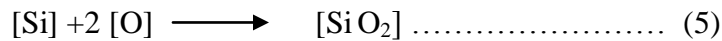
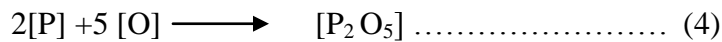


## Chapter -1 History of steel making

(Principles of steel making)

Pig iron from blast furnace contains some impurities along with iron. They are carbon (C) Sulphur (S), Phosphorous (P), Manganese (Mn), Silicon (Si) etc, so it is necessary to refine pig iron as it is quite impure, so steel making process is called as refining process. This occurs in an oxidizing atmosphere, so that these impurities will form oxide and will separate. It requires an oxidizing agent. In oxygen steel making process pure oxygen is used, but in modified conventional process iron oxide, air and pure oxygen are used as oxidizing agent. Generally temperature is maintained at 1700<sup>0</sup>C. The chemistry of steel making refining process can be simple given by the following relations.



Out of all these reactions, elimination of sulphur occurs in reduced condition. In the oxidation of carbon, the product being a gas will pass off into atmosphere. But the rest of the oxide product shall remaining contact with the iron melt in the from of a slag phase. There is the danger of backward reaction so all the above reaction should move towards right according to the of mass action. This can only be achieved by increasing the activities of the reactant and decreasing the activities of products. Also with the increasing of oxidizing potentials of the oxidizing agent. This occurs by using atmospheric air in place of iron oxide & pure oxygen in place of air. For a given composition of a pig iron the activities of the reactant are fixed. The only way is to decrease the activity of the products can however be decreased by combining it with the oxide of opposite chemical character i.e acidic oxide will mix with basic oxide and the basic oxide will mix with acidic oxide, so that they will easily form compounds and will pass to the slag phase. This is the chemical aspect. As per the physical requirements of the oxide products are

concerned, it should be readily separable from the iron melt. This is achieved by keeping both slag & metal as thin liquids, so that the metal being heavier will settle down & slag will float on the top in the form of two immiscible liquids and can easily be separated.

Out of all the oxide produced silicon & phosphorous forms acidic oxide, hence a basic flux is needed to form a suitable slag for their effective removal. Higher the proportion of base available lesser will be the danger of back ward reaction. For Mn elimination, since MnO is basic an acidic flux is required. During refining being the largest bulk iron itself gets oxidized to some extent as FeO which is basic in nature. It is possible to adjust the contents of silicon and Mn in Pig iron such that the amount of (FeO +MnO) forms during refining could be able to form a slag essentially of the type (FeO-MnO-SiO<sub>2</sub>) and fix up SiO<sub>2</sub> in it. In such slag P<sub>2</sub>O<sub>5</sub> is not stable because (FeO+MnO) together are not enough bases to fix it up in slag phase. In order to oxidize 'P' in preference to Fe, a strong external base like CaO or MgO is needed in sufficient proportion to form a basic slag to hold P<sub>2</sub>O<sub>5</sub> without any danger of reversion. 'P' is best eliminated by a slag of the type (CaO- FeO - P<sub>2</sub>O<sub>5</sub>) . Such a slag is also capable of removing 'S' from iron melt to a certain extent.

**Steel making process can now be divided into two categories;-**

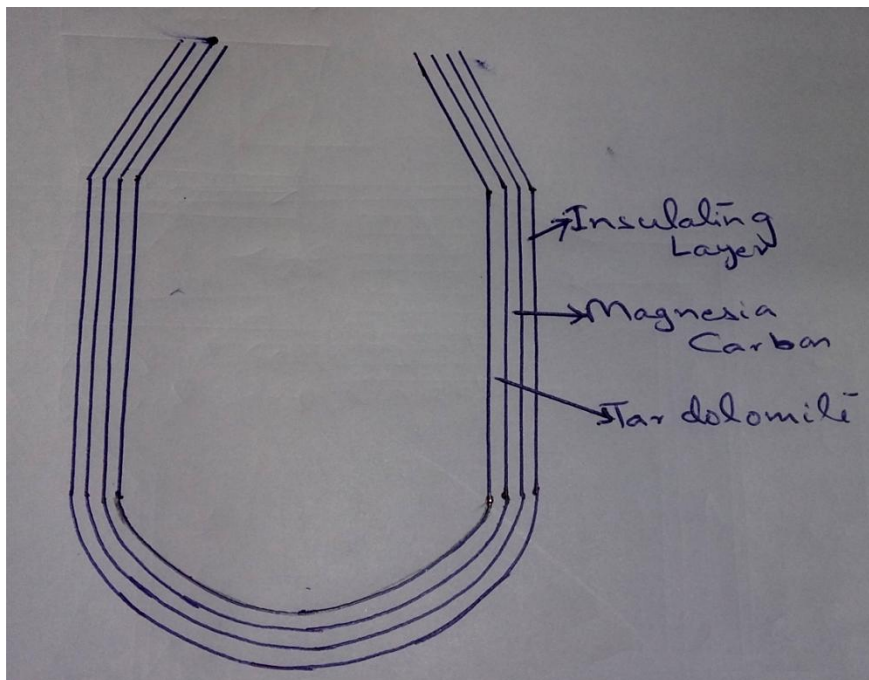
1. When 'Si' is the chief impurity to be eliminated from 'Fe' & the 'P' and 'S' need not be eliminated.
2. When 'P' and to a some extent 'S' are the chief impurities to be eliminated along with silicon (si).

In the finished steel except of few exception 'p' & 'S' each must be below 0.05%. higher 'S' content are recommended for free cutting variety of steel & slightly higher 'P' content is desirable for efficient pack rolling of steel sheet. If S is above 0.05% in steel then the steel becomes hot short and more P will create cold-short in steel.

## STEEL MAKING BY LD PROCESS

It is a basic oxygen furnace

1. Basic oxygen process or
2. L.D Process



In some cases of steelmaking,  $\text{SiO}_2$  content of slag is high.. This  $\text{SiO}_2$  tries to react with the lining. So lining will corroded till washing away, to avoid this tar-docomite refractories are used for the inner lining of the convertor. Here 'C' will react with  $\text{O}_2$  to give CO gas. This gas diffuses out and renders (Restrict) contact between lining and silica ( $\text{SiO}_2$ ) in the slag. Tar has low carbon

content. So graphite can also be used. Magnesia and carbon bricks are mostly available in Lathikata & Belpahar.

**Three ratios of L.D. Converter are**

1. Volume of the vessel in m<sup>3</sup> = 0.8 -1.0

Weight of the charge in ton

2. Effective height of the vessel = 0.5 -2.0

Inside diameter of the vessel

3. Effective height of the vessel = 4.5 -5.2

Depth of the bath

**Production date**

Installed capacity in ton	Charge to tap time in minute	Annual production in ton	
		Two vessel shop with one working	Three vessel shop with two working
30	30	460,000	920,000
100	35	1,300,000	2,600,000
200	40	2,300,000	4,600,000
300	45	3,100,000	6,200,000

**Raw materials**

1. Hot metal (Pig iron)
2. Scrap & ore
3. Flux
4. Oxygen

1.

<u>Hot metal – Composition</u>	<u>Temperature</u>
C → 4 - 4.5%	During charging the temperature of hot metal is 1250 -1300 <sup>0</sup> C
Mn → 4 - 4.5%	
Si → 0.65 - 1.5%	
S → 0.02 – 0.06%	
P → 0.05-0.45%	

Hot metal content in charge material → 75-90%

Scrap – 10-25% →

Under certain circumstances, it may be necessary to add cold pig iron as the charge to consume the excess of pig iron produced in the plant. Due to this sudden increase of temperature inside the convertor can be controlled. But here the main disadvantage is that granulated cold pig iron, however tends to settle down at the bottom and it does not come up until towards the end of refining. It causes reactions to take place while tapping the vessel, that may need a small reblow. Also cold pig iron in general tends to prolong the blow by disturbing the usual blow characteristics of the scrap plus hot metal charged and hence is not preferred.

2. **Scrap and Ore:** - Both of these are used as coolants to best utilize the excess heat energy available during refining. The main advantages of iron ore is for the early formation of slag. But Fe-ore is rarely preferred because the available excess thermal energy can be economically used in melting maximum load of circulating scrap in an integrated steel plant because according to its cooling effect 1% of ore in the charge is nearly equivalent to 3.5% steel scrap. But early formation of an effective slag is beneficial in many ways and hence many plants prefer to add scrap with a little ore as coolants.

3.**Flux:**

Composition

CaO – 86%

Ca CO<sub>3</sub> -3%

(Si O<sub>2</sub>+Al<sub>2</sub> O<sub>3</sub>) - 5%

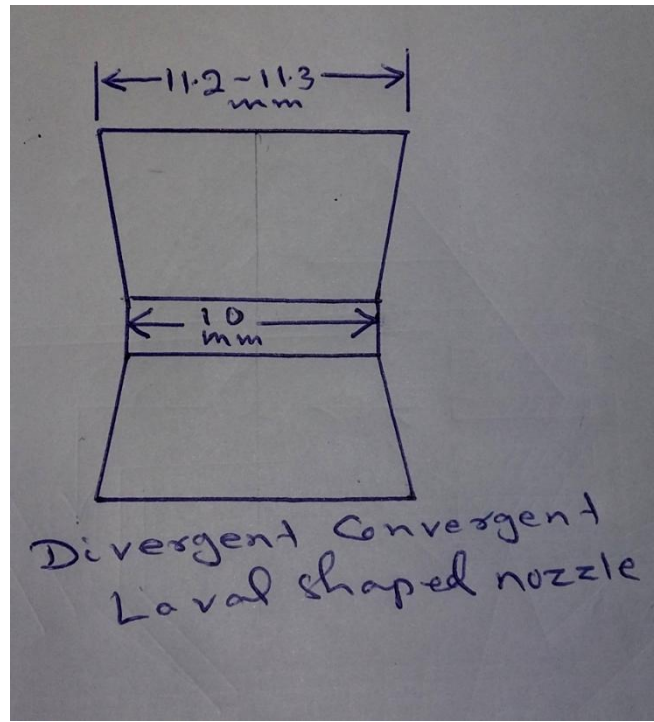
Ca (OH)<sub>2</sub> -2%

MgO -1%

Thermal energy available during the heat is utilized for melting scrap and at same time for disintegration of Fe-ore and hence is not recommended to be utilized for calcinations of CaCO<sub>3</sub> as added as flux. Also CaO is straightly available for fluxing and formation of slag. So CaCO<sub>3</sub> is generally not use for fluxing. Besides the available lime content of lime its reactivity is an important parameter to judge its quality as a first approximation, i.e., in terms of its particle size. A lumpy lime is slower to dissolve in slag than fine powder lime. On the other hand fine powders of it will have the tendency to fly off. In order to avoid this lime is used in small granular form. Lime consumption varies around 2-5% the total weight of the metal charged.

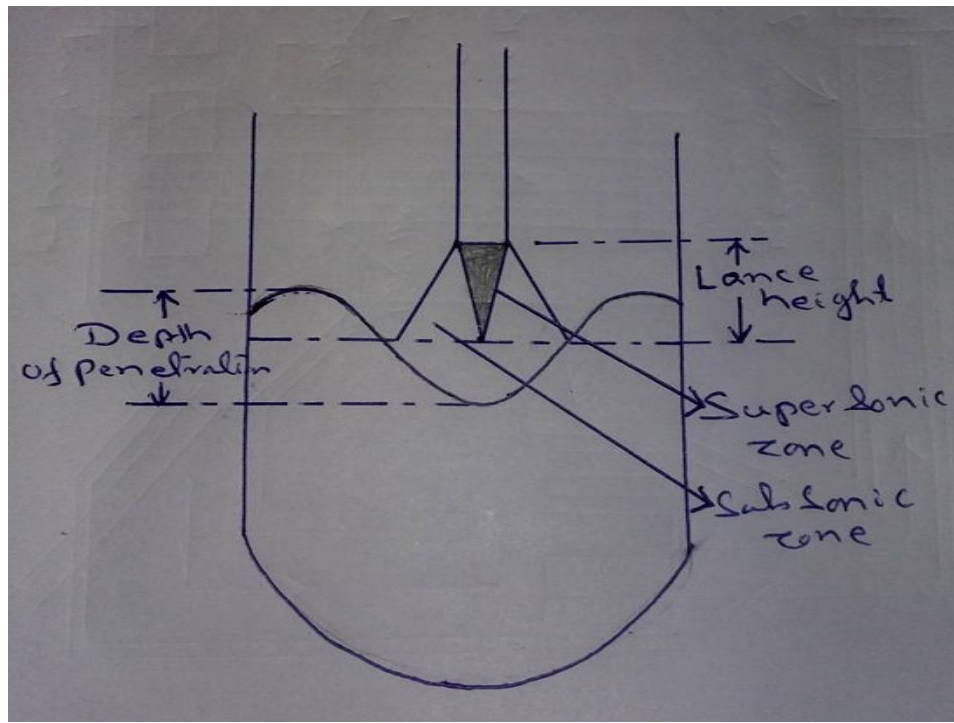
4. **Oxygen:** It has been observed that N<sub>2</sub> content of bath increases with decreasing purity of oxygen, hence O<sub>2</sub> purity should be 99.5% to keep N<sub>2</sub> level of finished steel below 0.00016%. It finally gives N<sub>2</sub> content below 0.003% in the steel ingots. The consumption of O<sub>2</sub> per ton of steel varies with proportion of scrap as added as coolants.

### Lance design:



Lance is made up off steel tube. As the tip of lance is exposed to very high temperature, it is made up of copper. There is a water cooling system to increase the life of lance. As the tip is exposed to very high temperature, water cooling is made more effective there. In the tip portion there may be 3 to 5 holes which depend on the capacity of the converter. These holes are not straight. In order to increase the pressure of oxygen out coming from the lance tip, a convergent divergent Laval shaped lance is used. The static pressure in a jet from a laval shaped nozzle disappears within a short distance from the nozzle tip and hence it does not interact much with the ambient atmosphere. Oxygen is generally blown at 8-10 atmospheric pressure through a laval shaped nozzle, so that the jet issuing at the nozzle exit is super sonic and generally has a velocity between 1.5-2-5 times the velocity of sound. Also due to this design  $O_2$  covers the maximum surface area but it does not react with the lining, otherwise it will destroy the lining as the temperature attaining is  $2000^{\circ}C$

## DISTANCE BETWEEN THE LANCE TIP AND TOP OF THE BATH.



Oxygen jet has two sections.

They are **1. Super Sonic Zone** **2. Sub Sonic Zone**

The points where the super sonic zone ends the bath should be there. Super sonic jet has so higher kinetic energy that if it penetrates the bath the slag and metal will be blown out of the L.D. Converter. The portion of the bath which is partially refined is denser and will sink down. This distance between lance tip & top of bath is between 0.8 to 1.0 meter. This is called **lance height**.

The number of holes may be 3 to 5. If bath diameter is larger then three holes will not cover the whole surface of the bath. For high capacity converter, lance used are 5 holes. Lance height may vary, when the carbon content of bath decreases, for further removal of carbon needs more dissolved  $O_2$ . In this case lance height is decreased to increase the amount of dissolved oxygen in the bath.



## **OPERATION:**

The sequence of operation is as follows:-

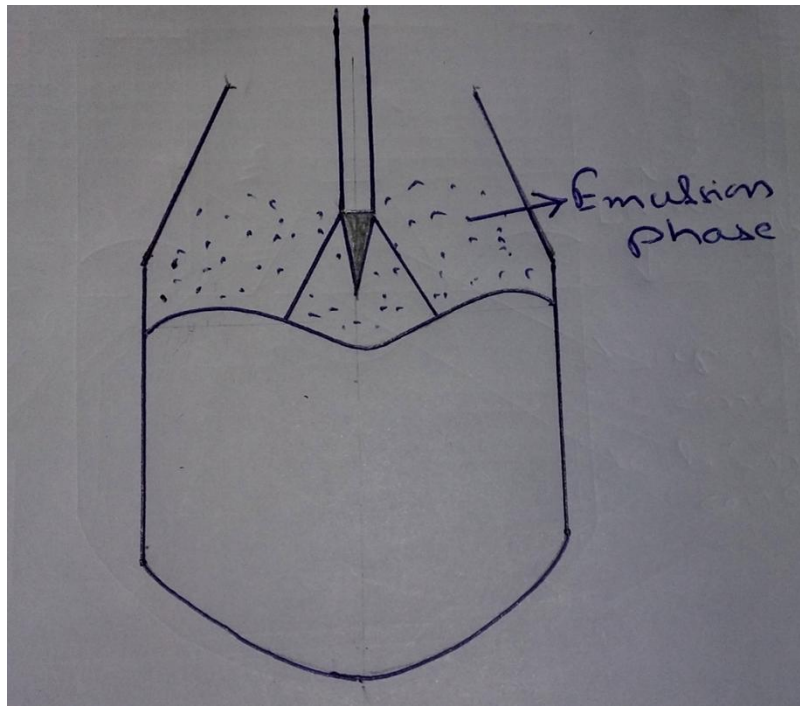
1. After the previous heat is tapped and slag is drained out the vessel is brought to inclined position to receive scrap. The scrap is virtually powered in the vessel from the charging chute in one lot. It is kept waiting to minimize delay. The lining is inspected. It takes 3-5 minutes.
2. The vessel is rocked to gently drop the scrap on the bottom and is brought back to horizontal position to receive hot metal. The metal is kept waiting in the ladle for being charged. The metal is charged. It takes 3-5 minutes.
3. The vessel is rotated to vertical position, lance is lowered to its first blowing position and the oxygen is turned on. It takes 1-1.5 minute.
4. As soon as ignition takes place part of lime is charges along with other fluxes to form early slag. The rest of the fluxes are added as per predetermined intervals but in the early part of the blow. Some prefers to add all fluxes in one lot after good ignition.
5. The blow continues for nearly 15-25 minutes, during this period the lance height may be altered as per pre-established practice. The oxygen is put-off and the lance is raised above. It takes 15-25 minutes.
6. The vessel is brought back to inclined position and slag and metal samples are taken out for analysis. Temperature of the bath is measured by immersion thermo couple. Analysis is received. Alloying additions in heavy lumpy form can be done here and 2-3 minutes of waiting time is allowed for homogenization of the bath. It takes 5-8 minutes.
7. If the analysis and tapping temperature are correct. It is rocked in tapping position and slag is tapped in the ladle already waiting for it. It takes 4-7 minutes.
8. As soon as steel just appears to come out the vessel is rocked further to tap out the steel.

This gives a tap-to-tap time of 30-50 minutes. Delays due to tap hole repair, cleaning of lance tip, etc. may increase the heat time by a few minutes.

## **The sequences of elimination of impurities**

The sequences of elimination of impurities during a L.D blow are established early by analyzing the bath sample. It has been found that the removal of Si is quite fast and more or less completes in about 6 min after commencement of the blow. Mn comes down concurrently with Si up to a certain point and it remains there for the rest of the blow. C & P oxidized

together and the process of oxidation starts after few minutes of blowing. Removal of C occurs by gas-metal reaction and of P by slag metal reaction. So decarburization occurs by decreasing lance height or by keeping the lance at the previous position but increasing the oxygen pressure. This is called as deep blowing. But de-phosphorisation occurs by increasing the lance height. This is called as soft blowing. Due to this an emulsion phase will form. It consists of slag-metal-gas combination. It is just like foam. Metal droplets of 15-100 mesh size are present in the foam, slag present in the foam consists of FeO, CaO, P<sub>2</sub>O<sub>5</sub> etc (generally CaO). Gas present is CO<sub>2</sub> 80% of dephosphorisation occurs in the emulsion phase. This is unique to the L.D. process. Remaining 20% P is removed in the bulk phase.



### **For 100 ton L.D**

Bath area = 13 m<sup>2</sup> (interfacial area between slag – metal)

Interfacial area between slag –metal (emulsion stage) – 7500 m<sup>2</sup>

Surface area of each droplet is (10-20) cm<sup>2</sup>/gm

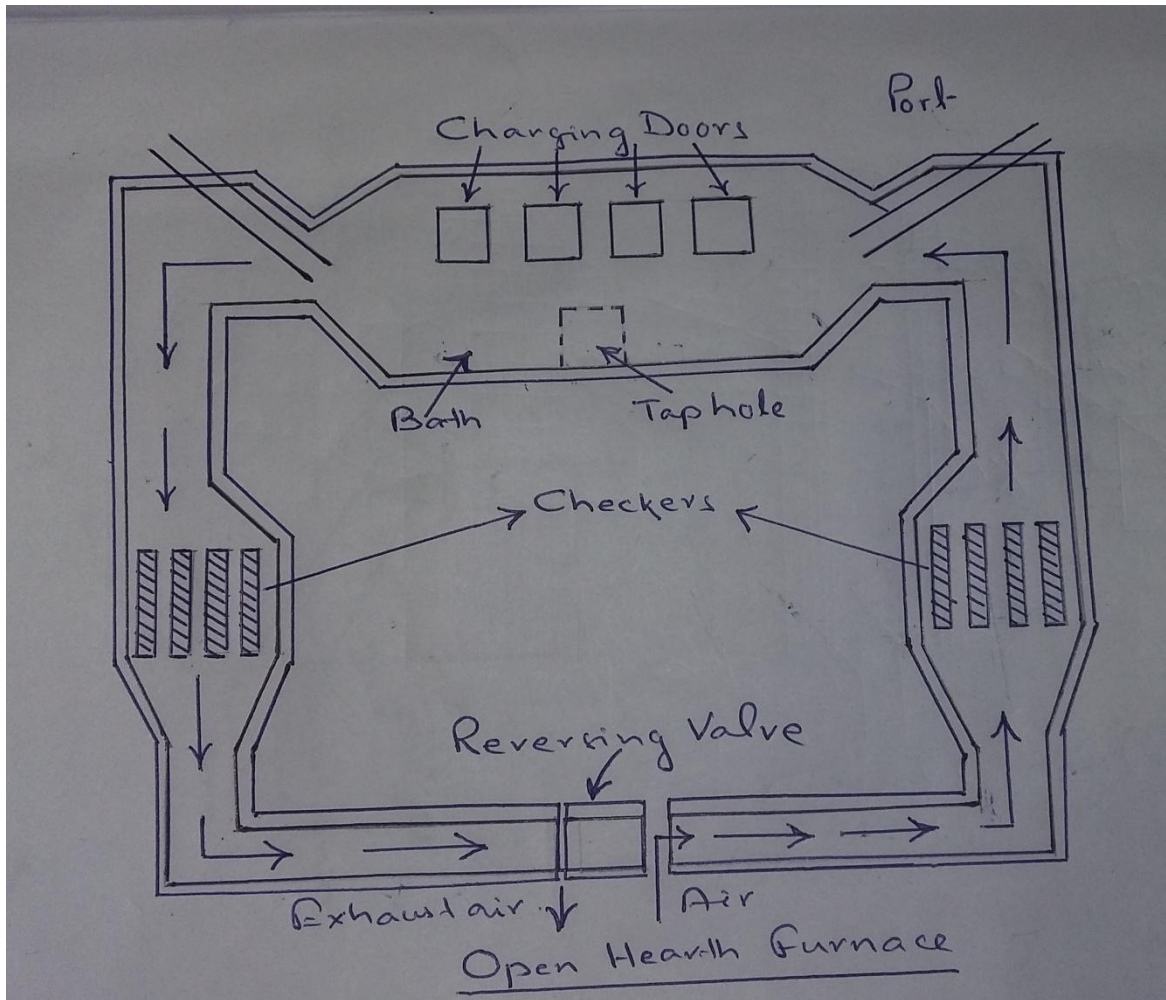
Here each metal droplets are surrounded by slag. Condition of dephosphorisation are that the slag should be basic, thin and oxidizing and that the temperature should be high. Dephosphorisation therefore does not takesplace efficiently until such a slag is formed in L.D.

process. Such a slag forms only after the initial 4-6 min of blowing. In the emulsion phase particle is through up and after its residence it falls back to the bath. The cycle is repeated as long as emulsion is stable. In the early part of blowing silicon (Si) & manganese (Mn) are oxidized in some drop lets. In some other droplets decarburization may occurs but is delayed due to lack of super saturation of dissolved  $O_2$  necessary for the reaction. Emulsion phase is supported by 'CO' gas formed. So by the time 'C' content of bath is 1%, dephosphorisation should be over because CO gas evolution will decrease with decrease of carbon content. Below 0.3% C the gas can't sustain the emulsion phase and it falls down. Also further removal of 'C' cannot occur by soft blowing. In that case deep blowing is done to further decrease the carbon C level.

### **Limitation of L.D Process:-**

1. Phosphorous (P) should be below 0.4% otherwise its removal will be difficult.
2. 1% of Fe is oxidized to  $Fe_2O_3$  and it escapes as L.D. dust so it leads to environmental hazard.
3. FeO content of slag is very high i.e, 25-30% (in R.S.P – 35%). Hence yield is less  
In India yield is – 91%  
In R.S.P yield is – 88-89%  
World average -90-93%
4. Depth of penetration of oxygen ( $O_2$ ) jet is very low i.e , 40-60mm, where as bath depth is 1.5-2.5m. So yield is very low. Due to low penetration depth reaction is confined to the top layer of the bath. Oxygen first oxidized the top layer then penetrates the slag layer and reaches the metal.

## OPEN HEARTH FURNACE



The open hearth furnace consists essentially of a heart in the shape of a elongated basic which can hold 60-500 tons of steel according to its size. In the acid open hearth process the hearth is made up of Silica sand but in the basic O.H. F/C the hearth is made up mixture of calcine magnesite or dolomite. Along one side is a row of charging doors while on the other side tap hole is present.

At each end a pair of ports for fuel gas & air is there. In this case of steel making, the refining is done by oxidation of impurities present in Pig iron, i.e, Si, P.S.C, Mn, Al etc. In this case mixture of coke oven gas & blast furnace gas is used as fuel and is injected through burners. Combustion of gases takes place in presence of preheated air therefore the combustion products of fuel should contain  $O_2$ , oxidizing gases like  $CO_2$  &  $H_2O$  and certain amount of  $N_2$ . Thus the atmosphere in an

open hearth furnace is oxidizing during all periods of a heat with a partial pressure of oxygen being almost always rather high. During heat, the bath absorbs 1-3% of  $O_2$  to the mass of metal, this  $O_2$  is used mainly for oxidation of impurities and partly for oxidation of Fe. Hence temperature attend is  $1600^{\circ}C$ - $1700^{\circ}C$ . Heat is supplied to the bath from the top and is remove through the bottom i.e, hearth, because of which the temperature of the slag is higher than that of metal, With a certain temperature gradient existing across the depth of the bath. The thickness of slag layer in open heart furnace varies from 50 mm -500mm and the depth of the metal from 500mm -1500 mm. equalization of temperature across the bath is done by rise of CO bubbles due to oxidation of carbon with ore boiling. The upper layer of the bath would be superheated excessively while those at the bottom would remain insufficiently heated. The temperature gradient across the depth of bath is  $70$ - $100^{\circ}C$  at the beginning and  $20$ - $50^{\circ}C$  at the end. The temperature of the metal is also not some along the bath. In particular it is higher just near the flame and lower near the exhausting port. The molten metal is all time under a coat of slag. Practically all additions introduced into the metal say oxygen from the furnace atmosphere also has to pass through the slag. Ferric oxide ( $Fe_2O_3$ ) is formed on the slag-gas interface. It diffuses through the slag and reacts with the molten iron on the metal-slag interface and is reduced to FeO, thus enriching the slag in this oxide which in terms gives up  $O_2$  to the impurities. The oxidation of impurities can occur in the slag-metal boundaries. The oxidation of carbon C to carbon monoxide (CO) is an exothermic one, so it produces heat to melt the bath. Si & Mn are easily removed by oxidation due to the presence of  $O_2$  in the furnace atmosphere. But in order to remove 'P', flux is added to from ferruginous-limy slag. But as the reaction  $[FeO] + [C] - [Fe] + CO$  is heat absorbing, so iron ore is added slowly to avoid sudden cooling of the bath. The furnace hearth participates actively in the process. In contrast to L.D convertor where the heat takes of only 50 minutes, a heat in open hearth furnace continues for a few hours because of which the interaction between the hearth material and metal is quite sensible.

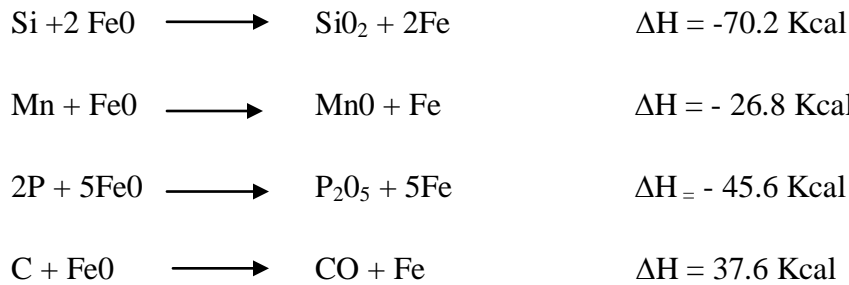
### **Operation of open hearth furnace: -**

Scrap metal, pig iron, flux, etc are charged into the furnaces through charging doors. Heating of these materials are done by burning of gaseous fuel, i.e, the mixture of coke oven gas and blast furnace gas. These fuels are allowed to enter into the Furnace through the nozzles. There are two burners working attentively for 20-30 minutes, i.e, when the 1<sup>st</sup> burner is working 2<sup>nd</sup> one is kept closed. Combustion of gaseous fuel is done by air. In order to increase the combustion temperature preheated air is used. After passing over the hearth products of combustion passes through second checker chamber and heats it. After 20-30 minutes the

processes reverses, the 2<sup>nd</sup> burner will start working and the 1<sup>st</sup> one is kept closed. In this case air is allowed to pass through second checker chamber, heat is transferred from 2<sup>nd</sup> chamber to the air and is preheated. Thus preheated air is used for combustion of gaseous fuels. This system of preheating of air is known as regenerative system and it heats air to about 2400<sup>0</sup>F before it reached the furnace chamber. Heating of metal is done for few hours. On the other side of the furnace has a tap hole in the lowest part of the furnace and is closed with a refractory plug, until the metal is ready to be poured. Before tapping the molten metal into the ladle a sample of metal may be tested as regards its chemical composition.

**Chemistry of basic open hearth furnace:-**

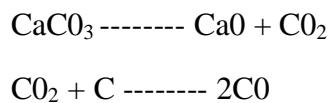
At the beginning lime stone, ore, steel scraps and a little amount solid pig iron is charged in the furnace. Due to combustion of gaseous fuel temperature rises to about 1200<sup>0</sup>C. By the rise of this temperature in about 2 hours all the charges are melted down. At this stage pig iron is added to the charge. The reactions occurring are



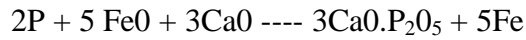
Out of all the above reactions the first three are being exothermic in nature, helps in melting down the scrap. During melting down stage most of the manganese & silicon gets oxidized by FeO and joined to the slag. The reaction of silicon oxidation is practically irreversible. But in the case of manganese (Mn) at elevated temperature a reverse reaction is possible, i.e reduction of manganese oxide from slag.

**Ore boil:-** The Ore boil beings at the end of melting down stage. During this stage reaction, C + FeO – CO + Fe, takes place. The CO gas evolved by the oxidation of carbon causes violent agitation of metal as it escapes in the form of bubbles.

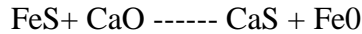
**Lime boil:-** Before the Ore boil is completed lime boil begins. This is caused by decomposition of lime stone into lime and CO<sub>2</sub>.



CO agitates the bath and brings lime in contact with  $P_2O_5$ .



Phosphorous is oxidized at the same time as silicon and manganese at the beginning of a heat. In common practice single slagging off is sufficient to reduce the concentration of 'P' to 0.01-0.015%. If charge is having high 'P', single slagging off practice is insufficient. In this case double slagging off practice is preferred. This is done in a tilting furnace which will tilt through  $30-35^\circ$  towards the tap hole to remove the first slag formed and refining is carried out further after which the 2<sup>nd</sup> slag is removed to get better quality of steel. Sulphur is removed as

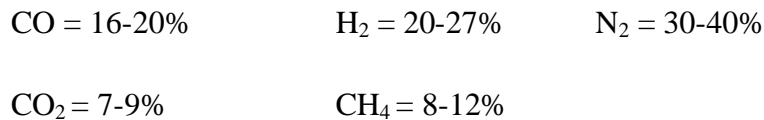


Special attention should be given to the sulphur content of the fuel.

### **Fuels for open hearth furnace:-**

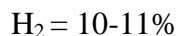
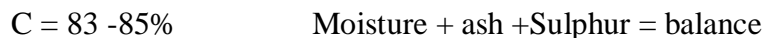
The temperature of the slag surface at the end of a heat is roughly  $1650^\circ C$ . Therefore the flame temperature must be at least  $1750^\circ C$ . In order that the flame heat should transfer effectively to the metal open hearth furnaces are generally fired with fuel oil, natural gas or a mixture of blast furnace gas and coke oven gas.

The coke oven and blast furnace gas mixture contains



Its calorific value varies depending on the proportion of blast furnace gas & coke oven gas. The brightness of the flame is usually improved by adding a minor quantity of a carburizer (fuel oil). The calorimetric temperature of combustion of a preheated blast furnace and coke oven gas mixture in a preheated air is around  $2600^\circ C$ , i.e., the flame has very high temperature.

But the places where blast furnace gas & coke oven gases are not available open hearth furnaces are fired by natural gas or fuel oil. Fuel oil is an excellent fuel for open hearth furnace as it gives bright, high temperature flat flame. Fuel oil usually contains



The content of the sulphur in fuel oil used in open hearth furnaces is 0.5-0.7%. High sulphur fuel oil containing more than 3% S are rarely used in steel making, since the sulphur of the fuel can pass to the metal. Before being fed to the burner fuel oil is preheated to  $70-30^\circ C$

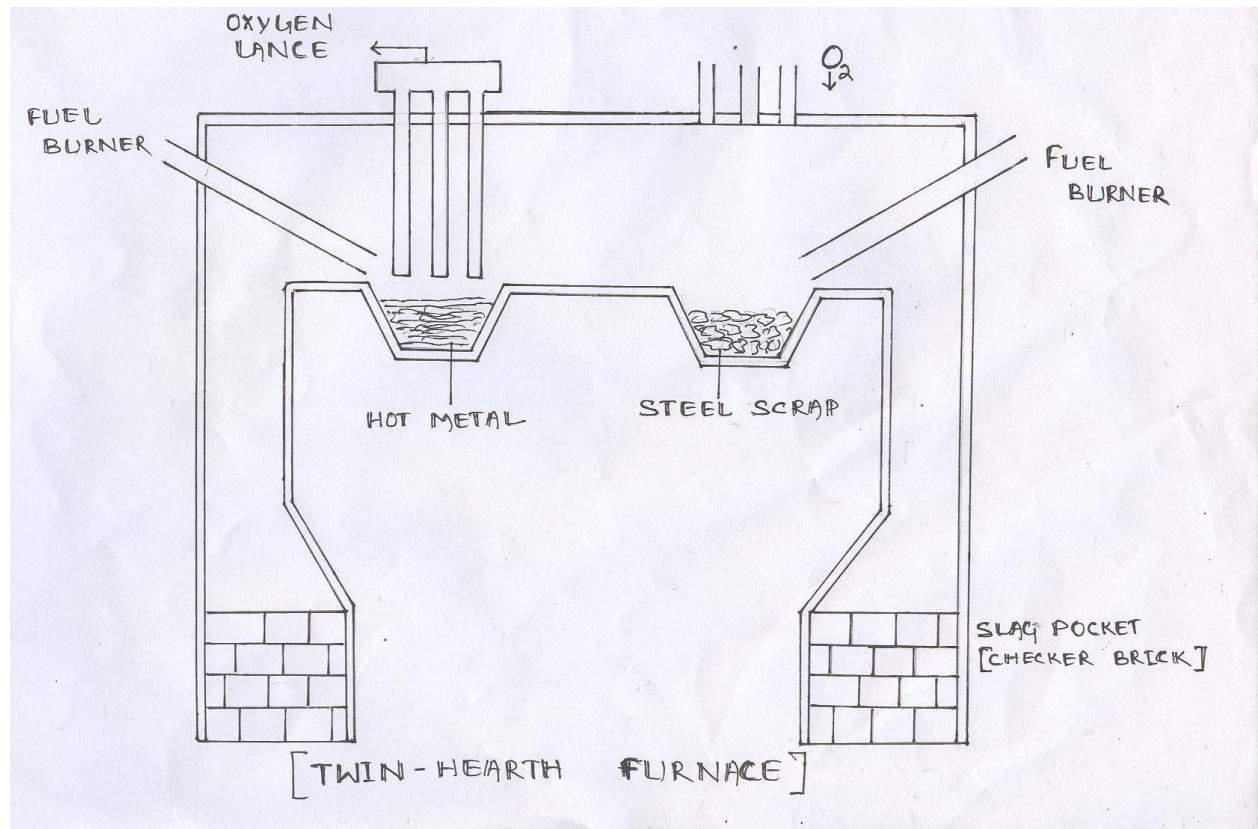
## **Disadvantages of open hearth furnaces:-**

### **Limitation:-**

1. The productivity is very low. Without oxygen lancing the total process takes 16-18 hours i.e, 32 tons/hour. But in L.D it is 300 tons/hour. Then, after  $O_2$  lancing from top of the furnace to the slag surface time came down for production of 500 tons of steel to 12 hours, i.e 42 tons per hour.
2. L.D is autogenous, but here fuel has to be burnt to melt steel scraps. Products of combustion leave the furnace in fraction of second so a very little amount of heat is absorbed by the molten metal. So thermal efficiency is very low that is 35%.
3. It has complicated design. Foundation must be strong to sustain the furnace, i.e very high capital investment.
4. High maintenance cost of checker chamber as slag pockets fills up gradually and after few heats it has to be opened & cleaned.



## Twin –hearth furnace :- (Dual hearth furnace process)



In the case of twin hearth furnace, two chambers are used. When in one chamber refining is occurring melting of steel scraps is occurring in another chamber. In this case pure oxygen is used to decrease the refining time. Oxygen is lanced from top to the slag-metal interface. During operations both the chambers are filled with steel scraps, then fuel is allowed through the burners to the first chamber and oxygen lances are lowered, so combustion will take place in first chamber. After melting of scraps, hot metal is poured into the first chamber and refining will take place. During this period burners and  $O_2$  lances of second chamber are kept closed. The hot products of combustion from first chamber will enter into the second chamber by heating the cold steel scraps taken in that chamber. After the refining in first chamber is over  $O_2$  lances will remove from slag-metal interface & burner is kept closed. Then only metals and slag from 1<sup>st</sup> chamber is tapped out & will fill with steel scraps. Then the process reverses,  $O_2$  lances of second chamber are lowered & refining is done in that chamber while heating of steel scraps is continuing in 1<sup>st</sup> chamber.

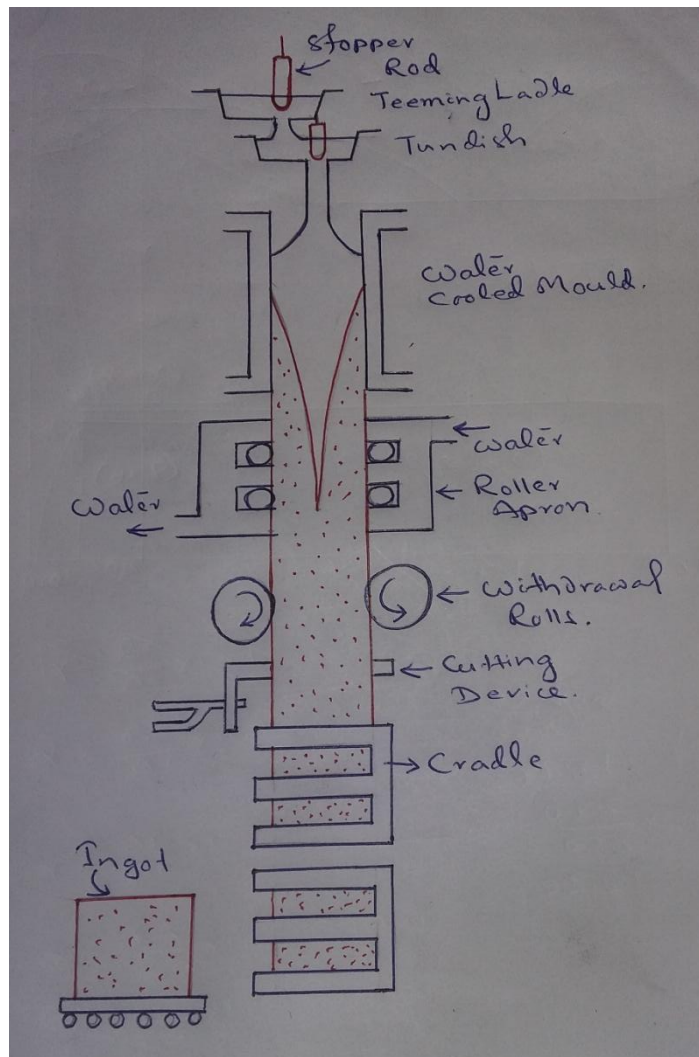
In villai steel plant, in 5 hours 20 minutes 500 tons of steel is produced. Before conversion to twin furnace time was 12 hours so productivity is doubled.

Energy consumption per ton of steel =  $0.2 \times 10^6$  Kcal (after Conversion)

## CONTINUOUS CASTING OF STEEL

Principle:- Continuous casting may be defined as teeming of liquid metal in a short mould with a false bottom through which partially solidified ingot is continuously withdrawn at the same rate at which metal is poured in the mould. The equipment for continuous casting of steel consists of:-

1. The ladle to hold steel for teeming.
2. The tundish to closely regulate the flow of steel in the mould.
3. The mould to allow adequate solidification of the product.
4. The withdrawal rolls to pull out the ingot continuously from the mould.
5. The cooling sprays to solidify the ingot completely.
6. The bending or cutting devices to obtain handenable lengths of the product.
7. The auxiliary electrical or mechanical devices to run the machine smoothly.



The mould is open at both ends and is water cooled. The operation is started by fixing a dummy plug bar to temporarily close the bottom of the mould. Steel is slowly poured in the mould through a tundish and as soon as the mould is full to a certain level, withdrawal of the plug begins. The rate of withdrawal must exactly match with the rate of pouring. For smooth operation of the machine, uninterrupted pouring and simultaneous withdrawal gives rise to the whole cast being poured in the form of one piece, which may be cut into smaller pieces as per the requirement. The ingot does not solidify completely inside the mould. But a thick skin will form and is able to stand the pressure of liquid core. If the bar is withdrawn rapidly this skin may break or produce cracks in the ingot. This is avoided by using moving mould instead of stationary mould.

The principle of moving the mould is known as Junghan's principle so named after the investigator. In this the mould is moved up and down variously through a stroke of 12 to 40 mm. The ratio of speeds of downward to upward strokes is nearly 1:3. The downward speed is being equal to that of the rate of withdrawal.

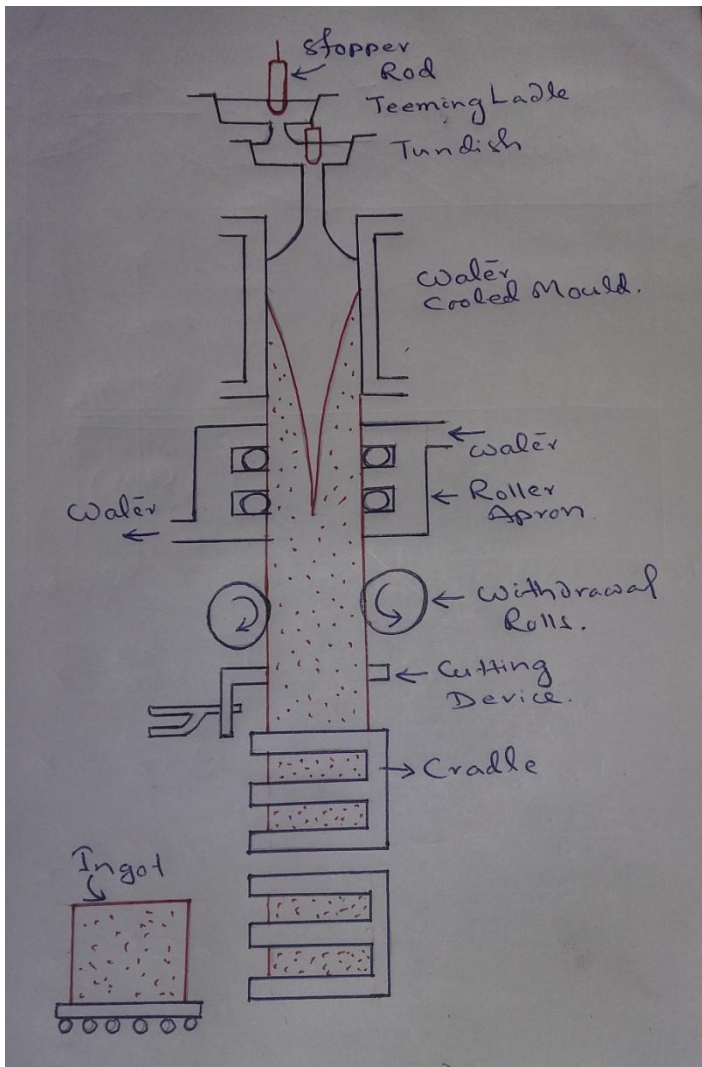
**TYPES OF CONTINUOUS CASTING:-** Three main types of machines are used in practice.

They are

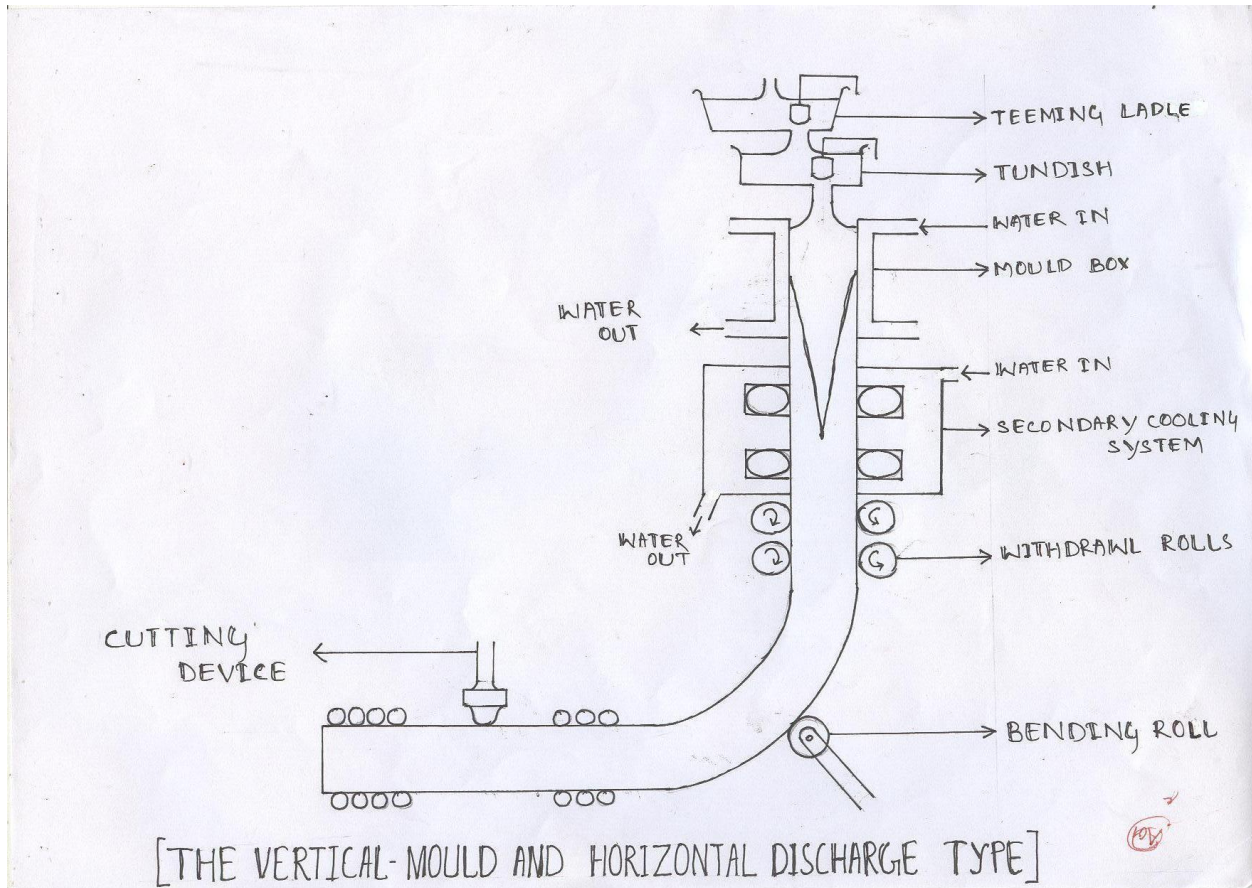
- i. Vertical Type
- ii. The vertical mould and horizontal discharge type
- iii. The curved mould ( S type)

### **i. Vertical type**

Here liquid steel is brought to the machine in a stopper controlled ladle and is teemed in a stopper controlled tundish which regulates the flow of steel to the mould. Below the mould is the secondary cooling zone in which rollers are set to make close contact with the ingot. The water spray nozzles are present in between those rolls. The number of sprays, pressure of water, etc are adjusted to control the degree of cooling. It is also known as a roller apron. This hold the product fairly tightly to support it. The main withdrawal rolls are situated just below the roller apron and just below it an oxy-acetylene cutting torch is provided. The cutting torch travels at the same speed as that of the withdrawal of the product. After cutting, the torch returns to its original position quickly. The product is then laid horizontal and is brought to the normal floor level.

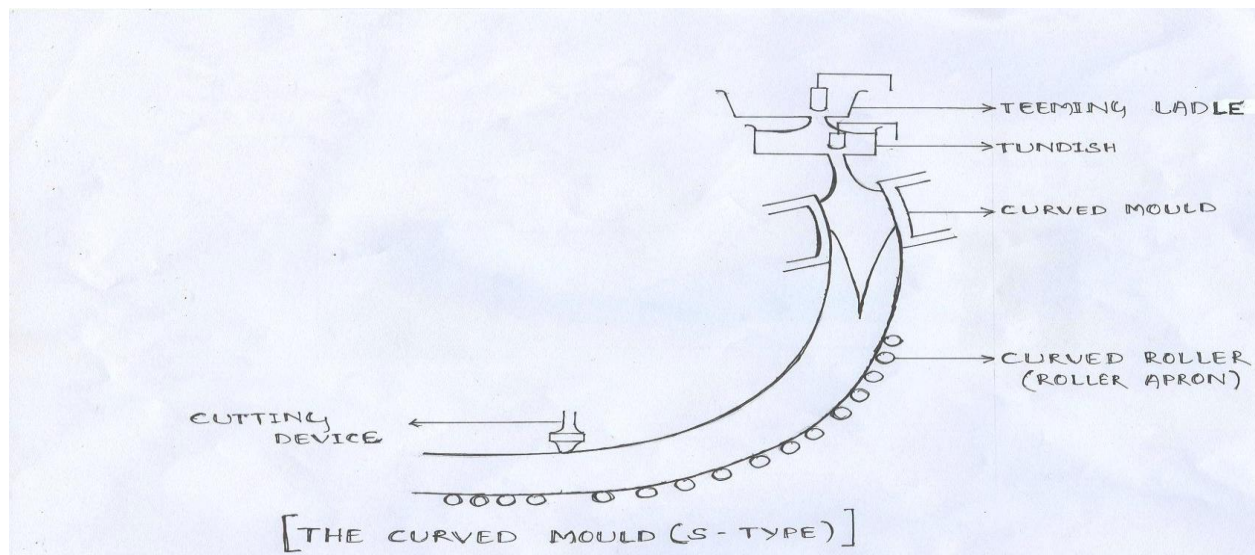


## ii. The vertical-mould and Horizontal-discharge type:-



This is a modification over the earlier vertical design to reduce the overall height of the machine. The mould, the roller apron design and the withdrawal rolls are similar to those in a vertical machine. After the product coming-out from the withdrawal rolls, it is bent to obtain the discharge horizontal. The cutting torch moves horizontally. A horizontal set of straightening rolls become necessary. A saving of 30% in height is thus possible by this design. The floor space requirement however is more. Heavy sections being difficult to bend cannot be cast by this machine. In the event of a breakdown it is more difficult to repair and restart this machine. This is quite popular for small and medium size cross sections.

**The curved mould (S type):-** In this the mould itself is curved one and it oscillates along the same curved path as the main axis of the product. The withdrawal rolls carry out the bending also and hence need to be of adequate strength. The height of the shop in this case is still less and hence is also called low head type machine. The bending of the ingot commences even before it is entirely solid in cross section and hence large sections can also be cast without much of bending problems



## INGOT TYPES

Type 1:- This is a typical killed steel ingot with inter connected bridged pipes. The killed steels are almost invariably cast in wide end up of molds with a hot top so that the pipe is confined to the feeder head as far as possible.

Type 2:- This is a partially deoxidized steel. The gas is not evolved in the early stages of solidification. The ferrous static head prevents it from evolving at the bottom of the ingot. The gas is evolved in small amount and that too towards the end of solidification, i.e, at the middle portion of the ingot. It is enough in volume to compensate for shrinkage and thereby reduce or nearly eliminates the pipes. The pressure developed by the gases is sufficient to cause the top to bulge out. This is a typical semi killed steel ingot.

Type-3:- The gas is still evolved only towards the end of solidification, since the amount of gas evolved is more than that in type-2 the pressure developed is high enough to burst the solidified top. This is called bleeding. The blow holes are near the walls and are continued to the upper portion of the ingot.

Type-4:- The gas evolution is appreciable. The liquid steel rises in the mould. The rimming action does not allow the top to solidify immediately after pouring. The rising level of the metal is stopped by putting a metal cap at the top. The remainder of the evolved gas is thereby entrapped to form a series of honey-comb shaped blow holes all around the walls and bottoms.

Type -5:- The gas evolution is so large and it evolves so early that a lot of heat escapes out from the ingot. The ingot slowly rises in the mould is capped to produce a typical capped ingot. The ingot is capped after the rimming action slows down. The net result is that a thick skin is formed first and then the honey combed blow holes are formed which are less than that in type-4.

Type-6:- A lot of evolved gas escapes out. The ingot therefore does not rise in the mould as much as in type-5. The honey comb blow holes are formed after thick skin formation confined to the lower portion of the ingot.

Type 7:- The gas evolution finally leads to the formation of a very thick skin and honey comb blow holes in the bottom quarter. The ingot does not rise in the mould to any appreciable extent. The volume of blow holes just compensate for the shrinkage. This is a typical riming ingot.

Type-8:- This gives a very violent rimming action such that no blow hole formation is possible. The ingot in fact shrinks to some extent during solidification.

## CONTROL OF INGOT STRUCTURE

The final structure of an ingot is determined by the degree of deoxidation carried out before solidification and also depends upon the steel making practice for a given type of steel.

The control aspects are described below:-

**Rimming steels:** - Rimming steels require a lot of gas evolution during solidification, so enough dissolved  $O_2$  should be present in steel and it is possible only when carbon content of steel is very less i.e., below 0.15%.

Heating of steel continues till the carbon level is less than 0.15% with respect to iron oxide content of the slag. In general no deoxidation is carried out in the furnace. Only a small amount of deoxidation, if needed is carried out using Fe-Mn, Fe-Cr or Al as deoxidizers in the ladle or in the mould itself.

The correct thickness of ingot skin without any blow holes can be obtained by carefully controlling the oxygen content and temperature of liquid steel while teeming or cooling, so that the necessary gas evolution takes place in the mould. The rimming action of the first ingot that is teamed is observed to decide whether rimming is less correct or more. In a properly cast rimming steel, primary blow holes formed next to the ingot skin of adequate thickness and the secondary blow holes formed still inside. The zone between primary and secondary blow holes is known as a rim, which is characteristic of a rimming ingot. Rimming steel has a smooth surface.

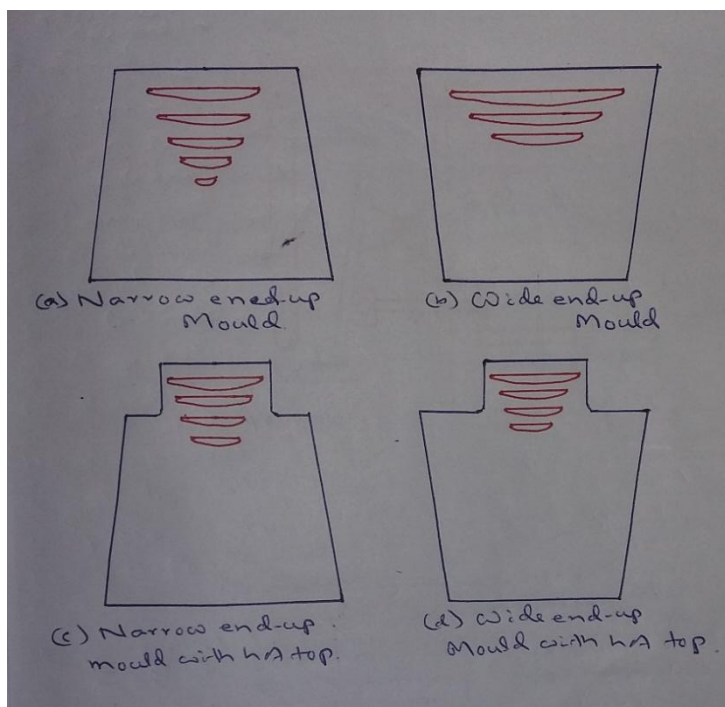
**Semi killed steels:-** These are partially deoxidized steels such that only a small amount of gas is evolved during solidification. The carbon content has to be maintained in the range of 0.15% - 0.3%. The required deoxidation may be carried out, at least partially and if permitted in the furnace itself. Fe-Mn, Fe-Si, or Al may be added as deoxidizers. Gas is not evolved immediately after pouring of steel in a mould. In general the top level freezes before the gas evolution commences. The gas evolved towards the end of the ingot solidification. Many a time steel contains more  $O_2$  than desirable and hence gas evolution takes place much earlier than required. This situation can be avoided by thoroughly deoxidizing the top of the ingot by Al, which is added just before completion of pouring or immediately thereafter. It makes the top to freeze quickly and the blow holes are formed mainly in the middle part of the ingot. Al should be added carefully so that it is not carried down to the lower portion of the ingot.



**Killed Steel-** No gas evolution takes place in killed steel during solidification. All steels containing more than 0.3%C are killed steels. The heat is worked in such a way that by the time the carbon level drops close to the specification level, the refining should be over. In general blocking of O<sub>2</sub> is done by adding ferro-silicon, silico-manganese to the bath in the furnace. Blocking stops C-O<sub>2</sub> reaction by lowering the O<sub>2</sub> content of the bath. Ferro-alloys are added towards the end of the operation. The deoxidiser addition should not be so large as to chill the liquid steel beyond a safe limit. The deoxidation product should be given adequate time to rise to the surface of the bath. Killed steels are always cast in wide end-up moulds. The killed steel structure is quite sound and dense which is particularly suitable for forging.

## **Ingot defects and remedies**

### **1. Pipe**



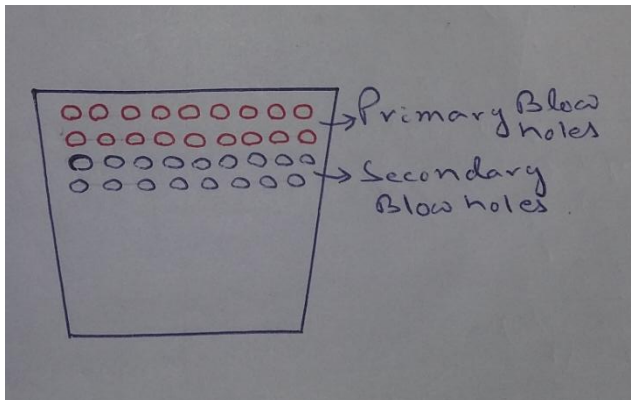
The volumetric contraction resulting from solidification appears in the form of a cavity is known as pipe which is about 2.5-3% of the total apparent volume of the ingot. In a wide end-up mould it is short and wide but in narrow end-up mould it is narrow and long.

Primary or open pipes get oxidized and do not weld during rolling. As a result that much of ingot portion has to be cut off. Secondary pipe forms in the interior portion of the ingot,

so it does not get oxidized and is easily welded during rolling. Longer is the pipe, lesser will be the effective length of the ingot, so wide end-up moulds are preferred. The effects of pipe formation can be avoided by using a hot top feeder head, so that the pipe is confined to the feeder box of a wide end-up mould. The volume of feeder box is 15% of the ingot volume. Rimming and semi-killed steel shows slight tendency for piping which can be eliminated by careful practice. But the problem of pipe formation is serious in the case of killed steel.

**Blow holes:-** The cavity produced by evolving gases is known as blow holes. It is of two types, i.e

1. Primary blow holes
2. Secondary blow holes.



Primary blow holes are elongated and are formed just behind the ingot skin. The secondary blow holes are spherical in shape and are located in the interior portion of the ingot. Deep seated blow holes don't open-up and thus do not get oxidized during rolling. But the primary blow holes first get punctured and then gradually oxidized during rolling. The formation of blow holes avoids the formation of pipe. So the effective length of the ingots having blow holes is greater than that of ingots having pipe.

## Surface defects:-

- (a) **Ingot cracks:-** The chilling effect of a mould forms a thin solid layer on the side faces and the bottom of ingot immediately after pouring and is known as ingot skin. The contraction of the ingot on the skin formation and the expansion of mould on heating tend to separate the two and form an air gap in between. If the skin is thinner one then the internal pressure of the liquid metal will rupture it, so cracks will be formed on the surface. The thickness of the skin formed depends upon the time of contact of steel with the mould wall and is given by.

$$\text{Thickness (t)} = K\sqrt{\text{time}}$$

Where, K = constant (0.9-1)

The value of K depends upon the mould mass mould design,  $\text{temp}^f$  of liquid steel,  $\text{temp}^f$  of the mould, pouring technique and the rate of pouring.

Rapid rate of cooling decreases the skin thickness and thereby increases its tendency for crack formation. The friction between ingot and the mould wall may also develop sufficient tension to cause surface cracking. Cracks are of following types:-

1. **Longitudinal cracks:** - These are more or less parallel to the vertical axis of the ingot and are formed due to the development of lateral tension in the skin. The tendency to form this type of cracks increases as the ratio of cross section to height increases.
2. **Transverse cracks:-** These are nearly parallel to the base of the ingot and are formed due to longitudinal tension of the skin. The tendency to form this type of cracks increases if the ratio of height to cross section increases.
3. **Restriction cracks:** - These may be longitudinal or transverse in direction and are located at the corners of the ingot. But the transverse restriction cracks are due to the friction between the mould and ingot of a small corner radius.
4. **Sub-Cutaneous Cracks:** - It is formed due to thermal shocks and are formed below the ingot skin. These are exposed during cooling.

## Other Surface defects:-

1. **Scab:** It occurs due to the presence of some cavities on the inner surface of the mould, so that liquid steel will enter that cavity and a small projection will form at that place after solidification of the ingot.

2. **Lappiness:-** Lap is a fold formed due to slow rising of metal surface during pouring of molten metal. So due to slow pouring, the surface of the metal will cooled before the completion of pouring. Simultaneous with cooling, oxide layer will form and will not easily attached with the further added metal, so that a fold will formed. Several such nearly parallel laps may occurs.
3. **Splash:-** During the pouring of metals in the mold, small drops are thrown due to impact and they became stick to the mould wall and get oxidized. When the metal level rises gradually, these drops will not weld up due to oxide coating on it. So during rolling they may form seams.
4. **Crazing:-** If a large no of cracks are present in the mould wall, steel may freeze in these cracks and give rise to a network of fins on the ingot face. This is also known as crocodile skin. This results in the formation of seams during mechanical working.
5. **Double skin:-** It forms due to slow pouring of metal or by rapid cooling of mould so that before completion of pouring a solid skin will form behind the mould wall in the lower portion. So due to solidification that portion will shrink and a gap will form between mould wall and the ingot skin. Molten metal will gradually build up there and due to oxidation of the skin formed, it will not weld properly so that it give rise to double skin.
6. **Sponge top:** - The viscous top tends to rise due to the late gas evolution and due to presence of gas it makes the top spongy.
7. **Flash:** - It is a plate of solidified steel formed due to molten metal entering the cavities in the mould assembly, for example, at the joining of mould with bottom plate and hot top.
8. **Boot leg:** - It is the sinking of an ingot top below the original level in the mould due to evolution of gases. It occurs due to slow pouring of molten metal and slow cooling of mould.

### **Casting pit practice:**

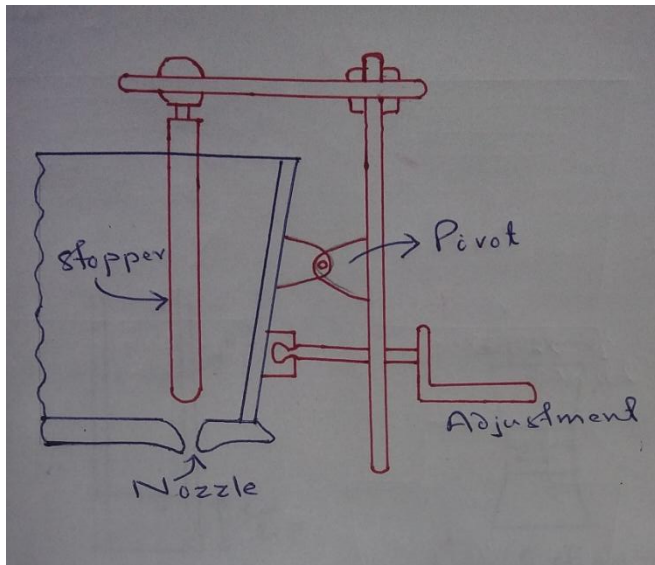
After refining of steel in a furnace, it is tapped in a special type of ladle known as teeming ladle .The entire process of molten the steel from the time of tapping to the solidification including stripping & maintenance of the assembly of the mold is known as casting pit practice and where the casting is carried is called PIT practice yard.

Different teeming method.:

- a) Direct teeming
- b) Tundish teeming
- c) Bottom teeming

a) **Direct Teeming:** In this process metal is teemed directly from the ladle into the mould. The rate of pouring can be controlled by using different sizes and different types of nozzles provided with the teeming ladle. The rate of teeming increases with increasing the nozzle diameter which is due to erosion of the nozzle head during continuous practice. Preferably magnesite and graphite nozzle are better than fire clay nozzle. The size of the nozzle used is decided with the type of steel to be teemed such as for more viscous and soft steel, slight large diameter nozzle is used where as for medium & high carbon steel smaller diameter nozzle of around 20 mm is used.

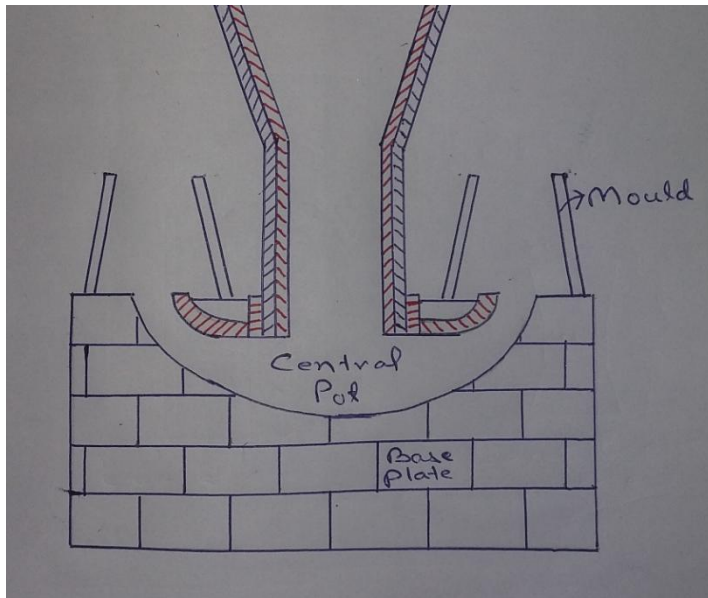
b) **Tundish Teeming :**



In this process transferring of molten metal into mould is carried out by a pipe like metal stream at a uniform rate so as to avoid any defects.

Tundish is inserted between the ladle and the ingot mould to ensure uniform metal stream while teeming from the top. Tundish has its own nozzle of different type to regular the flow. Also stopper is provided with the tundish to regulate the flow. First tundish is filled with molten steel to a certain depth which is maintained throughout the teeming so as to ensure the uniform teeming. However in this technique problems arising out during direct teeming process is avoided up to certain extend. Also one of the advantages of this process is that at a time up to 12 nozzles can be employed to the tundish so as to ensure better distribution of molten steel into a number of moulds at a time.

C) **Bottom Teeming :** First two process which are based on the pouring of molten metal from top causes some irregularities which are avoided in bottom teeming process which is sometimes known as indirect teeming or uphill process. Here molten steel is teemed into a vertical runner which is connected at the bottom to a horizontal runner. The upper portion of vertical runner is bell shaped so as to make teeming easier. The height of the vertical runner should be more than that of the mould so as to ensure complete filling. In general a vertical runner can fill at a time 2-12 numbers of moulds. Also with some special arrangement more no of moulds can be filled up.



**Central Pot** - This is the portion of the bottom teeming unit which is made up of high heat resisting refractories and divides the metal into multiple streams located at the bottom of the vertical runner. The end of the horizontal runner is designed for smooth discharge of the metal into the mold. In the case of big ingots some additional plates are used which are known base plates. The quality of the bottom teemed ingot is much superior to the top teemed ingot. However in bottom teeming process refractories used and appropriate preparation of moulds is costly one. But due to faster filling capacity or the extent of ingot preparation, it is one of the most popular methods of ingot making.

## **ELECTRIC ARC FURNACE :**

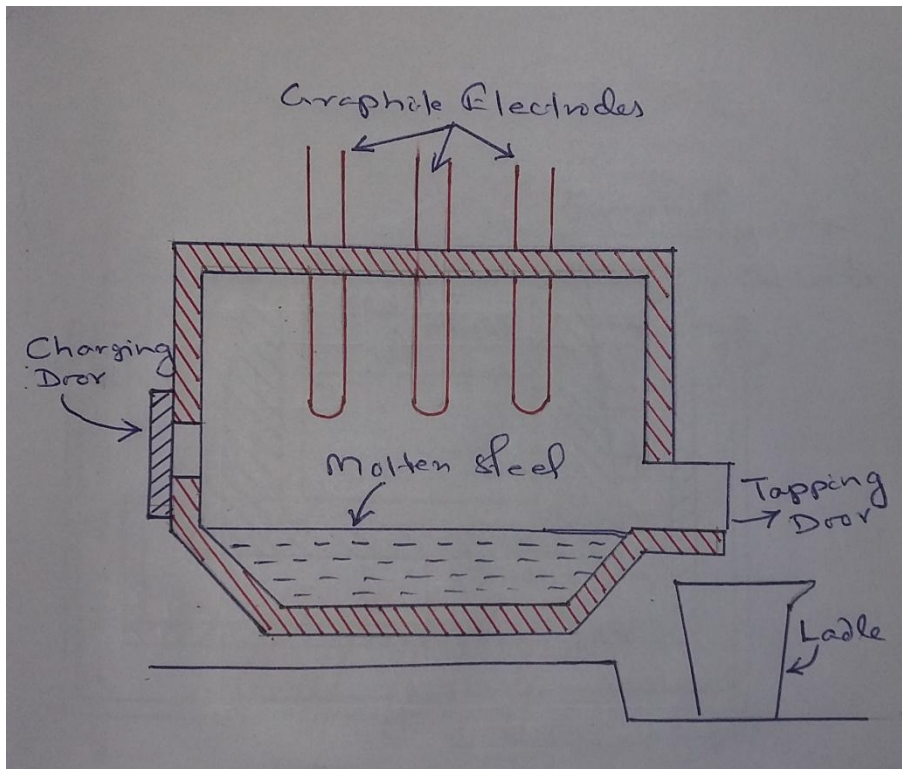
### **INTRODUCTION TO ELECTRICAL FURNACE:**

For the first time in 1878 siemens successfully used electric current for melting iron and for the 1<sup>st</sup> time electric arc melting furnace was installed in 1889 by French metallurgist. After that in subsequent years it has passed through several modification. Originally electric furnace are used for manufacturing of very small amount of high grade tool steels and alloy steels. However in modern integrated steel plant now a days electric arc furnace are used for the production of high quality steels using 100% scrap materials.

For the production of steel mainly two different types of electric furnace are used

1. Direct electric arc furnace
2. High frequency induction furnace

### **Direct Electric Arc Furnace**



### **Construction :**

It consists of a very heavy steel shell lined with refractory bricks. Silica refractory are used for acid lining furnace and magnesite refractory are used for basic lining furnace.

A base lined furnace is advantageous because here inferior grade of scraps may be used for the production of steel. The basic process removes P & S from the melt.

The roof of the arc furnace consists of steel sheets in which silica bricks are fixed in appropriate position. Here materials are charged from the charging door. Slag is taken out from the charging door. Depending upon whether it is 2 or 3 phase line, 2 or 3 pure graphite electrodes are inserted through the holes in the roof into the furnace. Provision is there for rising up and down the electrodes. All arc furnaces are rest in bearing on their two sides. So that furnace can be tilted backward or forward for charging, tapping of slag and metal.

**Operation :** It involves the following steps

**1. Preheating of internal lining :** Here the interior of the furnace i.e refractory lining is preheated before placing the metal charge into the furnace which is done by alternately striking and breaking off the arc between the vertical electrode and the broken parts of the electrode (graphite pieces) kept on the hearth. After preheating the graphite pieces are removed from the hearth .

**2.Charging:** Here the furnace is charged through the charging door. For melting steel the charge is usually steel scraps and depending on the percentage of P & S content an acid or basic lining of furnace is decided . Beside re-melting purpose a direct arc furnace is also used for making steel where charge consists of maximum amount of steel scraps and some pig iron,.

3. After putting cold charge into the furnace electric arc is drawn between the electrodes and the surface of the metal charged by lowering the electrodes down till the current jumps the air gap between the electrode and charge surface.

4. The arc gap between the electrodes and the charge is automatically controlled and maintained desire arc length by maintaining constant voltage. Smaller arc length provides more heat but there is possibility of contamination of molten metal with the graphite electrodes.
5. Three arcs burning simultaneously produces a temperature which is sufficient to melt the scrap metal as well as the flux. After the process is over the arc between the electrodes and the charge is broken by lifting the electrodes.
6. Arc furnace is tilted backwards so as to remove slag from the charging door.
7. The furnace is then tilted forward and the molten metal is poured into the ladle.
8. Hearth, sidewalls and roof of the furnace are repaired with suitable refractories and made ready for the next heat.

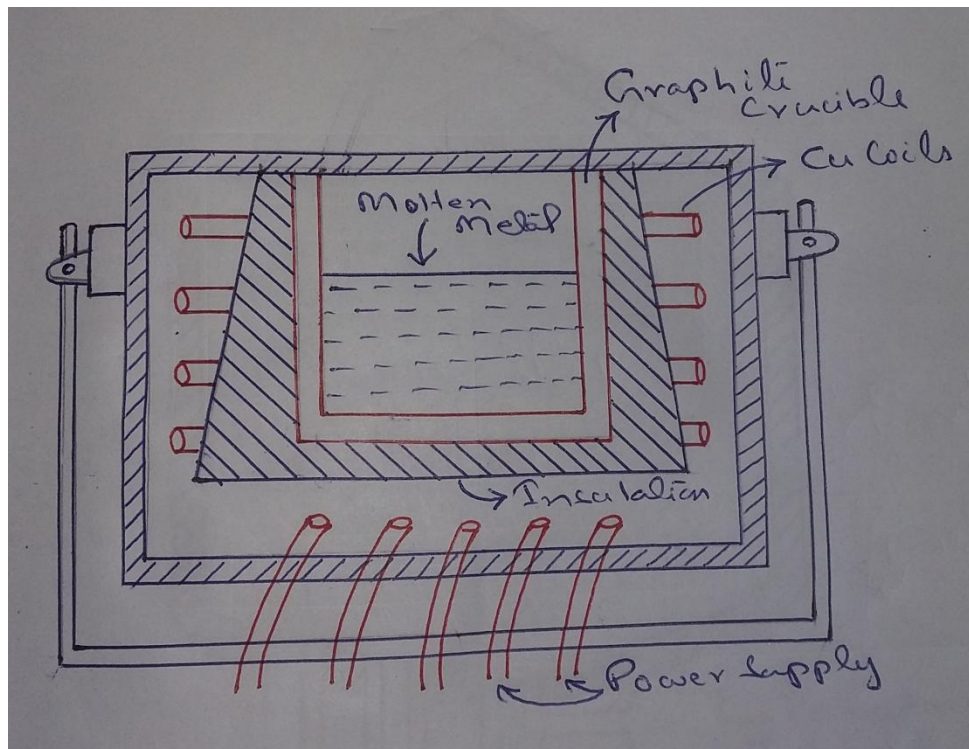
**Advantages :**

1. Analysis of the melt can be kept to an accurate limit.
2. A direct arc has a thermal efficiency about more than 70%.
3. Furnace atmosphere can be easily controlled above the molten metal.
4. Direct arc f/c can be used for steel making directly from the pig iron and steel scrap as compared to only steel scraps in induction furnace.
5. Arc f/c are larger and its components are cheaper.
6. An arc furnace is preferred for steel making because it is a quicker process and has long hearth life & easy to repair.

**Disadvantages :** In spite of above advantages arc furnace has some limitations also. They are

1. Heating cost is higher than other furnaces.
2. Very good quality of graphite electrodes are used in this process which is very costly. So it increases the cost of production.

**Induction Furnace**





**Construction :** A high frequency induction furnace consists of a refractory crucible which is placed at the centre of the water cooled copper coil and packed by ramming dry refractory between the crucible and the copper coil.

A high frequency induction furnace is of two types :

- a) Tilting type
- b) Lift coil type.

**Principle of Operation:**

1. Steel scraps are placed into the furnace as metal charge.
2. A high frequency current is passed through water cooled copper coil which acts as a primary of a transformer and the metal charge becomes the secondary.
3. Heavy alternating secondary current thus induced in the metal charge by electromagnetic induction.
4. As the metal charge offers resistance to the passage of secondary current, the heat developed in the surface of the metal which transmit to the inner surface of the charge by induction and melts the charge.
5. The secondary current associates with magnetic field which provides a magnetic stirring action on the molten metal thus mixes the charge uniformly.
6. Once the charge is melted, it is poured into the ladle either by tilting the furnace or by lifting away the furnace shell along with the induction coil.

**Advantages:**

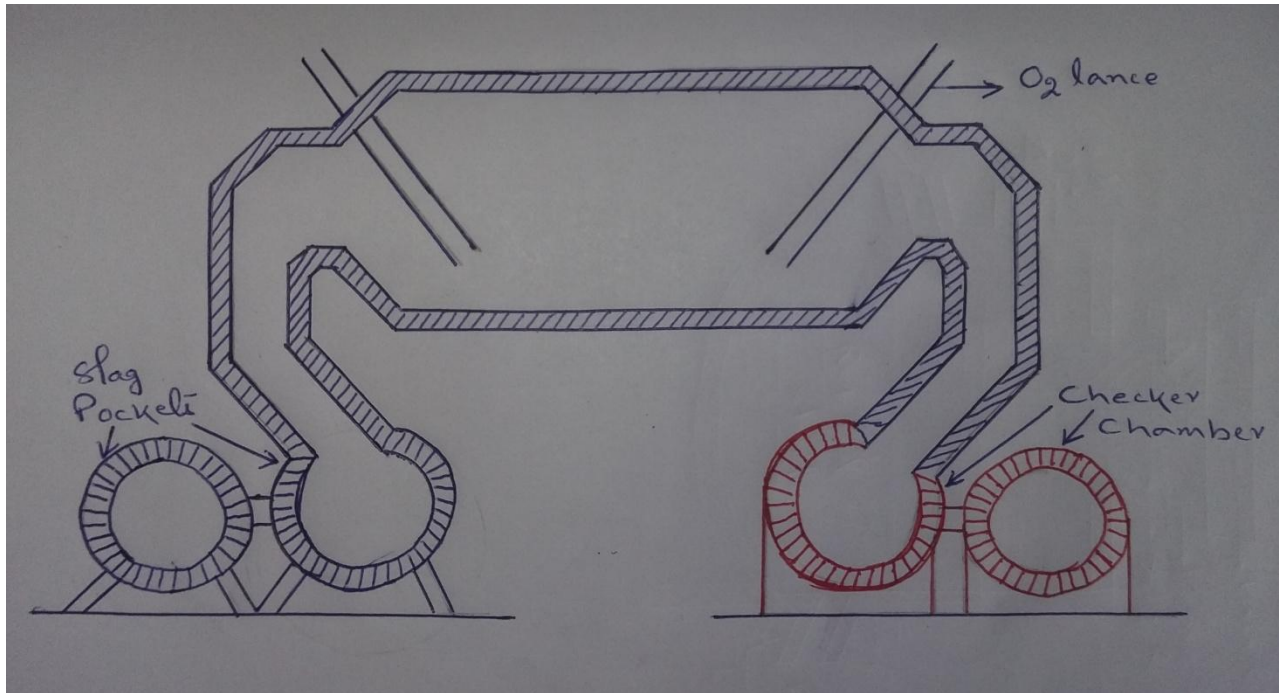
1. An induction furnace can melt small quantities of a wide variety of metal and alloy in a quick and convenient way.
2. Magnetic stirring of the melt produces and accelerates uniformity of metal composition.
3. Rate of energy supply and furnace atmosphere can be easily controlled in an induction furnace.
4. High frequency induction furnaces do not need the preheating of charge material.
5. Alloying elements like Ni, Co, Cr, V, Mo etc can be easily added in between the operations.

**Disadvantages :**

1. The initial cost of the furnace and its auxiliary equipments are quite high.
2. A limited quantity of high quality metal is produced through induction furnace.
3. As it is very fast process, in between the operations analysis of metal is not possible.
4. As analysis in between the operations is not possible, charging materials should be selected as carefully as possible. On the other hand copper coil should be protected properly so as to avoid the oxidation, since at high temperature oxidation of copper is very fast.

## Other Recent Processes of Steel Making

### Ajax Process:-



This process was developed at the Appleby Frondingham steel company of U.K in 1957 and several of these units were installed thereafter at different places. The process is popularly known as Ajax Process and the furnace used for this process is called as Ajax furnace. It is just like a open hearth furnace. The end walls, ports, down takes, slag pockets and checkers are suitably altered keeping the general design of open hearth furnaces in view. The down take, slag pocket & checkers are cylindrical steel shells with appropriate openings for fastening them with each other in proper place. The slag pocket has its axis horizontal and that of the checker as vertical. Another set of slag pocket & checkers are provided on each side so that at any time one is in service while the other is being repaired. The furnace is fired with coke oven gas through a pair of burners. On each side oxygen lancing is done by water cooled lances and are used alternately along with the direction of fuel firing. The lance is has at an angle of  $27^{\circ}$ - $34^{\circ}$  to the surface during blowing and has generally three nozzles. Oxygen is blown at 5-6 atmospheric pressure and at a flow rate of about  $30$ - $35$   $\text{m}^3/\text{minute}$ .

In this process, scrap is charged first in the furnace and is preheated by fuel firing. Combustion of fuel is done by burners provided on sides. After heating of scrap, hot metal is charged and fuel supply is cut off. Then oxygen lancing is immediately stated from one end by lowering the lance inside the furnace. Hot gases of combustion passes through the checkers thereby heating the

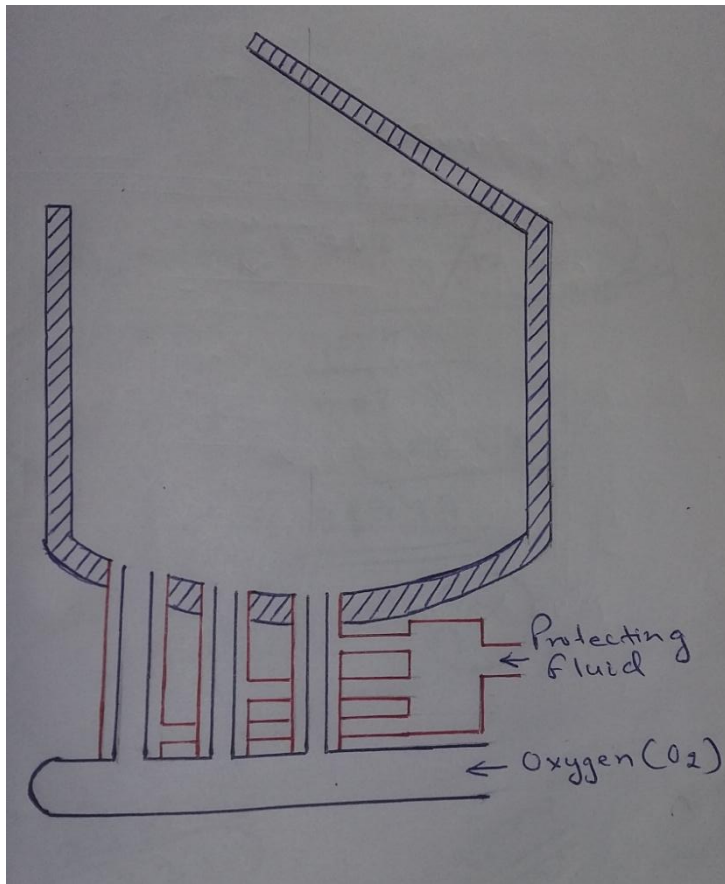
walls. After some times the process reverses and the heated walls of checkers transfer heat to the supplied fuel when flowing to the furnace through it. Oxygen blowing continues till carbon drops to 1% and P to 0.1 -0.15%, then O<sub>2</sub> lancing is cut-off and di-slagging is done. The lime is charged to the furnace and O<sub>2</sub> lance is down till the carbon is reduced to 0.4%. After that O<sub>2</sub> lancing is cut off and deslagging is done. The total process takes 5-6 hours for 200 ton capacity furnace, out of which O<sub>2</sub> lancing takes 3 hours.

The tilting design helps to remove the slag and metal readily. It gave about 70-100% increase in productivity over similar capacity standard tilting open hearth furnace. The draw backs of this process is that Fe content of slag is about 10-20% in this process as compared to 9-10% in open hearth furnace.

## **OBM Process of Steel Making :**

**Principle-** The principle of this process is similar to that of L.D process. Where at high pressure oxygen is blown from the bottom and materials are charged from the top. As a result of bottom blowing of oxygen, simultaneously oxidation of impurities and string of molten metal takes place which helps to bring better slag-metal contact and hence brings the system closer to equilibrium condition.

### **Construction:**



In bottom blowing process tuyers are inserted from the bottom in such a way that oxygen will be surrounded by a protective hydrocarbon gas like propane. The tuyer is therefore made off two concentric tubes.  $O_2$  being blow through the inner tube and the protective fluid through the annular space between the tubes. Generally protective fluids are either saturated hydrocarbons like propane or steam or some fuel oil. On entry of propane at high temp it cracks which itself an endothermic reaction so takes some of the heat generated at the entry of  $O_2$ . The relative feed rate of oxygen and protective fluids are adjusted so as avoided any overheating of the tuyer. Also when propane which is used as protective fluid when cracks gives some free carbon which deposits around the central tube, thus prevents from damage due to over heating. To achieve better slag metal contact the tuyers are arranged only in half the converter bottom. As a result of which oxygen lancing promotes turbulences in the bath and ensures good slag-metal contact. Also by such arrangement of tuyer damage of tuyers during charging is avoided up to a great extend , i.e material can be charged in other half of the vessel where tuyer arrangement is not there .

### **Operation of OBM process:**

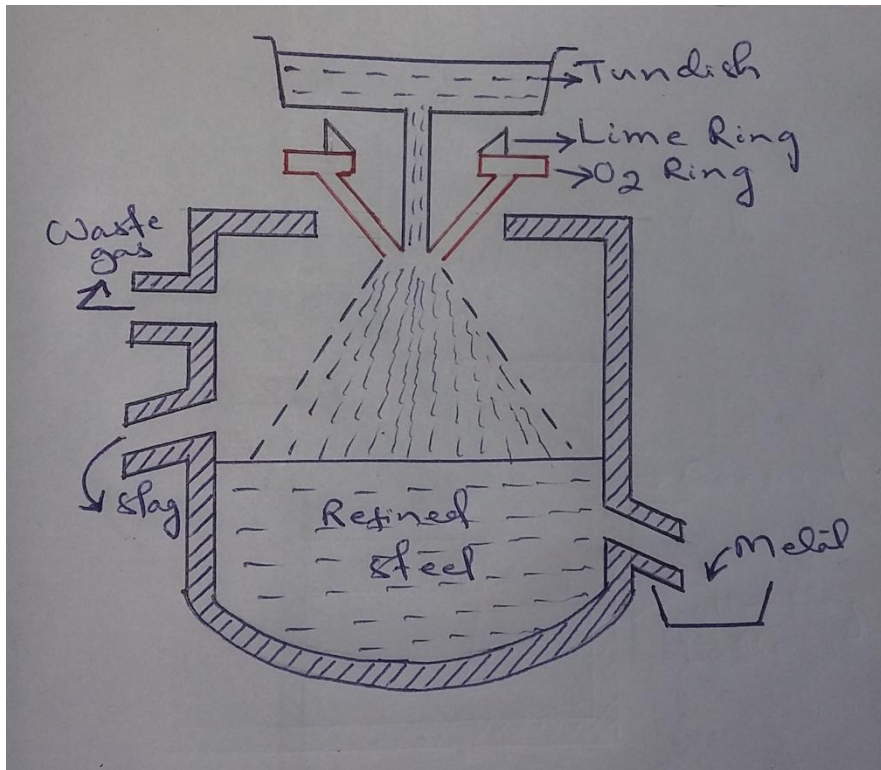
The operation of OBM vessel is more or less similar to the Thomas process of steel making which contains around 1.8% of P. After charging scarp & hot metal into the OBM vessel, blowing is started and lime is added thereafter. The blowing of oxygen here is divided into three parts.

1. O<sub>2</sub> blowing continues for 16-17 minutes & at the end of which high P slag which contains around 18-22% P<sub>2</sub>O<sub>5</sub> and 12-15% FeO is taken out. Taking samples from the OBM vessel it is analyzed to maintain the appropriate compositions of the steel which is going to be produced. The analysis shows 0.08% P & 0.3% C.
2. Here some fresh lime is added & O<sub>2</sub> is blown for further a minute or two. During which carbon comes down to 0.1% & P to 0.025%.
3. In final blowing, in place of O<sub>2</sub> some nitrogen is blown without protective gas which helps in reducing the hydrogen % in the molten metal and finally analysis shows hydrogen upto 0.0004% & nitrogen 0.03 %.

#### **ADVANTAGE OF OBM :**

1. A higher efficiency of O<sub>2</sub> utilisation and the relative lower O<sub>2</sub> consumption.
2. Higher rate of decarburization and ability to refine to a much lower level of carbon content in the metal.
3. With lesser consumption of lime, higher degree of dephosphorisation and Desulphurisation.
4. A good homogeneous bath can be achieved due to turbulence flow and hydrogen percentage can be.

## SPRAY STEEL MAKING PROCESS :-



Spray steel making process was developed by BISRA in UK and put into commercial practice in 1966. The hot metal is feed through a tundish in the form of a vertical falling stream which is surrounded by water cooled ring. O<sub>2</sub> is forced through the holes on the inner side of the ring at such velocity and angle to cause atomization of the falling stream of metal. The oxidation of impurities is almost instantaneous because of tremendous increasing gas-metal contact area. Mixer of lime and ore in powder form is feed into the zone of atomization to form slag. The slag and metal mixture is allowed to settle into 2 layers at the bottom of the spray chamber. The process is well designed from the point of heat and mass transfer involve in refining reactions. In spite of the problem of wire of refractory nozzle, the process is satisfactorily running at 3 different commercial plants in UK. But the only drawback is the iron loss in slag is very high.

## Secondary Steel Making Processes

**Vacuum Oxygen Decarburizing Process (VOD) :-** Steel Practically always contains a certain quantity of carbon. During vacuum treatment the equilibrium of the reaction  $(2C+O_2 \rightleftharpoons 2CO)$  shifts to right, so CO will form. In cases when O<sub>2</sub> is present in the metal in the form of non-metallic oxide inclusion, a pressure reduction leads to partial or complete decomposition of these inclusions due to their reaction with carbon. Less stronger oxide inclusions such as MnO<sub>2</sub> or Cr<sub>2</sub>O<sub>3</sub> are reduced in Vacuum completely



Whereas the stronger inclusions such as  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$  can only be reduced in very high vacuum. Vacuum treatment of metal can produce following effects.

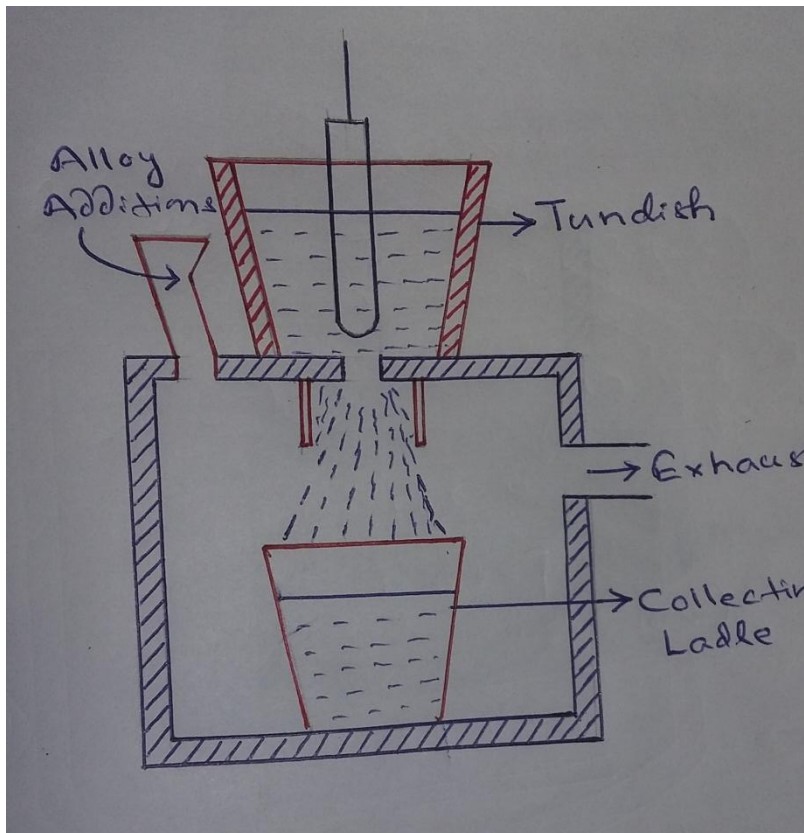
1. Decreases the concentration of dissolved  $\text{O}_2$
2. Decrease the concentration of dissolved  $\text{N}_2$  and  $\text{H}_2$  of the metal.
3. Decreases the contents of non-metallic oxide inclusions
4. Due to evolution of large quantity of gas bubbles, metal is agitated vigorously and its composition becomes more homogeneous.

The VOD system essentially consists of a Vacuum tank, a ladle furnace with or without Ar stirring, a lid with oxygen lancing facilities etc.. The metal level in the ladle should be 1-1.5m below the ladle top, so that the agitation of bath can possible during  $\text{O}_2$  lancing. The charge is melted in an arc furnace and the molten metal with around 0.7-0.8% carbon is transferred to the VOD system. Oxygen lancing and perhaps argon bubbling from the ladle bottom are commenced when required Vacuum is established. Argon stirring is necessary otherwise decarburization is delayed due to lack of mass transport of carbon from bottom portion to the surface where carbon and oxygen reaction is feasible. The carbon is lowered to around 0.03%. At the end of the refining the vacuum is broken.

### **AOD Process :- ( Argon Oxygen Decarburisation Process )**

This is carried out in a special AOD converter which is a solid bottom vessel with tuyers provided on the sides. The tuyers are few in number depending upon the capacity. The vessel is lined with basic magnesite refractory. Molten charge from arc f/c is transferred to this vessel & blowing is started with Ar- $\text{O}_2$  mixture, the proportion of which varies from 1:3 in the beginning through 1 or 2 descript stages to 3:1 for the final part of the blow. The temp. of the bath rises at the end of the 1<sup>st</sup> stages to nearly  $1710^\circ\text{C}$  & coolant like steel scrap, ferro-chrome etc. are added in predetermine proportion to finally arrive at correct turn down temp. The heat is finished by de-oxidation with Fe-Si addition. It also reduces back the chromium from the slag. So the Cr recovery is therefore 97%. A measure change in blowing practice is the substitution of Ar by  $\text{N}_2$  in the 1<sup>st</sup> stage. Many stainless steel have high  $\text{N}_2$  specification & hence  $\text{N}_2$  substitution of Ar can be done in letter stages also. The total duration of an AOD heat is around 2hrs & the lining life is around 80 heats.

### **Stream Degassing :-**



In this process molten steel is exposed to vacuum in the form of stream of metal flowing from one vessel to another. Sudden exposure to vacuum result in such a rapid rate of degassing that the stream explodes into droplets. Steel is poured from a teeming ladle or tundish & is received in a ladle or mould kept inside a vacuum chamber. If the metal is received in a mould it solidifies under vacuum & the resulting ingot has the lowest gas content. If the metal is received in a ladle, it is teemed in a normal way. The major amount of degassing takes place during the fall of metal drops & as such the height of the pouring vessel from the receiving vessel will be an important parameter. A small amount of degassing takes place after the metal is received in the ladle.

The following processes are used in commercial practice:-

- i. Ladle to mould degassing.
- ii. Ladle to ladle degassing.
- iii. Tap degassing.
- iv. Therm-I-vac process.

The vacuum chamber should be big enough to accommodate the ladle or mould. The top cover of the vacuum chamber should be adequately away from the metal level in the inside ladle so as not to get heated by the radiation. The entrance in the top cover of the chamber through which steel stream enters the chamber is sealed by an Al disc. As the metal stream explodes on entering the vacuum chamber the metal drops tends to spread out considerable & may fall outside the ladle or mould. So a stream director is used which is just like a refractory tube to protect the stream. The chamber is evacuated by connecting it to the pumps. Inlet valve is provided for the introduction of air into the chamber, to raise the chamber pressure to atmospheric level after the



process is over. The tundish that is used to pour steel is provided with a nozzle in the bottom & a stopper rod assembly. It is placed above the vacuum chamber so that the nozzle is just above the entrance in the chamber cover, so that steel can easily flow into the chamber. The rate of pouring can be controlled by the stopper rod assembly provided for the purpose. Once the stopper rod is raised metal flows down, the Al seal is melted and metal enters the vacuum chamber. Suitable alloy additions can be made if the metal is received in a ladle.

### **OLP Process :- ( Oxygen Lime Process)**

This is a modification of LD process which is developed to successfully refine the pig iron containing more than 1.5% P. To remove P during O<sub>2</sub> lancing some amount of lime powder is blown with O<sub>2</sub> in this process. The vessel design is more or less similar to LD process. However lance design is different to allow supply of lime powder along O<sub>2</sub> because it is solid-gas lancing process. The lime powder will move fastly along with the O<sub>2</sub> jet & strikes the molten bath. 80% removal of 'P' occurs during the soft blowing due to the formation of emulsion phase because the removal of 'P' is due to the reaction of slag-metal & gas which is only possible by the formation of emulsion phase. But that emulsion phase will collapse when carbon content of bath will reach 0.3%. So this emulsion phase retains for a short duration of time & reaction of lime with that of P<sub>2</sub>O<sub>5</sub> will be a limited one. But in this case the rate of 'P' removal is faster because powder lime is moving along with the oxygen jet & mixing fastly with the slag. So by this process pig iron containing higher 'P' can be refined to produce a steel containing very low 'P'.

#### **ADVANTAGES :**

- Rate of production is high.
- It deals with poor grade of pig iron, containing high 'P'.
- Powder lime can be used efficiency along with the O<sub>2</sub> lancing.

#### **JET FORCE NUMBER**

Jet force number (JFN) = (Gas pressure × Nozzle throat dia.) / Height of the nozzle

JFN indicates the depth of penetration of jet in the bath.

### **Combined Blowing Process :-**

Instead of vigorous stirring by the O<sub>2</sub> jet as well as the CO bubble in the bath, we couldn't get the proper mixing of O<sub>2</sub> with the bath & with the impurities. So the removal of impurities is limited up to a certain limit. We can get better result if a small amount Ar or N<sub>2</sub> is bubbled from the bottom of the f/c into the bath. The process was successfully done in OBM vessel where O<sub>2</sub> along with the shielding gas are blown from the bottom of the converter. But by this the amount of FeO in the slag is increased to a larger value. Therefore to achieve the best of the top & bottom blown process, several process are developed & are commonly called as the combined blowing process.

Combined blowing process means a process where in a fluid medium, whether it is O<sub>2</sub> alone or O<sub>2</sub> and an inert gas like Ar or N<sub>2</sub> are blown simultaneously from top & bottom to achieve relatively a better agitated bath than in common with top blowing alone and result in a lower % of iron oxide than the bottom blowing process. This process has been developed in last few years at a number of places. Although initially it is carried out on pilot plant, full scale operation were carried out on existing LD, OLP, OBM vessels etc. after modifying them suitably. All those processes in which refining is carried out by introducing O<sub>2</sub> both from top & bottom, the bottom O<sub>2</sub> being protected by peripheral neutral or hydrocarboin gas. For introducing O<sub>2</sub> from both top & bottom, the original LD vessels are modifies to fix up tuyer at the bottom of the vessels. Alternatively a top lance was provided in the existing OBM vessels. The proportion of O<sub>2</sub> blown from top & bottom varied from process to process. But the advantages of bottom blowing process remains constant even if a small amount of oxygen is blown from the bottom. Attempts have been made to increase the scrap proportion in the charge without losing any other advantages of the combined blowing process. Similarly lime powder, with or without additional flux was introduced along with the top & bottom blown O<sub>2</sub> to decrease the 'P' content in the bath.

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