IRON MAKING

Introduction

$3Fe_2O_3 + CO \longrightarrow 2\,Fe_3O_4 + CO_2$

(Hematite) (Magnetite)

$Fe_3O_4 + CO \longrightarrow 3\,FeO + CO_2$

(Wustite)

$FeO + CO \longrightarrow Fe + CO_2$

$FeO + C \longrightarrow Fe + CO$ (direct reduction endothermic on nature)

(L) (S)

The source of iron is its ore where iron exist mainly as oxides either as hematite Fe_2O_3 or as Magnetite Fe_3O_4 and sometimes in small proportion of hydroxides and carbonates. Hematite presents in largest proportion in all iron bearing minerals used for blast furnace smelting. When chemically pure hematite contains 70% iron and magnetite is about 72.4% iron. Iron contents in iron ore ranges from 50-65% for rich ore and 35-50% for lean ores and the remainder is represented by gangue material which consist of mostly silica (SiO_2), Magnesium oxide (MgO), as well as a small amount of moisture or chemically combined water. Ores are used either directly for mines but now-a-days mostly it is used after agglomeration. In addition with a Al_2O_3 and SiO_2 very small amount of other materials like compound of Zn, Cu, Ti, Cr, As, sb, Na, K are also present in the gangue materials. Actually an ore is a mineral from which the desired elements can be extracted economically. Any Fe bearing materials can become an ore provided the cost of the mining, transporting, smelting is such that the iron thus produced is competitive in price. Fe ore fines which few years ago used to be considered as wastes, now a days it can be agglomerated into lumps by sintering and pelletising and can be use in the furnace.

Essential characteristics of Iron Ore:-

1. Reducibility
2. Size and size distribution
3. Strength
4. Melting temp and Range of softening
5. Iron,moisture and gangue content
6. Swelling and vol. Change

1.Reducibility

It is defined as the rate with which the oxygen combined with iron ore can be removed indirectly. A higher reducibility means a greater extent of indirect reduction that may be obtained in the blast furnace, resulting in lower coke rate and higher productivity. The reducibility of Fe ore depends on

2. Size and size distribution

Here the main aim is to keep the ore in contact with upward moving gases. So grading of ore is necessary. If the size is bigger one then the upward moving CO gas will move fastly. So its utilization will decrease. On the other way if the size of the sinter is smaller one, then it will obstruct the flow of upward moving gas and also the gas will obstruct the downward movement of sinter. So the production rate will decrease. By considering both the factors, we have to take the mixture of smaller and bigger particles and the bigger should be 2 to 3 times than that of the smaller one. The smaller should be ≥ 10mm and the bigger should be ≤70mm. For example the size range may be 10mm – 25mm , 20mm – 50mm ,30mm – 70mm.

3. Strength

Inside the furnace the material should fall from the top through a certain distance. So the sinter should have sufficient impact strength to avoid breaking. The sinter also has to pass through the environment of other solid material, so it should have sufficient abrasion resistance to avoid dust formation. Also the sinter present in the lower part of the furnace should have to bear the entire load of the burden, so it should have sufficient compressive strength.

4. **Melting and range of softening**

Iron ore is a complex oxide system. Number of other compounds are also mixed with the iron ore. Although they have more or less definite melting temp., but due to intermixing the material being resulted have lowering melting temperature. Since the product(sinter) is a multi component system the melting occurs between a range of temperature that the solidus and liquidous of a complex oxide system. For ores it is 700-1350^{o}C and that for sinters it is 1000-1350^{o}C. Smaller the range of softening & melting the shorter the distance in which highly viscous semi fused mass forms and better the rate of gas flow. Hence the rate of production will increase.

5. **Iron, Moisture & Gangue content**

The richer the ore, the higher the iron content, this helps the blast furnace smelting process economically. However the quality of gangue material is the major factor in the smelting process that is the ore having basic gangue with low Fe content is smelted economically than the ore having siliceous gangue with higher Fe content. So some self fluxing ores having 25-30% Fe may have even lower coke consumption then silisious ores with higher Fe content.

Moisture increases the thermal energy necessary for reduction, also the deficiency of it will lead to the generation of dust during handling large amount of moisture will increases the coke consumption rate and hence will increase the cost of production it varies according to the condition under which they are stored transported and also according to the seasons humidity etc. Higher moisture content is the major problem in cold countries.

6. **Swelling and volume change**

Some pellets have the tendency to swell in a reducing atmosphere at 800-1000C. The consequent loss of strength and compaction under load decreases the voidage and resist the flow of gas. The operation of blast furnace under such condition is very difficult.

BLAST FURNACE FUEL

Coke is the universal fuel used in Blast furnace. It acts both as a supplier of heat as well as a reductant. Also it provides supports to the descending burden. Coke is charged from the top of the furnace along with the iron ore.

Function of coke

1- It acts as a fuel by providing thermal energy to the furnace.
   $2C + O_2 \longrightarrow 2CO + 2300(Kcal/Kg)$
   So 2300 kcal of heat is produced by burning 1kg of coke, but on complete combustion to CO_2 heat evolved is 8150 kcal. So about 28% of total heat is supplied by the coke.
2- It provides CO for the reduction of iron oxide.
3- It allows the ascending gases to pass through their voids.
4- Also it provides mechanical support to the large burden. Coke is the only charged material that descends as solid up to the bottom of the blast furnace.

Physical properties of coke:-

1- Coke Size:-

The coke comprises of about 50-60% of the volume of the total charge material. Coke provides permeability for the passage of gas both in the shaft where charge materials are in the solid form as well as the bosh zone where liquid product are found. So in this case coke should be smaller in size compare to the ore. Coke also provides mechanically support to the descending burden. So in this case the coke size should be as large as possible to avoid flooding .considering both the case that is better permeability minimum flooding, coke should be about 3-5 times larger than the ore.

2- Coke strength:-

Coke has to stand repeated handling and charging which includes drops and flows at several places before landing in the furnace. It has then to stand the abrading action of the surrounding particles until descent into the bottom of the furnace, in addition to this coke has to stand against high temperature and nearly 20-25 mt. tall burden lying over it when it reaches the bottom of the furnace. The coke that breaks down to finer sizes under this condition will affect the permeability of the bed. In fact the height of the morden furnace is controlled mainly by the strength of the available coke. So considering all the factors it is necessary to estimate suitability of coke for blast furnace in terms of its strength. It can measure by shatter and abrasion indices. The shatter test gives the resistance of coke against impact where as the tumbler test is designed to measure the resistance of coke against abrasion. Study of different samples of coke shows that the best variety has a regular distribution of pores with adequate thickness & hardness of the wall between the pores and are free from cracks internally. Such a structure can withstand high compressive force and high temp. inside the furnace.

Chemical properties of coke :-

(1) Carbon content
(2) Moisture content
(3) Ash content
(4) Amount of P & S

1. **Carbon content**

Coke is used both as fuel as it provides thermal energy and also as a reductant because it gives CO for reduction. So the calorific value & amount of CO should be as high as possible. Both of these should not vary to a greater extend is different coke samples, otherwise uneven generation of heat at different places of furnace will severely affect the quality of pig iron produced.

2. **Moisture Content:-**

Greater the amount of moisture present in the coke, more heat will require to drive out the moisture which requires additional coke. Also by increase of blast temp. furnace temp. will increase. Furnace temp can be controlled easily but simultaneous with changing of the temp. iron produced will differ in quality, so it will difficult to control the quality of iron which is more important than the increase and decrease of blast temp. It has been found that with every 1% increase of moisture, the blast temp. should be increase by 25-50˚C. So moisture content of coke should be low.

3. **Ash content**

The amount and quality of ash of coke has a considerable effect on blast furnace operation. Ash usually contains refractory oxides like SiO_2, Al_2O_3 ,P, S and FeS (iron Sulphide). The increase in ash content of coke by 1% over a critical limit results in decrease in production by 3-6% and involves an increasing coke consumption of about 4-5% in normal blast furnish operation. The ash content of coal used for coke oven is therefore adjusted by washing to produce finally coke of low ash without vary its physical properties.

4. **S & P content:-**

About 80-95% of sulphur and part of phosphorous in pig iron generally comes from coke and the remaining P & S comes from iron ore. If they are presents beyond certain limit affect the steel making process seriously. The adverse effect of S is more harmful than that of P and hence high S containing coke should be avoided while using in blast furnace smelting operation. If S content is high its removal is possible by higher slag basicity, higher temperature and desulphurisation outside the furnace. All these increases the cost of production. The coal available in the north eastern part of India is having good coking quality. But since it contains 2-7% S, it can't be economically used for coke making and produce iron therefore.

Agglomeration

4 types of agglomeration process are

1. Briquetting
2. Nodulising
3. Sintering
4. Pelletising

1.Briquetting:

It is a process of pressing the ore particles with or without a binder into a block or briquette of suitable size and then subjected to hardening process. Binders used are tar, sodium silicate ($NaSiO_2$), cement, betonites, iron sulphate, magnesium chloride ($MgCl_2$) or lime etc.

Fine ores mixed with water and binders are pressed into rectangular blocks which are hardened in tunnel kiln by heating to about

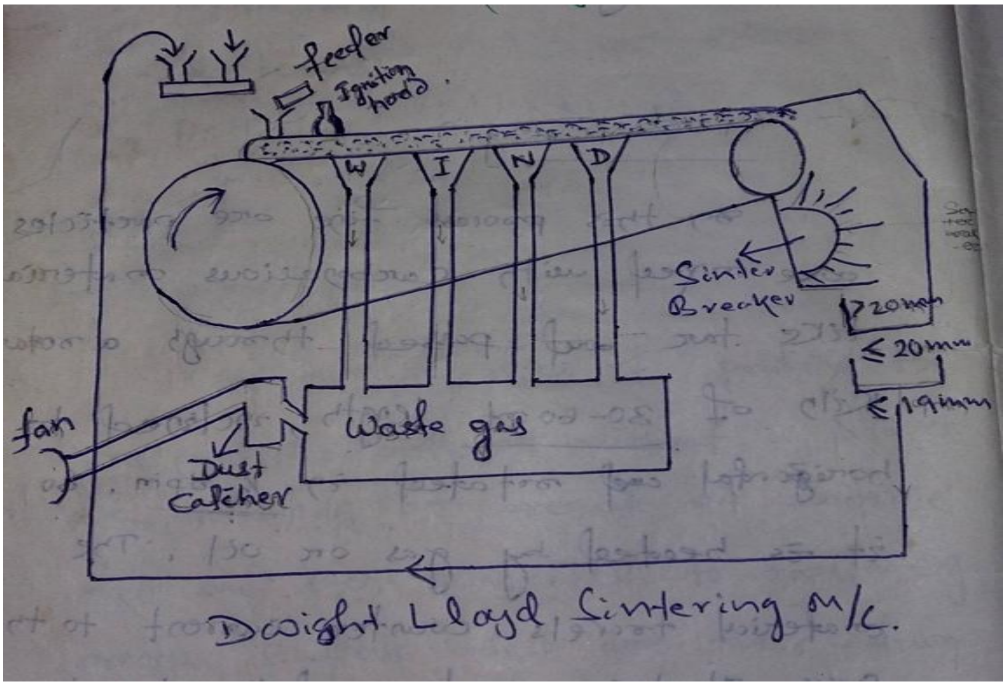
1350˚C. Nowadays briquette of adequate strength is being produced in cold condition without firing by adding 10% cement and aging without applying any process for several days.

2.Nodulizing:

In this process fine ore particles are mixed with carbonaceous material like tar and passed through a rotary kiln of 30-60 mt length, inclined to horizontal and rotated in 1/2rpm. It is heated by gas or oil The material travels counter current to the gases. It takes about 1.5 hr to 2 hrs for the charge to travel the total distance inside the kiln. The diameter at the feed end and at the discharge end is about 2 mtr which is double at the centre zone. Due to varied composition, too dense and absence of porosity, it is replaced either by sintering or pelletising.

3.Sintering Process:

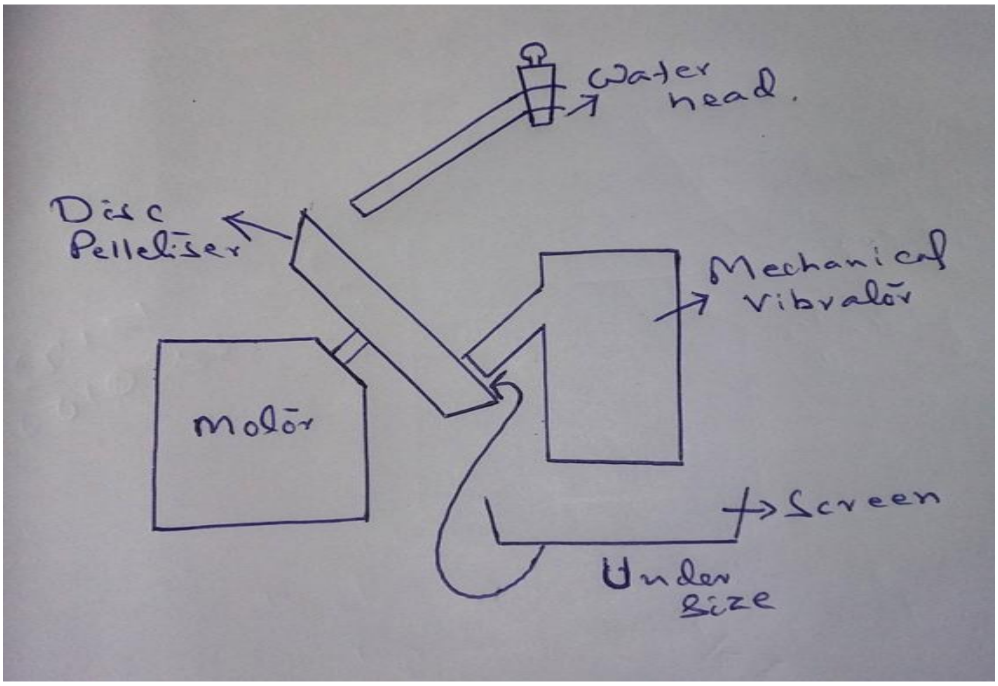
(Dwight Lloyd sintering M/C)



Sintering is a process of heating a mass of fine particles to a stage of incipient fusion in order to agglomerate them into the lumps of desired size. Sintering of iron ore is now universally carried out on travelling great machine running on continuous basis called Dwight Lloyd sintering machine.

The Dwight Lloyd sintering M/C is essentially an endless belt moving over rolls situated across and over two huge pulleys. One of which is driven by a motor. The raw materials are loaded at the one end of the machine, the top layers is ignited by a fixed ignition hood. Sintering of the charge is completed by the time the material travels over the useful distance of the belt. The sinter cake drops at the other end of the belt. The cake is broken and screened. The under size is returned for re-sintering and the oversize is charged to the sinter breaker and the required size is taken to the furnace for use.

4.Pelletising:



During the ore dressing operation a large amount of 0.05 mm fine particles are produced. These are not capable for sintering, however these fines can be agglomerated into relatively large lumps by a process known as pelletising. In this process green balls are formed by rolling fine iron bearing materials in presence of moisture & suitable additives like bentonites or lime (CaO). Green (wet) balls of 8-20mm or large in size can be obtained. These green balls are then dried, preheated and fired at a temp. of about 1200-1350 ˚C when bonds of good strength can be developed between the particles.

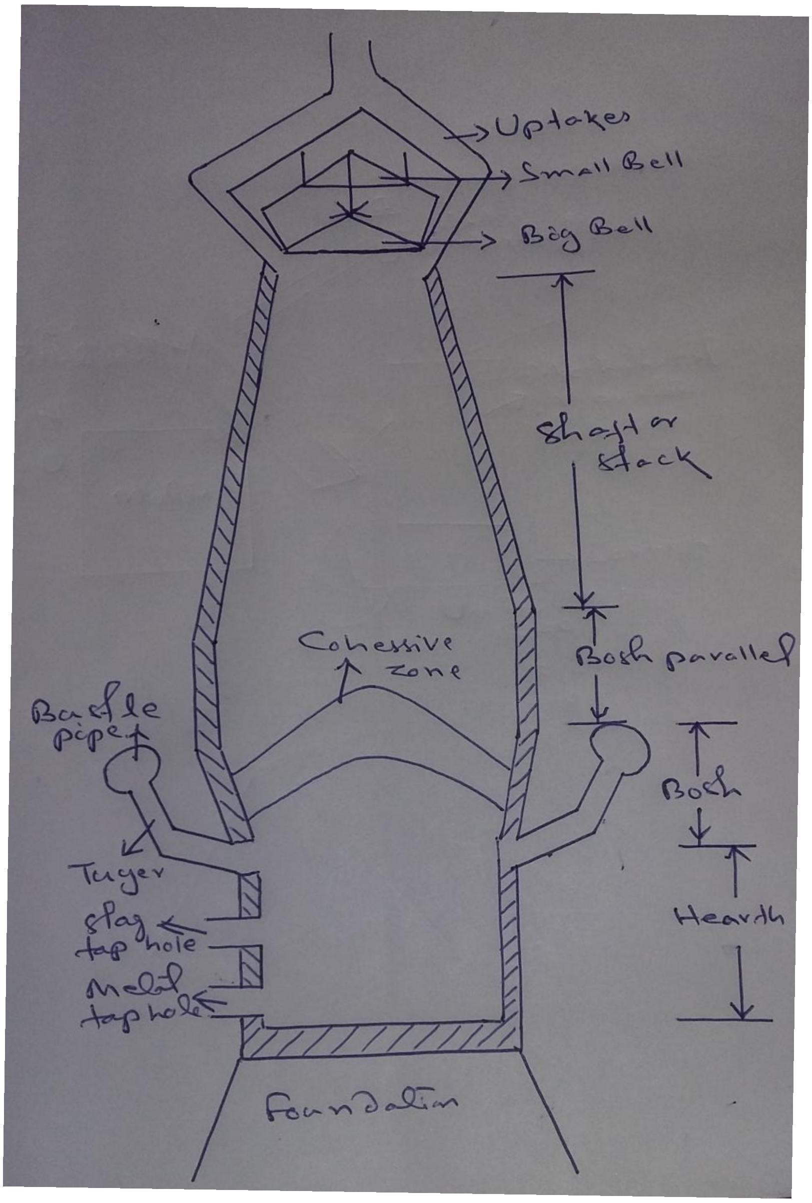
Palletising process consists of following stages:-

(i) Feed preparation
(ii) Green ball production
(iii) Green ball induration
  (a) Drying
  (b) Preheating
  (c) Firing

(iv) cooling of the hard pellets.

The disc of the palletiser is generally 2.5-3.6 mt in diameter, incline at about 45˚ to horizontal and rotates with 15-30 rpm about its axis. The materials to be pelletize is feed directly into the disc with optimum moisture with the help of a water spray. Scrapers are provided to the disc to control the flow of materials. The seeds are formed in the region where water is added. During the downward movement these small balls encounters the feed materials and growth takes place by layering. These green balls after screening are sent to the induration plant where it is subjected to drying, firing & cooling. Heating units used are vertical shaft furnace & travelling grate machine.

BF Accessories



To keep better contact between CO & solid charge material the diameter of the shaft gradually decreases towards top (As the solid charge materials after being charged expands to larger volume), the diameter of the shaft gradually increases towards bottom.

Foundation

It is a massive steel reinforced concrete structure made to support the entire blast furnace.

Hearth

It is a just like a crucible to collect liquid slag and metal. Its height is 4.6 mt & diameter is 8-9 mt. In the hearth wall , a tap hole is located for pig iron above 0.3 -0.6 mt from the hearth bottom level. A slag hole is located at about 1.2- 1.6 mt above the iron tap hole these holes are closed with mud gun. Refractory's used in hearth are generally carbon refractories.

Tuyers & bustle pipe

Immediately above the hearth tuyers are located at the periphery through which hot air blast enters into the furnace. Air from hot blast stove is supplied to a huge pipe encirculating the furnace at the top of the hearth level called as bustle pipe from which air blast passes through the tuyers into the furnace.

Bosh

It is conical in shape though it bears intense heat. Carbon refractories are used in this portion.

Bosh parallel

The furnace structure above the bosh is supported on a heavy steel circular section at the top of the bosh called as bash parallel.

Shaft or Stack

It is a huge inverted cone found on the bosh parallel and extended to the top of the furnace.

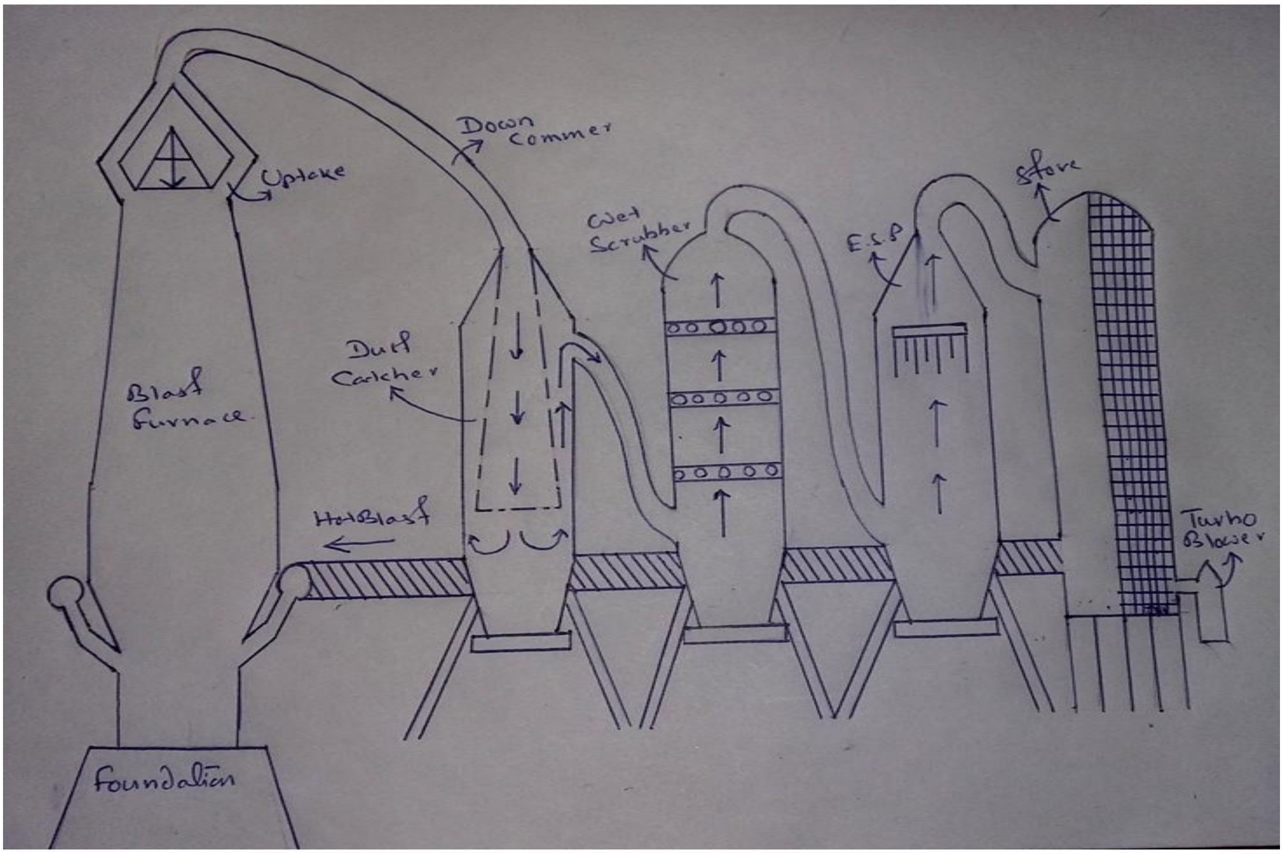
Bells and hopper

Bells & hopper in the modern furnace are used for charging raw materials uniformly inside the furnace.

Uptake

These are exhaust pipes which are connected to the furnace top rise vertically above and joined to a single pipe known as down comer which delivers blast furnace gas to the gas cleaning system.

Gas cleaning system



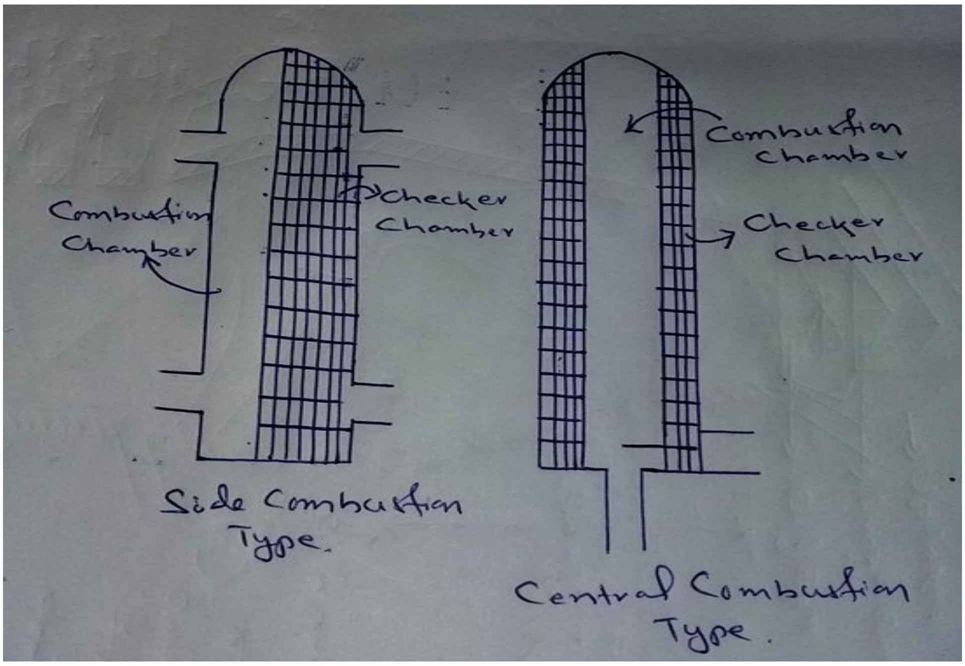
The blast furnace gas is cleaned thoroughly before used as a fuel. The down comer opens up in the dust catcher where coarse particles settle down by virtue of change in the direction of the flow. Then the semi cleaned gas passes through the wet scrubber where water is spread from the top and gas comes from the bottom. Dust present in the gas are washed away by the counter current flow of water. Then the semi cleaned gas passes through the electrostatic precipitator (ESP). Under the action of high applied static voltage the dust particles get ionised and are attracted through an electrode of opposite polarity where they are washed away by water flowing through it. Then the cleaned gas passes to the stove to exchange its heat.

Utilisation of BF gas

1- Preheating the cold blast (air) for blast furnace through stoves.
2- Firing of an open hearth furnace by mixing it with coke oven gas.

Construction of stove:-

Figure:-



Stoves is a cylindrical steel cell with height ranging between 20-36 mt and diameter around 6-8 mt. It is lined with good insulation and fire clay refectories. It has dome shaped top so that the hot products of combustion raised upward in the combustion chamber and then passes through the checker chamber only once before leaving the stove. This is called two pass design. If the checkers are divided into two chambers, then the gas has to pass two times inside the checker chamber. This is called as three pass design. Since the efficiency of stove depends upon the outgoing gas temp. The checkers are constructed according to control this temperature.

In another aspect if the combustion chamber is located at the centre & the checkers all around it in annular shape it is called central combustion type.

Principles of stove :-

Although the design of the hot blast stove varies it comprises of two different chambers.

1. Combustion chamber
2. Heat generator unit or checker chamber

The cleaned blast furnace gas is burnt in the combustion chamber in presence of air and hot products of combustion later heats the checker bricks. In this condition the stove is said to be “on gas” and is maintained on gas till the checker bricks are heated to a certain temperature. Then the firing is stopped & cold blast is allowed to pass through the checkers which extracts the heat stored in the checkers and there by producing preheated blast. The stove is called “on blast” during this period. It can continue heating the blast till a certain temp. is attained. The stove is put on gas again and the cycle is repeated. In practice a stove may be “on gas” for 4-2 hrs and “on blast” for 1-2 hrs. For steady supply of blast at specific temp. a battery of at least 3 stoves is necessary. So in a 3 stove system one is on blast and other two are on gas at any time. When repairing of a stove is necessary it is cut off from the line and is replaced by a fourth reserve one. The efficiency of stove varies from 75-90%.

Instruments supplied to the stove

1. The stove is provided with a burner to burnt the B.F gases in the combustion chamber.
2. Stop valves are provided to close & open the blast furnaces gas & cold blast mains at convenient location.
3. Air relive valve is provided to release the extra pressure while changing from on blast to on gas.
4. A pyrometer circuit is provided to measure the temp. Rise or fall inside the stove.

BLAST FURNACE OPERATION

1. BLOWING IN

Blowing in is the process of starting a newly lined blast furnace. Blowing in consist of following stages.

(a) Drying
(b) Filling or charging
(c) Lighting
(d) Operating

(a)Drying

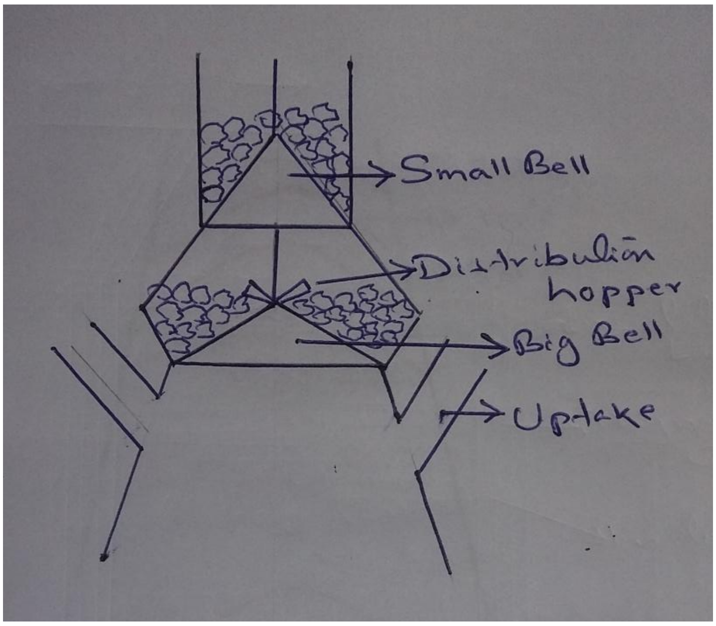
A newly lined blast furnace contains a significant proportion of moisture which is removed by heating the furnace slowly and steadily. Drying can be carried out by the supply of hot blast from stove, use of auxiliary furnace to generate & supply hot gases or by the use of wood or coke fire on the hearth.

The stove that are lined newly are dried by the use of hot gas same as in blast furnace. At the end of the drying of the furnace by any of the above process the furnaces is cleaned before filling, coolers are turned on to reduce the inside temp of the furnace so that the personnel can get into the furnace for inspection and then now the furnace is ready for filling.

(b)Filling or charging

From metallurgical point of view efficient iron making means lower fuel rate & higher productivity. This can be obtained by well prepared burden & efficient gas distribution. So top charging system plays a very vital role in controlling the burden distribution & there by the gas flow. The most popular method of charging is the double bell system.

Figure:-



Charge host:-

The solid charge materials are hoisted up to the furnace top by any of the following 3 methods like bucket hoist, skip hoist or conveyer belt.

Bucket hoist is now completely replaced by skip hoist. Conveyer belt has been adopted in blast furnace of BSP & TISCO. Skips are so attached to the two ends of the string such that when the bottom skip is feels with raw materials, the top skip is discharging the material into the furnace. In conveyer belt system the materials are raised to the top of the furnace by system of a belt.

(c & d)Lightening & Operating

After filling the furnace the bells are opened but the dust catcher valve is kept closed. The furnace is lightened either by introducing a red hot bar through the tap hole or by a gas torch. Burning is allowed for 24-36 hrs. A light blast is put on thereafter. As soon as good amount of gas comes out from the furnace top, the bells are closed. The dust catcher valve is slowly open to receive the blast furnace gas. A full blast is on by the end of a week, after the furnace is ignited. The tap hole is kept open to escape the hot gases during the early period. Once the ore burning & slag formation starts, the tap hole is closed immediately thereafter. Sudden decrease of out coming gas through the tap hole indicates the formation of slag.

2. Banking

Due to labour trouble or shortage of raw materials or serious break down the furnace may have to be shut down for some days. The temporary short down of the blast furnace is known as banking. It means the reduction in combustion rate by taking the blast off, covering the bed with excessive coke. The fire is simply maintained inside the furnace for future use. In general blank charge of coke is put into the blast furnace. The amount of coke charged along with light ore charge depends on the time of shut down period. All metals and slags accumulated in the hearth are tapped out. The dust catcher valve is closed to isolate the blast furnace from the gas cleaning system. The stock is inspected every day during the banking period.

3. Blowing out / down

The process of stopping the furnace operation after the end of a campaign is known as blowing out/down & it can be done in two days.

Charging is stopped, stock is allowed to descent until a minimum of it will remain inside the furnace. Then the blast is reduced and the top of the stack is cooled by water spray from the top. The furnace is isolated from the gas cleaning system in the mid way through the blowing out.

Alternatively blowing out starts by charging some amounts of silica over the stock. The stocks will descent gradually with the silica particles over it. Water is used to control the temperature of the refractory wall inside the furnace. Finally the silica particles are washed out by water flow. It requires 6-8 hrs to blow down the furnace.

4. Tapping

Blast furnace produces 3 different products i.e metal, slag and B.F gas. The metal & the slag are removed from the bottom of the furnace periodically when the furnace is in operation. The time interval between the two consecutive tappings depends on the size of the furnace. 1 tonne of materials produces 500 kg of slag but in volumetric wise the volume of slag is twice that of the metal. In general metal is tapped in every 4-6 hrs but slag is tapped in every 2-3 hrs.

5. Fanning

If the coke production is reduced, the furnace can be maintained by decreasing the production rate by reducing the pressure of the blast. If the pressure is reduced to a value less than 25% of the normal requirement, it is called as fanning. This is better than the total shutting down the furnace because the normal production can thereby resume without any difficulties.

6. Back draughting

Whenever the furnace is required to put off the blast for a short duration of 1-2 hrs to repair the tuyers, it is called as back draughting. The blast is put off and the bustle pipe is now under negative pressure to force the furnace gas to flow in reverse direction. A special back draughting chimney may be provided.

7.Slag Disposal

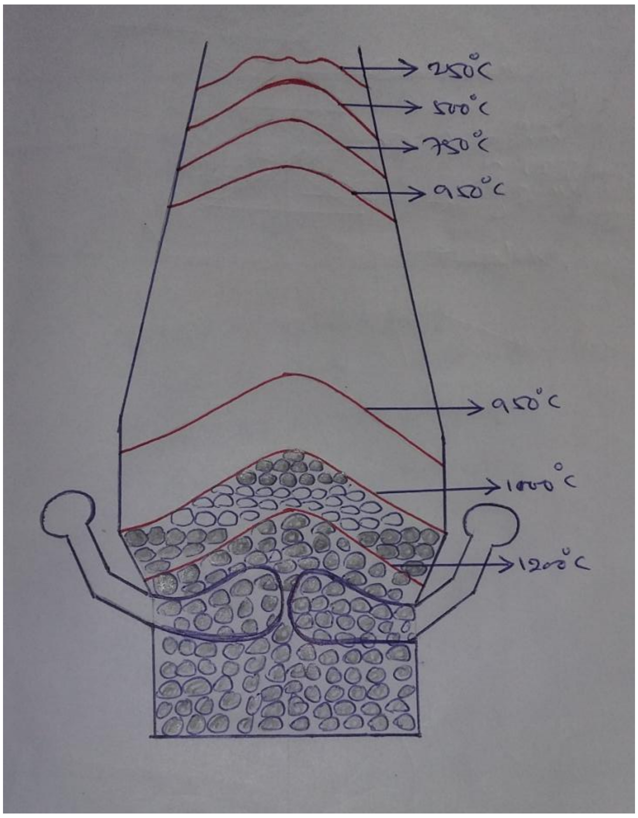
Slag is carried out in ladles to the slag dumping yard, where it is kept as a waste material. Alternatively slag granules are produced in granulation plant where molten slag is poured in high speed turbulent water. These granules are increasingly used as construction material and for the manufacturing of B.F cement. If the slag is not used as a by product, it is dumped as a waste material which requires large dumping space.

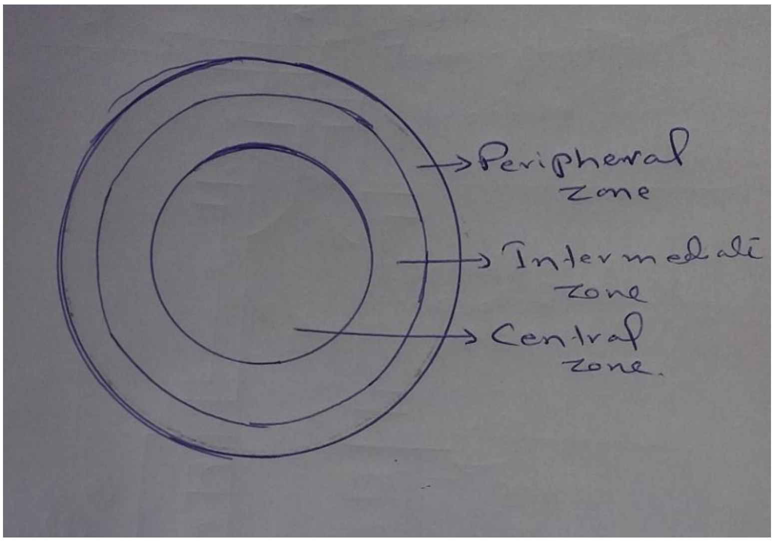
Chemistry of Blast furnace

The fundamental principle of Blast furnace is based on the development of the practice to its maximum efficiency & economy. So the small experimental blast furnace being installed at different places. The results are co-related with the actual practice.

In blast furnace the solid charge materials like iron ore, coke, lime stone are charged in the shaft from the top. The hot blast is blown through the tuyers located at the bottom level. Therefore the blast furnace is called as a counter current heat exchanger as well as a chemical reactor.

In order to ensure free fall of charge materials since it expands progressively with gradual rise in temperature, the cross section of blast furnace is uniformly increase to almost double in size from the top of the shaft to the bosh parallel level.





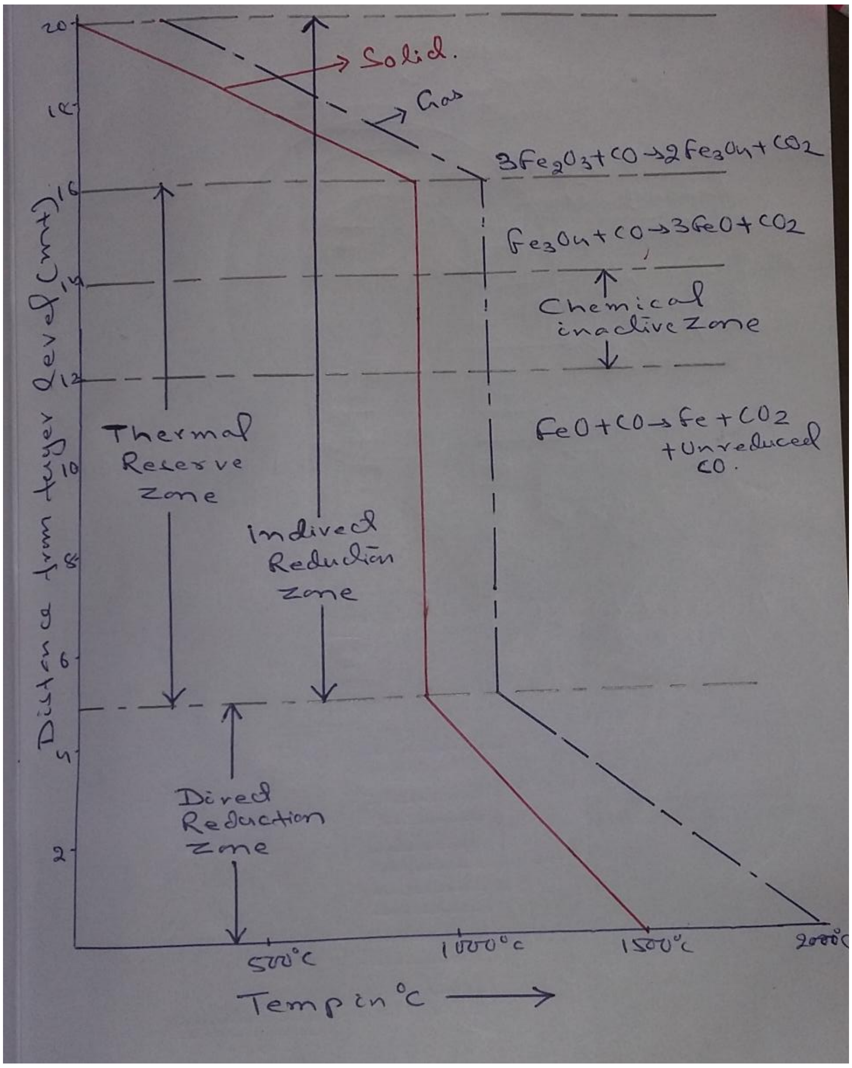
Blast furnace productivity depends on the quantity of air that can blown in unit time so the quantity of gas that should pass through the furnace is governed by uniformity of voidage & particle size. The stack line cross section can be divided into 3 zones.

1. Peripheral zone
2. Intermediate zone
3. Central zone

The intermediate zone consists of 50% of total cross-sectional area and 30-35% of total gas passes through this area. Each of peripheral and central zone consists of 25% area and 65-70% of gas passes through these areas.

When the hot air comes in contact with the solid coke it produces CO gas and this gas when comes in contact with the solid charge(sinter) particles, fusion starts and they forms a inverted U shape at the lower part of stock section. This inverted U shape is the chareteristic features of fusion and melting zone called cohesive zone.

Temperature Profile



In a physiochemical process the chemical part is influenced by the concentration, pressure and temperature of the reductant(CO), whereas the physical part is influenced by the surface area of the solid(sinter), porosity of the reductant. All the reactions in the B.F except gaseous reduction (indirect reduction) of iron oxide gives thermal deficiency i,e absorption of heat.

The reduction of iron oxide is a high temperature process which is fulfilled by burning of coke by the hot blast infront of the tuyer. Due to differential heat requirement at various levels, the temperatre profile acquires "Ƨ" shape.

Reactions at the tuyer

Coke descends as the main constituent upto the tuyer level where it burns and generates a temperature of about 2000°C. The combustion is in the form of pear shape called raceway in which the hot gasses moves at high speed. The main reactions are

$C + O_2 \rightarrow CO_2$ ------------ (1)

$CO_2 + C \rightarrow 2CO$ ---------- (2)

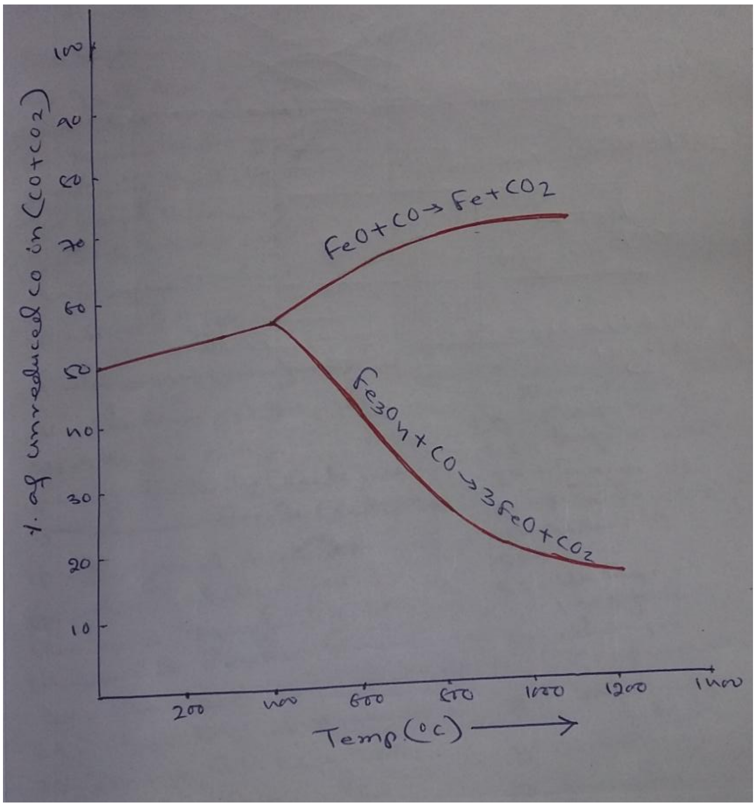
$2C + O_2 \rightarrow 2CO$ --------- (3)

The forward reaction of equ^n(2) is called solution loss, Boudourd reaction or carbon gasification reaction. The backward reaction, ($2CO \rightarrow C + CO_2$) is called carbon deposition reaction or Neumann reverse reaction below 700°C. As a whole the reaction(3) is called as equilibrium boudourd reaction.

There is always some moisture present in blast, which is more in rainy season and less in summer. This moisture also reacts with coke in the tuyer area and produces CO gas.

$H_2O + C \rightarrow H_2 + CO$

Reactions at the Shaft



The function of B.F shaft is of two fold. It should progressively reduce iron oxide to iron using CO gas and it should extract heat from the ascending gasses and thereby the iron oxide gets heated up.

Reduction reaction occours indirectly through the gassious phase i.e, by CO gas is called gaseous or indirect reduction. These are as follows

$3Fe_2O_3 + CO \rightarrow Fe_3O_4 + CO_2 + 10.33$ Kcal

$Fe_3O_4 + CO \rightarrow 3FeO + CO_2 - 8.75$ Kcal

$FeO + CO \rightarrow Fe + CO_2 + 3.99$ Kcal

If the reduction occurs directly by the carbon, it is called as direct reduction and is represented by

$FeO + C \rightarrow Fe + CO -37.2$ Kcal

Although the direct reduction is endothermic in character, it is economical from the point of carbon consumption. Hence not entirely harmful. The proportion of direct reduction of wustite(FeO) by carbon and indirect reduction by CO is a great bearing on the thermal requirement. Although the direct reduction reaction needs less carbon, but of its endothermic nature an additional coke has to burn in front of the tuyer to fulfil the heat thus consumed which will produce extra amount of CO and all these unwanted CO will pass through unused which gives rise to higher $CO:CO_2$ ratio in the top gas.

The utilization of CO is represented by

$$\eta_{co} = \frac{\%CO2}{\%CO+\%CO2}$$

It is maximum 80% in respect of magnetite to wustite reduction, only 30% for wustite to iron reduction and 100% for hematite to magnetite at 900°C and can be represent by

$$3Fe_2O_3 + CO \rightarrow Fe_3O_4 + CO_2 + 10.33 \text{ Kcal}$$

$$Fe_3O_4 + 1.25CO \rightarrow 3FeO + CO_2 + 0.25CO - 8.75 \text{ Kcal}$$

$$FeO + 3.3CO \rightarrow Fe + CO_2 + 2.3CO + 3.99 \text{ Kcal}$$

Most of the Fe_2O_3 and Fe_3O_4 are reduced in the upper zone of the furnace, While FeO reduction takes place in the lower portion of the shaft.

Reaction at the Bosh Zone

The reduction of iron oxide by the CO of the ascending gas and directly by the solid coke completes in this region.

$$FeO + CO \rightarrow Fe + CO_2$$

$$2FeO + C \rightarrow Fe + CO_2$$

Calcination of lime stone($CaCO_3$) takes place in this zone

$$CaCO_3 \rightarrow CaO + CO_2$$

Reduction of impurity oxide takes place

$$SiO_2 + 2C \rightarrow Si + 2CO$$

$$MnO + C \rightarrow Mn + CO$$

$$P_2O_5 + 5C \rightarrow 2P + 5CO$$

$$Cr_2O_3 + 3c \rightarrow 2Cr + 3CO$$

Separation of slag and metal starts below the cohessive zone.

Reaction at the Hearth

The hearth temperature is one of the parameter to be adjusted to obtain desire grade of pig iron. So the working temperature of the B.F is supposed to be the hearth temperature. The entire desulphurisation takes place in the hearth.

BLAST FURNACE IRREGULARITIES AND REMEDIES

1. **Scaffolding** – A scaffold is a larger mass of material formed inside the B.F. This larger mass sticks to the wall of the furnace particularly in the top portion of the bosh. It results in reduction in cross-sectional area of the furnace and affecting like.

- Uneven movement of stock.
- Rise in blast pressure
- Decrease in the rate of operation.
- Increase in coke consumption

Causes :-

- The alkali oxide present in the sinter first evaporates and then condenses on the brick lining to which ore particles sticks, resulting in the formation of massive block.
- It forms due to sudden lowering of the cohesive zone.

Remedies :-

The tendency to scaffold formation can be minimised by decreasing the

- Alkali content of the charge material
- Erratic working of the furnace.

The trouble can be corrected by

- Charging a few blank coke.
- Blast is put off suddenly to release pressure under the scaffold.
- Rigid scaffold ultimately removed by use of a small dynamite when every other remedies gets failure.

2. **Hanging** – If the uniform descend of the charge material in the furnace is interrupted either by bridging of the stock or by the scaffolding, it is known as hanging. Hanging can be classified into three categories as top hanging, bottom hanging and general hanging.

Causes :-

- Condensation of alkali vapours in the upper part of the shaft, thereby cementing the charge particles into a bigger mass.
- Excessive blast pressure applies counter acting force against the downward moving stock.

Remedies :-

- Add coke of larger size which generates sufficient amount of CO_2 gas thereby improves the permeability of the bed.
- A persistent hanging can be cured by sudden decreasing the blast pressure.

3. **Slip** – It is defined as sudden sinking of the stock resulting in chilling of the hearth or explosion.

Causes :-

- Due to collapse of the hanging scaffold.

- Bad bosh design.

Remedies :-

- The best remedy is to allow the furnace to slip itself by the adjustment of blast pressure.
- Bosh behaviour towards the burden material needs to be examined before finalizing the bosh design.

4. **Chilled Hearth** – chilling of the hearth occurs when the hearth becomes cold and temperature of molten metal falls suddenly.

Causes :-

- Sudden and massive slip, when cold material falls into the hearth.
- Leaking of the bosh or hearth cooling plate.

5. **Pillering** – If the blast is unable to penetrate right to the centre of the furnace, it may lead to the formation of cold central column of stock with an annular hot zone all around it. This is known as pillering. It can be detected by entering a bar through the tuyers. It will show red hot

portion at both the ends with cold middle portion, if pillering exists in the furnace.

Remedies :- Pillering can be eliminated by increasing the blast pressure, so that it can penetrate up to the centre of the furnace.

6. **Breakout** – Generally breakout is caused by failure of the bosh wall, wall of the hearth with a result that liquid pig iron and slag will flow out of the furnace in an uncontrolled way. It is called as break out.

Remedies :- It is essential to remove maximum amount of hot products like pig iron and slag from the furnace through the tap hole and the blast is put off. The break out area is repaired first and the furnace operation is resumed thereafter.

7. **Chocking of gas uptakes** – Furnace operation is generally stopped if the dust gets accumulated in the uptake and also in down comer. It occurs due to faulty gas uptake design particularly inadequate cross section and improper joints. It can be cleared by maintaining the blast without charging iron ore.
8. **Flooding and coke ejection through the tap hole** – In bosh both liquid slag and metal flows through permeable coke bed against the upward thrust of the ascending gases. An increase in gas pressure can prevent liquid metal and slag from flowing down and causing it to accumulate in the coke interstices until the weight of the liquid overcomes the upward thrust of the gases. It descends suddenly into the hearth after overcoming the upward thrust of the gases. This phenomenon is known as flooding. If the uniform blowing rate is interrupted, the raceway collapses and again it resumes. As a result small particles of coke can not re-enter the raceway and consequently remains inside the hearth, instead of burning in front of the tuyer. Thereby chocking the hearth and causing ejection from the slag and pig iron tap hole during tapping. Uniform blowing rate is the best remedy to avoid this.
9. **Channeling** – Preferential flow of ascending gases through certain area of the burden because of their relatively much better permeability is called as channelling, since this appears as channels. This arises basically

due to improper size distribution and wide size range of the charge material in the furnace.

10. **Leaking of tuyers, tap hole and coolers** – In spite of proper design if the water cooler part fails, may be due to failure of the refractories, should be replaced immediately. If it is not possible to repair, the faulty cooler has to be cut off from the water mains and put out of use.

    Leaking of tuyers leads to the loss of blast and also decreases the blast pressure. So faulty tuyer first disconnected from the bustle pipe and reused after repairing.

    Leaking of the tap hole leads to the ejection of slag and metal in an uncontrolled way. So repairing and recharge of the mud gun should be done immediately.

Modern development of B.F

1. **Oxygen enrichment of blast :**

   For every unit of coke burnt at the tuyer, nearly 4-5 unit weights nitrogen of the blast are heated to nearly 2000^{o}C. Generally it is accepted that the blast containing pure air contains 79% of nitrogen by volume. Thus the blast restricted the temperature generated in front of the tuyer. This temperature can be increased by decreasing the nitrogen content that is the oxygen enrichment of the blast. So higher temperature is possible. There is however a limit to which higher temperature in front of the tuyer is desirable. Since any excess over that causes sticking of the stock and also due to the rise of temperature cohesive zone will shifts towards up, which obstructed the flow of CO gas. So use of 25% oxygen in the blast has been found to be advantageous if it is done with adequate humidification. For every percent increase of oxygen, production rate is increased by 3-4%.

Advantages:

a) The increased oxygen content of the blast will increase the rate of combustion, thereby productivity is increased.
b) The decrease of nitrogen in the ascending as but higher CO content of these gases provides more reducing condition in the shaft and favours

higher percentage of indirect reduction. Hence the coke rate is decreased.

2. **Humidification of blast :**

   There is always some moisture present in the blast. It is more in rainy season and less in summer. This moisture reacts with hot coke in front of tuyer areas as

   $$C + H_2O \rightarrow CO + H_2$$

   As a result it produces additional reducing agent in the form of hydrogen. This reduction is endothermic in nature. However for every unit of coke burnt, it generates 1 unit of CO.

   $$C + ½ O_2 \rightarrow CO$$

   But if it is burnt with H_2O it generates 1 unit of CO and 1 unit of H_2. If extra heat is available in tuyer areas it can be made advantageous by adding steam in the blast. This is the principle of humidification of blast in the modern B.F. Steam is introduced in the cold blast before it is preheated in the stove. If it is introduced in the hot blast, since the steam temperature could not be close to that of the hot blast, it will have cooling effect which is not desirable.

Advantages :

a) It generates additional reducing gases. So coke rate will be reduced and rate of combustion will increase.
b) Decreases the nitrogen content of the ascending gases.

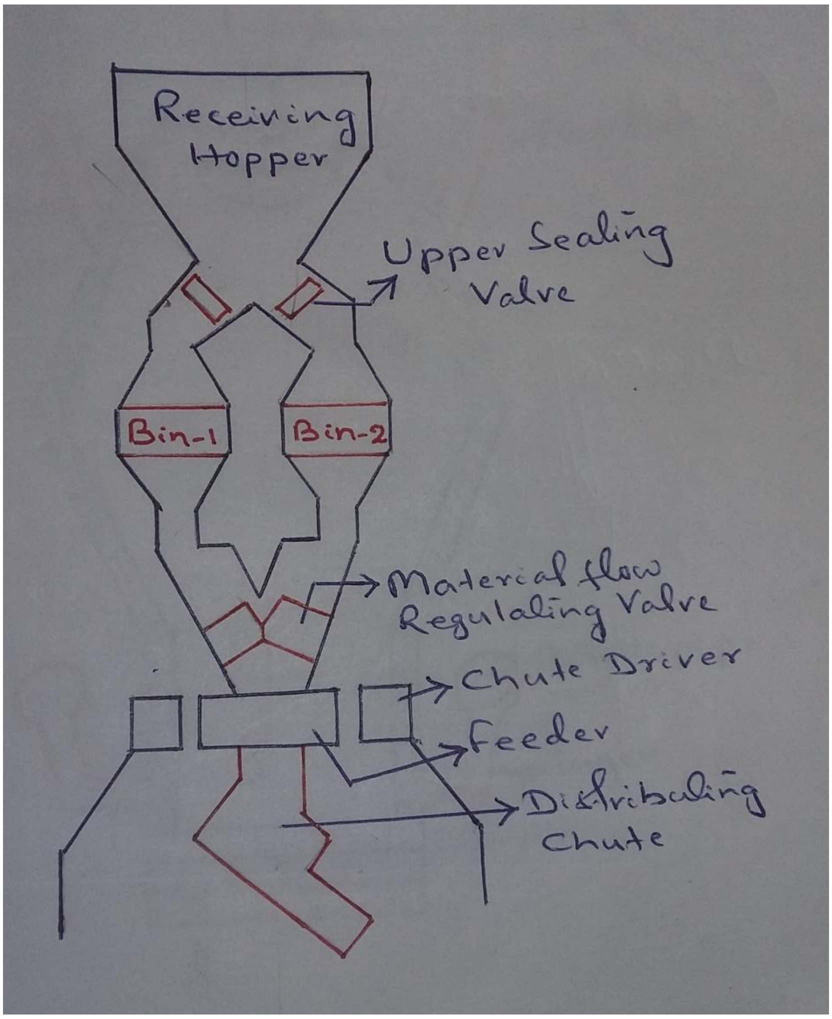
3. **High Top Pressure (H.T.P)**

   If it is required to blow more air to increase the furnace output, a stage may reach when the gas velocity exceeds the critical limit if flooding resulting in hanging, slips, and irregular furnace operation. However furnace can be forced even with conventional burden material if the linear velocity is reduced with the help of high top pressure. By this the furnace output can be increased because the gas is remained inside the furnace for more time. In conventional process the pressure inside the furnace gradually decreases from bottom to the top of the furnace. But by applying HTP the pressure of the gas is maintained uniform from hearth to the top of the furnace. In the conventional furnace the top is almost open. If the top pressure is increased with suitable valves and seals at the top, an increased blast pressure can be created at the top part of the furnace. For a constant blast volume the average gas pressure inside the furnace and therefore the density of the gas will increase with corresponding decrease in the linear velocity of gas.

Advantages :

1- Increased reduction rate with increased total pressure and hence decrease in the direct reduction and hence in coke consumption.
2- More uniform distribution of gas velocity and pressure.
3- Benefits higher with unprepared burden or supper large furnace due to higher pressure of the gas.
4- Increase in the metal tapping rate.

4. **Bell Less Top charging system –**



This is a unique design in which the large bell is replaced by a distribution chute. The problems of distribution associated with large bell are entirely eliminated. A rotating chute is provided inside the furnace top cone. All the materials are charged through the holding hopper with seals at its top and bottom which are charged and discharged alternatively, while the third is acting as a spare. Regulating gates in each hopper are provided to control the rate of charging to facilitate uniform distribution on the stock line. A typical Paul-Wurth bell less top is shown above.

Since the chute can rotate in a circular and helical fashion and at variable angle and hence not only the fundamental characteristics of large bell distribution retained but charging at a point, in sequence and in spiral form is possible. It means virtually any type of distribution as desired can be obtained.

Advantages :-

1- Greater charge distribution flexibility with a small amount of mechanical equipment.
2- The total overall height of the top can be much less.
3- Substantial reduction in investment for top construction.
4- It gives more operational safety and easy control over varying charging patterns.

5. <u>**External Desulphurisation –**</u>

Presence of sulphur in pig iron or steel increases the brittleness of the material. So sulphur content in pig iron or steel should be as low as possible, but it is quite difficult to reduce the sulphur content during the B.F smelting operation. So it should be reduced externally after the smelting operation. It is done by –

1- Use of soda ash (Na_2CO_3)
2- Use of lime(CaO)

1- **Desulphurisation by soda ash –** Soda ash is usually employed for ladle desulphurisation. Here bags of soda are thrown in an empty ladle and pig iron is added to that. Sodium possess greater affinity of sulphur and forms sodium sulphide(NaS) in contact with FeS.

$$FeS + Na_2CO_3 \rightarrow FeO + Na_2S + CO_2$$

Na_2S is obtained in a liquid state above 900^oC.

The reduction of FeO is possible by reaction with carbon and Si present in the hot metal

$FeO + C \rightarrow Fe + CO$

$2FeO + Si \rightarrow 2Fe + SiO_2$

Silicon on one hand reduces the oxygen potential but on the other hand it consumes Na_2O by forming sodium silicate. Due to formation of sodium silicate there is a danger of attack on the ladle refractories, health hazards due to alkali fumes. So the use of soda ash is confined to a limited extent.

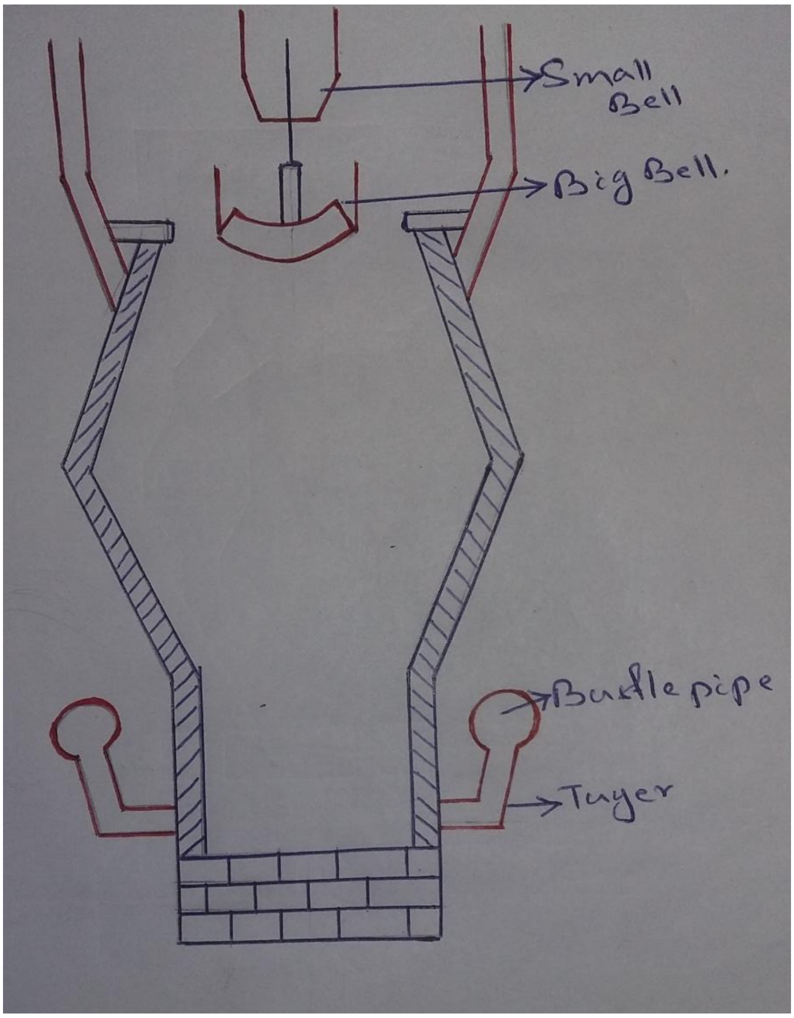
2- **Desulphurisation by lime** – An extensive sulphur removal can be achieved by injection of burnt powder lime with nitrogen or other inert gases in the hot metal. By this process the sulphur content can be brought down to a very low level required for high quality iron and steel. The injection of nitrogen produces turbulence ensures intimate solid-liquid contact.

$FeS + CaO + C \rightarrow Fe + CaS + CO$

$2FeS + 2CaO + Si \rightarrow 2CaS + 2Fe + SiO_2$

Alternative Routs of Iron Making

A. Low Shaft Furnace –



The extremely high thermal efficiency of a conventional B.F is essentially due to the tall shaft where the presence of the ore, preheating and reduction takes place before it descends into the melting zone. The effective height of the shaft required to carry out the processing of the ore depends on the reducing power and the temperature of the furnace gas generated at the tuyer level. In normal B.F the gas phase generated at the tuyer level contains 60% N_2 which is inert. The question that arises therefore is whether it is possible to reduce the shaft height without affecting the thermal efficiency of the furnace. The shaft height can be reduced without affecting the thermal efficiency if the heating and smelting zone in the furnace are compressed by accelerating the heat exchange and chemical reaction. This can be achieved by oxygen enrichment of the blast.

Low shaft furnace is successfully run on two type of charges. One of the type consist of lumps of individual charge material and the other type consist of briquettes made from suitable mixture of ore fines, lime stone, lignite coal with tar as binder.

In low shaft furnace very little reduction occurs in the upper part of the furnace but rapid reduction occurs at a short distance above the tuyer. The reduction of ore takes place predominantly directly by the carbon rather than the CO gas because of the low shaft height. The top gas from a low shaft furnace therefore is not only at high temperature but also it contains heavy amount of CO.

In general the low shaft furnace has effective height of more than 5mt. The hearth area is generally around 8-10mt^2. Many of the recent innovation in normal blast furnace practice like high top pressure, humidification of blast etc can be adopted in a low shaft furnace practice also.

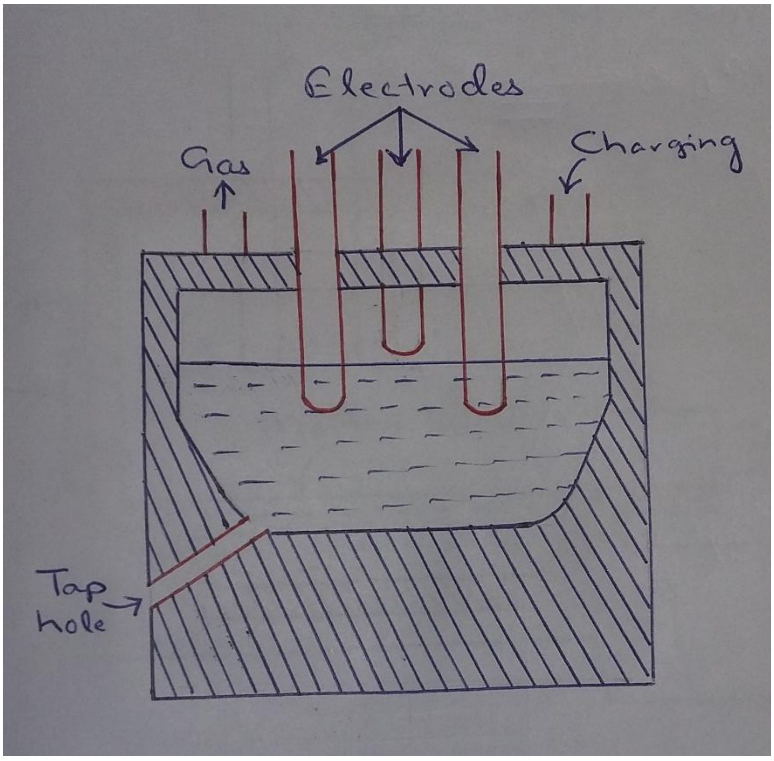
Advantages :

1- It can take fine low grade or improper quality of ores in the charge.
2- The fuel of inferior grade like lignite, bituminous can be successfully used.
3- Preheating of the blast can be readily accomplished in reccuperator and hence costly stoves are not necessary.
4- Agglomeration of ore is un-necessary
5- Silicon content of the pig iron should be reduced to a minimum level.

Disadvantages ;

1- Briquettes if the charge mixed may be necessary for the efficient production which adds to the cost of raw material production.
2- The outgoing gas moves out of the furnace at high temperature and with high CO concentration.

B. **<u>Submerged Electric Arc Furnace –</u>**



Small B.F is replaced by an electric arc heat input in electro thermal smelting process. So no significant indirect reduction of iron oxide by CO is possible. But coke or other forms of carbon are still necessary because the reduction of iron oxide takes place predominantly by electro thermic direct reduction.

$$Fe_xO_y + YC \rightarrow XFe + YCO$$

The furnace is a steel shell lined from inside with basic refractories like magnesite or chrome magnesite. The furnace is closed from the top by an inverted bowel like roof, lined from inside with ordinary fire bricks since it does not have to stand very high temperature. The roof is provided with openings for insertion of three electrodes vertically downward. It is also provided with one or more holes for charging and one or more holes for the gases generated during smelting to go out of the furnace. Modern furnaces are provided with self baking soderburg type electrode. The electrode is made by joining piece by piece steel sheet cylinders with welded ribs from inside to support the electrode paste while baking. The electrode paste is made from coke and bituminous binder. As the electrode is consumed and is allowed to slip in, fresh steel cylinder is fixed to it from top and is allowed to slip gradually.

The reductant has to perform a dual function of being the reducing agent and also resistance for generation of heat within the furnace. The reactivity of the reductant is important since reduction of iron oxide has to take place directly by carbon in relatively short duration. The electrical conductivity of the reductant is also equally important since a bed of reductant is formed under the electrode and its resistance to passage of current generates heat

The charge consists of ore, coke and lime stone. Coke or fuel rate is almost half that of the normal B.F.

One of the important developments in electro thermal smelting has been the use of furnace gas for preheating or prereduction of the iron ore charge in a rotary kiln located just above the furnace. The preheated or pre reduced charge is fed in hot condition to the furnace. The degree of direct reduction is aimed at 50% removal of total oxygen content of ore.

An important calculation :

For Making of 1 ton of pig iron, raw materials required

- 1.75 ton of iron ore
- 0.75 ton of coke
- 0.25 ton of lime stone
- 4 tons of air