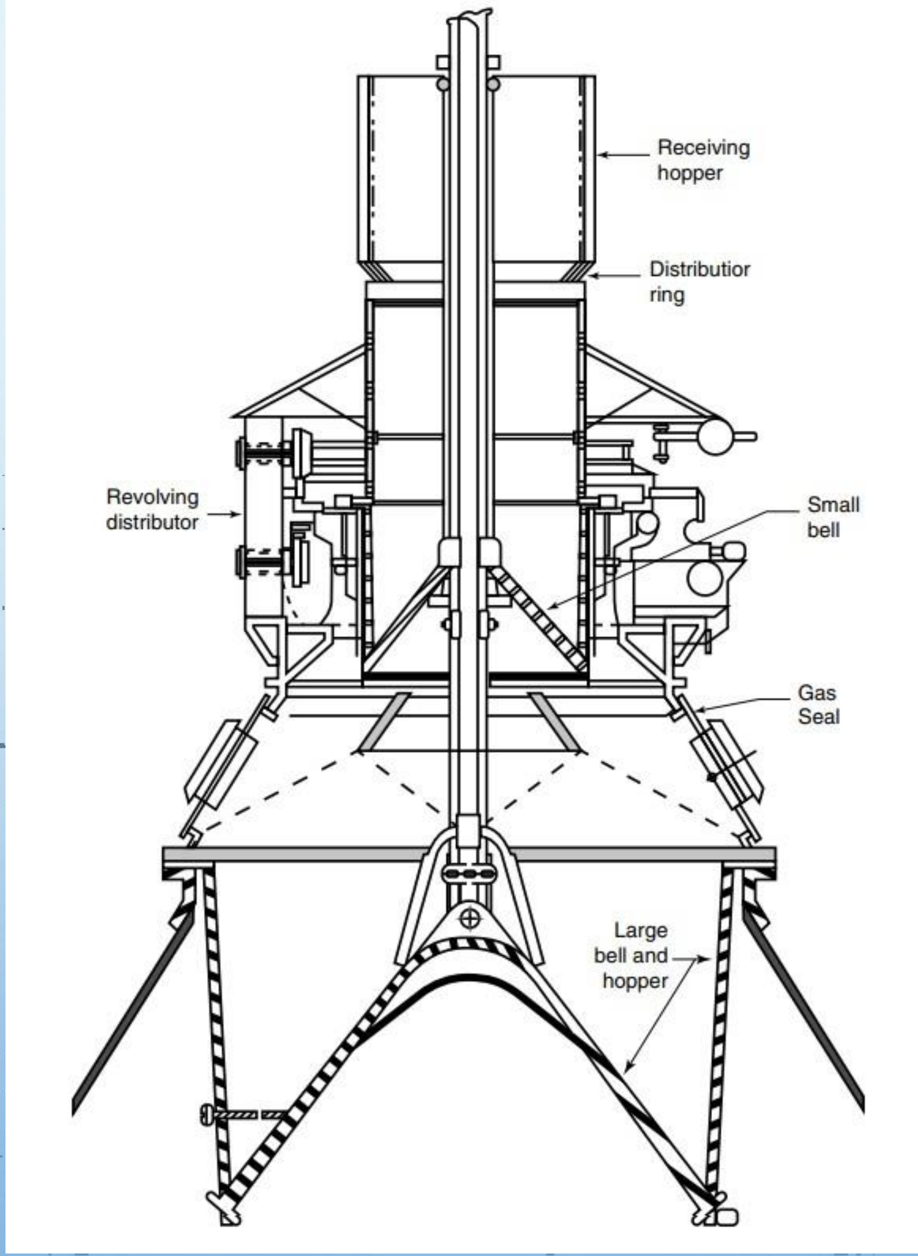


Fig. 6: Two-bell charging system.

The furnace charging is done in four steps by two-bell charging system:-

Step 1 The charge materials are taken to the furnace top either by a skip car or by a conveyor belt, and the materials are delivered to a receiving hopper. Small bell and large bells both are in closed condition. The charge materials from skip car or conveyor belt are dumped in hopper above the small bell. Gas flowing from top of furnace through uptakes located in the dome (top cone).

Step 2 With the large bell closed, the small bell is lowered down, and the charge material is dropped to the hopper of large bell.

Step 3 The small bell is closed to prevent gas escape to atmosphere. Now the large bell is lowered down, and the charge materials are discharged into the blast furnace.

Step 4 Both the bells are closed, and the system is ready for further charging.

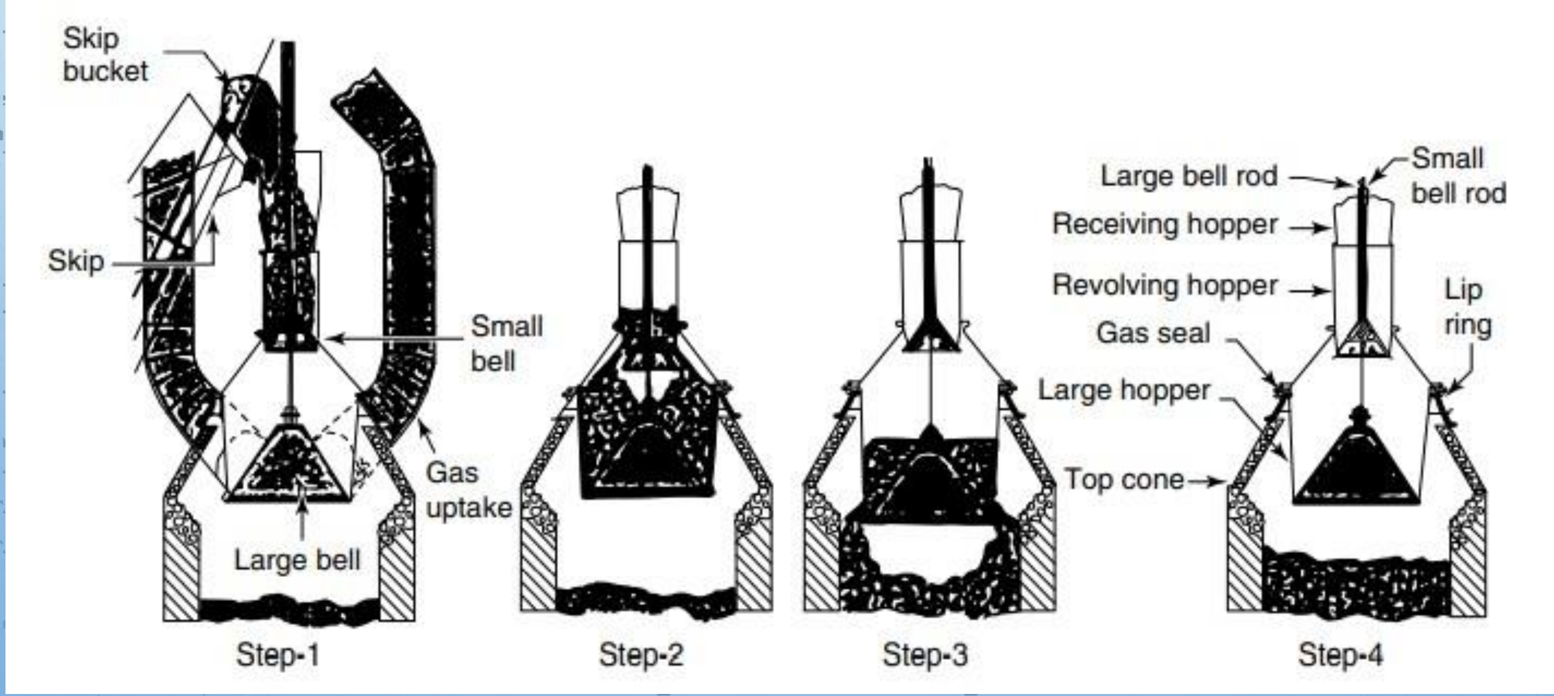


Fig. 7: Four steps of two-bell charging system in BF.

Good size ranges are as follows:-

- Ore: 10–35 mm,
- Sinter: 5–50 mm,
- Pellets: 9–16 mm,
- Coke: 10–50 mm,
- Limestone: 10–50 mm.

Types of stock line profiles:-

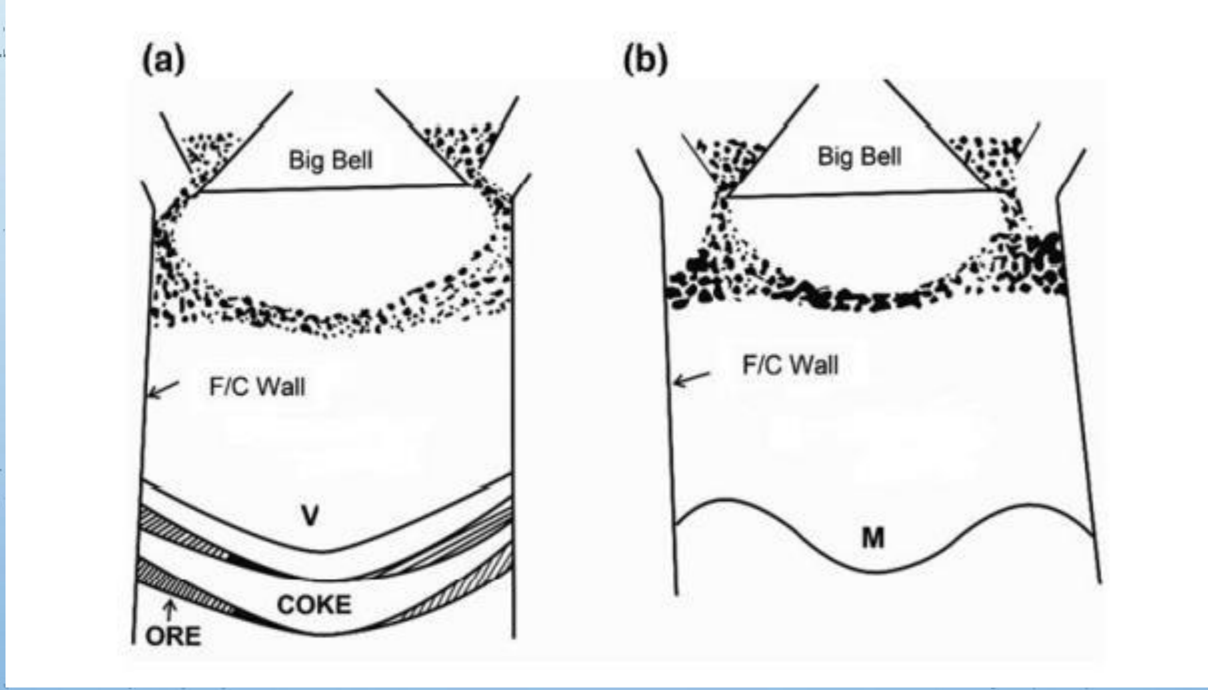


Fig. 9: Burden profiles in BF showing ore and coke layers: a) smaller clearance between the bell and the BF wall and b) larger clearance between the bell and the BF wall

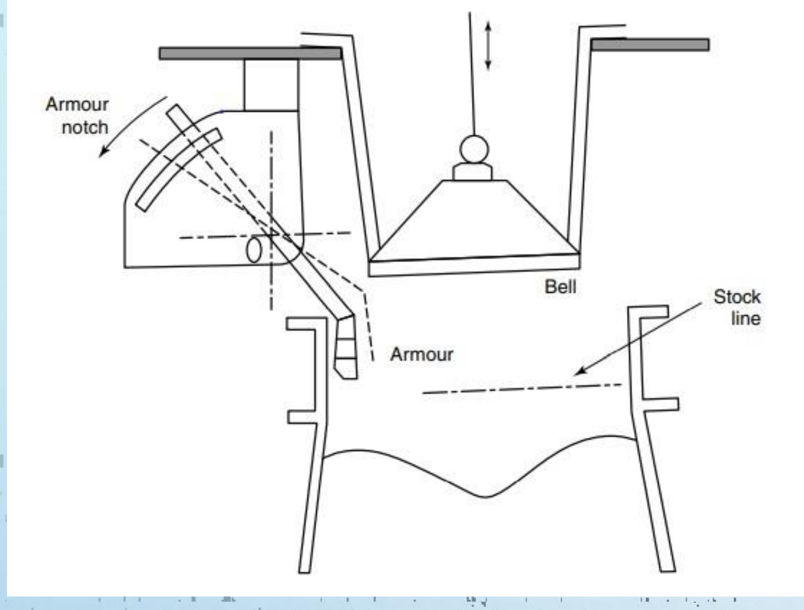
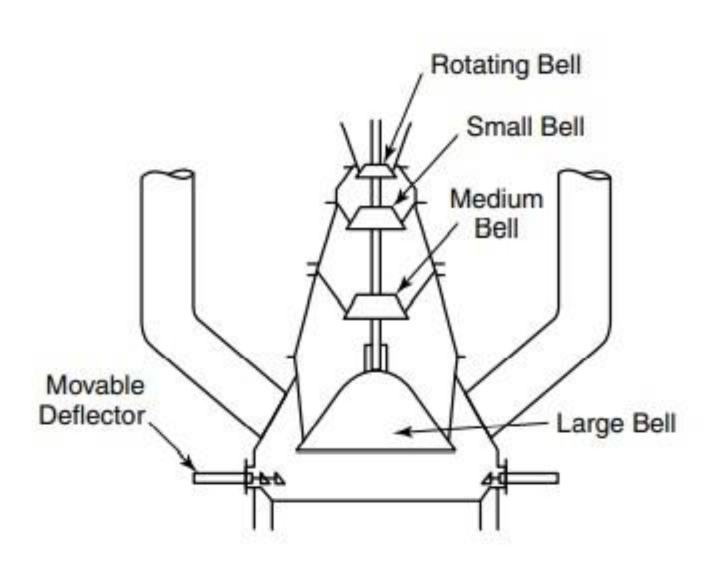


Fig. 10: Two-Bell Type with Throat Armour Systems

Fig. 11: Four-bell system



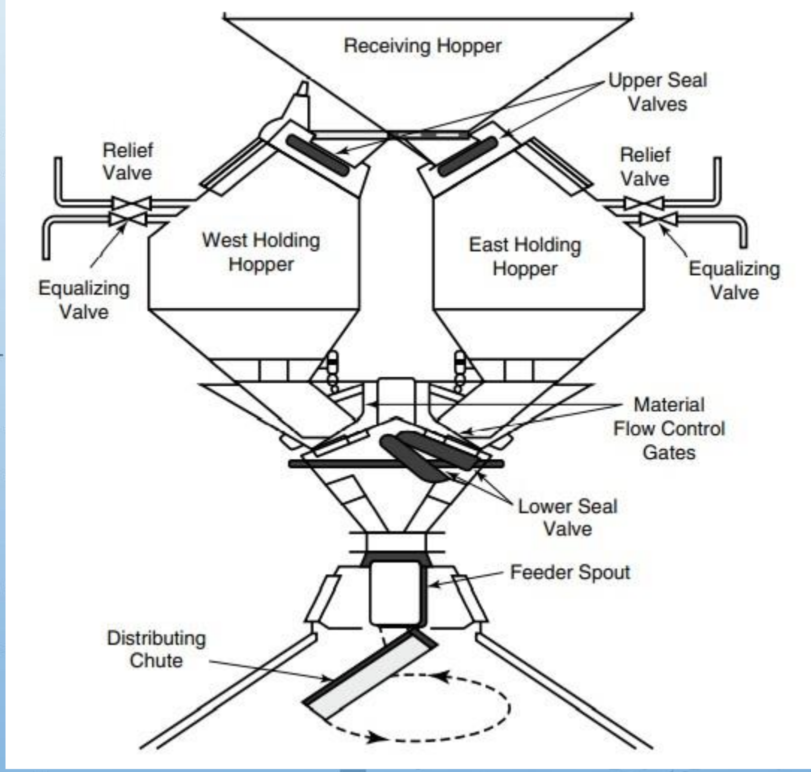


Fig. 12: Bell-less top (BLT) system

The advantages of bell-less top (BLT) charging system are as follows:-

- It allows continuous charging of the BF. While the rotating chute is distributing, the materials from one lock hopper bin and the other hopper bin can be filled.
- The problem of gas sealing under a high-pressure operation is solved.
- Charge distribution flexibility is more with a small amount of mechanical equipment.
- Improved BF operational stability and efficiency, feeding for better hot metal chemistry control.
- Increases in the BF productivity.
- Reduces BF coke rate and helps to achieve higher injection rates of pulverized coal.
- Contributes to higher campaign life due to reduction of heat loads on BF wall.
- Access to any part of the system is easier, and hence, one or two parts can be changed even during normal shutdown of the furnace.
- Wearing parts are rather few and inexpensive, and hence, these can be regularly changed during routine maintenance.
- Gives more operational safety and easy control over various charging patterns.
- Largely reduces the maintenance time and frequency of maintenance of top equipment. The chute can be replaced within a short period of time.
- The top equipment is light and simple construction compared to other high-pressure top charging system

Compare BLT with Two-Bell System:-

The top of the blast furnace is closed, as modern blast furnaces tend to operate with high top pressure.

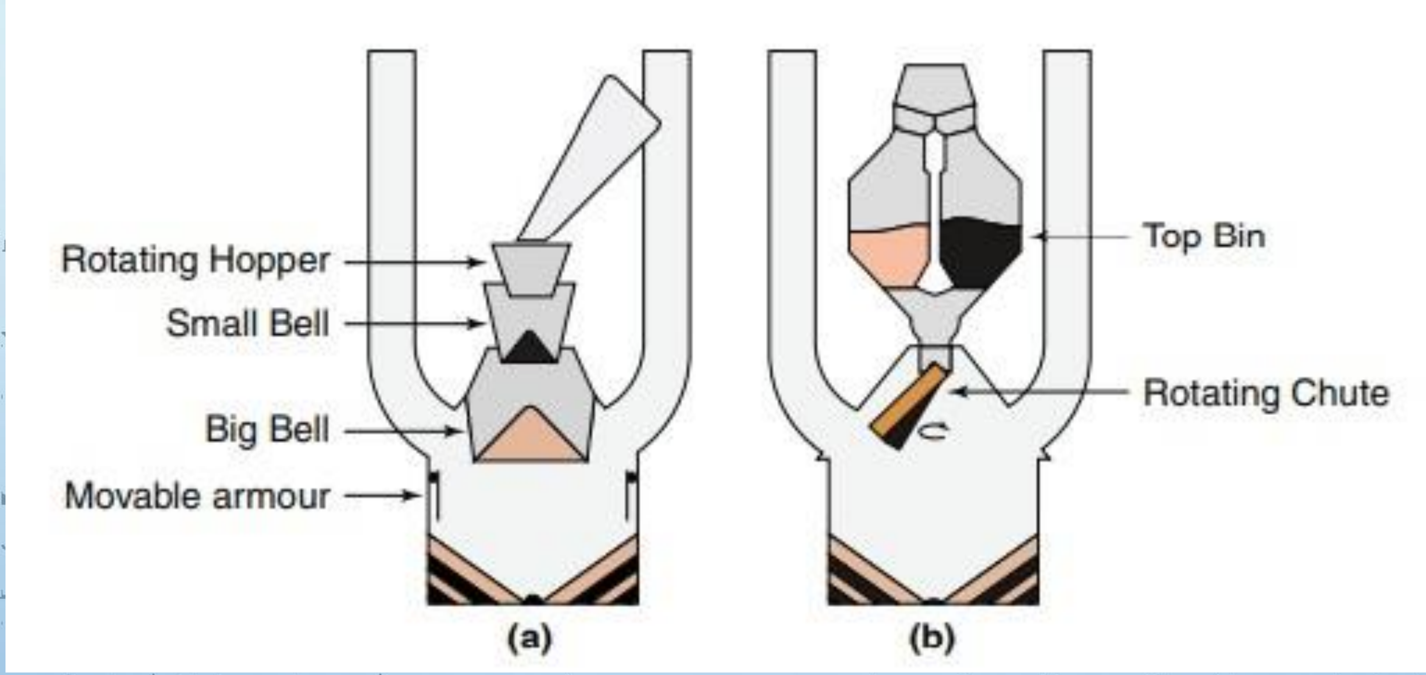


Fig. 14 Modern blast furnace top charging systems, a) two-bell top with movable armour and b) bell-less top


Thank You!