

LECTURE NOTES
ON
FERROUS METALLURGY (STEEL PRODUCTION)

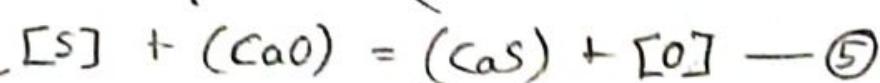
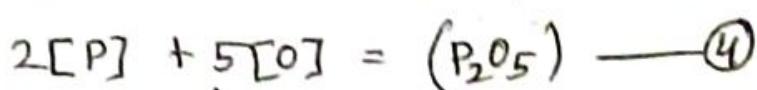
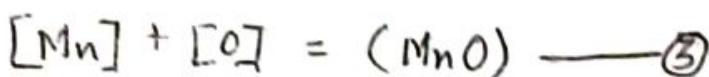
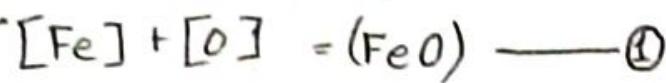
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General Principles of Steel Making :-

- Since steel making is an oxidation or refining process it requires oxidising conditions for the elimination of the impurities. (Sulphur being the exception which requires reducing condition)
- Sulphur can be oxidized by the gaseous oxygen but its rate of removal is so small that it can't be considered.
- Therefore steel making is a refining or oxidation process as it requires a source of oxidizing agent, which may be air, pure oxygen, iron ore, mill scale etc.
- If the bath is oxidised by an iron ore the metallic charge will be lower and it greater if it is oxidized by oxygen.
- Since in the former case i.e. when the pig iron is oxidized by iron ore, is partially reduced to iron thus increases the yield of steel.
- The chemistry of the process of removal of impurities is given below.



gas-metal reaction

(1)

- All the reactions except reaction ⑤ are favored under oxidising condition of steel making.
- In reaction ⑥ the reaction product of $[C] + [O] = \{CO\}$ being a gas will pass off into the atmosphere but rest of the oxide products will remain in contact with the iron melt and form a slag phase.
- So In Indian condition,

Pig Iron (av. composition)

2	In the form of	Present Removed as
Fe - 92%		
C - 3.5-4.0% $[C]$ or $[Fe_3C]$	$\{CO\}$ or $\{CO_2\}$	
Si - 1.2-1.5% $[Si]$ or $[FeSi]$	(SiO_2)	
Mn - 1% $[Mn]$ or $[FeMn]$	(MnO)	
P - 0.2-0.3% $[P]$ or $[Fe_3P]$	(P_2O_5)	
S - 0.4-0.5 $[S]$ or $[FeS]$	(CaS) , $\{SO_2\}$, (MnS)	

Raw Material For Steel Making :-

The chief raw materials for steel making,

- Sources of metallic iron
- Oxidising agents (oxidants)
- Fluxes
- Sources of heat
- Deoxidisers and alloying additions
- Furnace refractories

Sources of Metallic Iron :-

- The metallic charge for making steel may contain,
 1. Pig Iron (Molten or solid)

2. Steel scrap (or pig iron)

3. sponge iron

- Pig iron and steel scrap constitute the main mass of metallic charge.
- The quantity of metallic charge is on the average of 1130 - 1140 kg per ton of steel produced.
- The use of metallic charge is lower ~~in~~ cases when impurities are mainly oxidised by iron ore and greater when this is done by oxygen.
- In the former case, iron ore is partially reduced to iron and thus increases the yield of steel.
- At present time, the metallic charge of steel making plant consists on the average of 55-56% pig iron and 44-45% steel scrap.

1. Pig Iron:-

- The composition of pig iron produced in an integrated steel plant is always adjusted to suit the steel making process.
- In other words, the choice of the steel making process is made in relation to the quality of iron that would be produced.
- If the iron contains < 0.05% phosphorous then acid steel making process could be adopted. Such a iron is known as acid or hematite or Swedish iron.
- This type of iron can be produced at some exceptional places. By and large, the iron produced all over the world contains phosphorous more than 0.05% and generally 0.2-0.4%.
- Iron containing more than 0.05% P is called basic iron and basic steel making process is adopted.

- A special category of basic iron but contains more than 1.5% P is known Thomas iron and special basic steel making process is adopted.
- At steel making works having no own blast furnace, Pig iron for charging the steel plants is employed in solid state, where both blast furnace and steel making plant are in operation.
- Pig iron is usually transferred molten to the steel making shop.

2. Steel Scrap:-

- After pig iron scrap is another main component of the metallic charge.
 - In any industrially developed country, an appreciable quantity of iron containing scrap is accumulated each year.
 - The collecting and processing of this scrap is an important problem for national economy.
 - In the total quantity about 30 to 45% of scrap is from directly at iron and steel work. This is called home scrap or home returns, which must be recycled.
 - On the whole it can be said that 50% of each hot metal and steel scrap go to the steel making furnace to produce total ingot.
 - The proportion of steel scrap in the charge varies from process to process as shown below.
1. Conventional process
- Bessemer process - upto 8%
 - " with modification - upto 12%

- Open hearth process - upto 75%
- Electric process - upto 100%

- 2. Oxygen steel making process
 - LD process - upto 25%
 - " with modification - upto 45%.
 - Kaldo process - upto 45%
 - Rotor process - upto 45%

- 3. Sponge Iron (DRI) :- Direct Reduced iron

- In addition to pig iron and scrap, the charge for making steels can also contain products of direct reduction of iron or so called metallized material.
- According to their applications the sponge iron can be divided into three categories.

 1. With iron content of 70-85%. (These products are used in blast furnace charge)
 2. Those containing 90-98% iron (they are used for steel making)
 3. With around 99% iron, they are employed for making iron powder.

- The materials to be used in steel making should satisfy the following requirements.

Metallization degree $> 90\%$

Iron content $> 90\%$

Oxygen content (as FeO) $< 2\%$

Sulphur Content $< 0.01\%$

Phosphorus content $< 0.045\%$

Graunge $\leq 4\%$

- The use of sponge iron over pig iron and scrap has the following advantage.
 - Metallized products are free from impurities, typical of common scrap. This makes them suitable to produce clean steels.
 - Sponge iron contains a certain quantity of carbon (1-2.5%). This requirement should be considered when using these material for making low carbon steels.
 - Metallized products are porous and oxidised easily.

✓ 4. Oxidising agents or Oxidants:-

- Oxidants are added to the bath in order to faster the oxidation of carbon and other impurities.
- They are used either in the solid state such as iron ore, sinter, pellets or in the gaseous state such as air, oxygen etc.
- Solid oxidants have a high concentration of iron oxide and least content of silica of silica (SiO_2). (a high concentration of silica in the ore can lower the slag basicity, which will required a larger addition of lime at thus increases the bulk of slag)
- Besides lumps of the solid oxidant should have a high density.
- Dusty ore can partially carried off by exhaust gases.
- Gaseous oxidant should be clean and should be as low in nitrogen as possible.

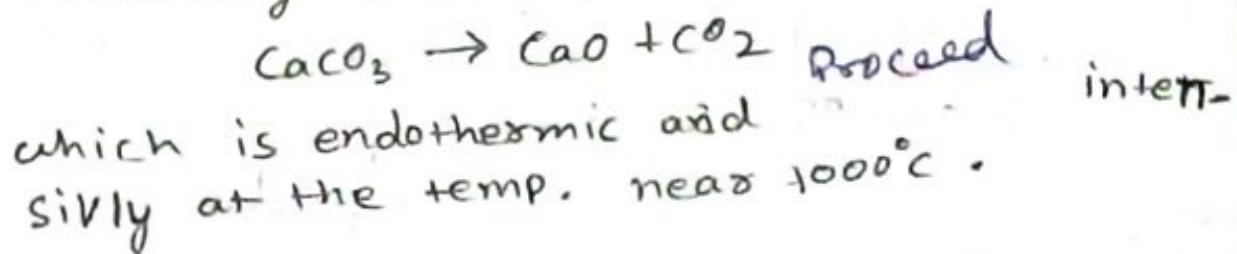
- Only oxygen with less carbon gives proper condition for making steel free from nitrogen.

5. Flux:-

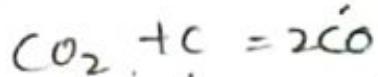
- A flux is a substance which is added during smelting and refining to bring down the softening temp. of the gangue material and reduce the viscosity of slag.
- The following are the fluxes used in steel making furnace.

Limestone:

- The main constituent of limestone is CaCO_3 , on heating it decomposes by the reaction,



- The CO_2 formed by the reaction reacts with the carbon of the melt.



- In this case limestone serve as an oxidant. A good quality limestone contains,

$\text{CaO} - 52-56\%$.

$\text{SiO}_2 - 0.6 - 1.0\%$.

$\text{S} - 0.005 - 0.010\%$.

$\text{P} - 0.008 - 0.015\%$.

Lime:

- Lime is obtained by burning limestone in lime burning kilns.

- Fresh burned lime should contain not less than 90% CaO and less than 3% SiO₂ and should preferably low in Sulphur.

Bauxite:

- It is employed in steel making as a flux which can lower the melting point of basic slags and increase fluidity, which can faster slag formation.
- The use of bauxite with more than 10% SiO₂ should be avoided.

Fluorspar: (CaF₂)

- It is applied in steel making as a mineral to faster the dissolution of lime in basic slags and increases slag fluidity.
- The main constituent of fluorspar is CaF₂ (90-95%) and it usually contains less than 5% SiO₂.

Sources of Heat:-

- Pneumatic Process like Bessemer and BOF's are autogenous since enough heat is generated during refining by the exothermic oxidation of impurities.
- These process need hot metal, as a charge to run the process.

The amount of heat generated is always more than necessary so that the scrap or iron ore is required to keep the bath temp. within required limits.

- These processes can not be run with cold charges alone.
- But, heating process like OHP and electric arc provide a source of heat to melt solid charges to maintain steel making temp. inside the furnace. These take upto 100% cold charges.
- The sources of heat are,
chemical Heat - • Solid - pulverised coal
• Liquid - Oils, tar, etc.
• Gas - producer gas, water gas, coke oven gas, natural and blast furnace gas.
- For economic reasons, the chemical fuels, should be burnt with excess air and thus the furnace atmosphere would always be oxidising.

- Electrical Heat -
- Induction heating
 - Resistance heating
 - Arc heating

Deoxidizers and Alloying Addition:-

- Elements like Al, Si, Mn etc are added primarily as common deoxidizers.
- Elements like Zr, B, Ti, etc are added for deoxidation in special cases and elements like Cr, W, Mo, Ni, V, Nb etc are added generally as alloying addition.

Silicon:

- It is used as a primary deoxidising agent in a furnace.
- It is also used as a common deoxidizer in the furnace or in the ladle when killed or semikilled steel made.
- This is a very effective common deoxidizer and used in the form of ferro-silicon (FeSi).
- Silicon is also added as an alloying element for better strength, hardenability and electrical properties.
- Typical use is for making transformer grade steels.

Manganese:

- It is a weaker deoxidizer than silicon.
- As an alloying element it gives strength and toughness.
- It is added as ferro-manganese of various grades.
- Typical use is for making hardfield and structural steel.

Aluminium:

- It is a very effective deoxidizer and used in the form of bar, rods, pellets, wires, powder etc.
- It is an alloying addition in heat resistant Steels.

Nickel:

- It is added as an alloying addition in stainless steel.

Chromium:

- It is used as an alloying addition for stainless and heat resistant steels
- It is used in the form of ferro-chrome of various grades.
- It increases hardness, strength, yield point and elasticity of steels.

Titanium:

- It is a strong deoxidizer and neutralises the effects of nitrogen on steel.
- Titanium steels are useful for aircraft industry for its ~~lightest~~ coupled with strength.

Vanadium:

- It is a strong deoxidizer.
- It increases the strength, plasticity and impact resistance.

Tungsten:

- It is a strong deoxidizer.
- As an alloying addition, it increases hardness, strength and elasticity of the steel.
- It is used in tool steels, high speed steels, cemented carbide alloys etc.
- It is added as ferro-tungsten.

Molybdenum:

- It is only as alloying addition to improve the mechanical properties.

Zirconium:

- It is used as a deoxidizer.

- It decrease the deleterious effects of nitrogen and sulphur in steel.

Boron:

- It is used as a deoxidizer.
- As an alloying element, it enhances mechanical properties and hardenability of steel.

Niobium:

- It is used as an alloying addition to Stainless Steels and heat resisting Steels to enhance their plasticity and corrosion resistance.

Cobalt:

- It is used as an alloying addition for magnetic steels.

Carbon:

- Coke, graphite and anthracites are used as decarburisers.

Furnace Refractory:-

- Steel making furnace is lined by suitable refractory materials.
- The lining is corroded during steel making and hence the refractory to be used should have high refractoriness, thermal stability, resistance to action of slag and melting dust, high mechanical strength at high temp.

- The lining is made either by laying bricks or by shaping the required contour using a refractory mix.
- The materials used for lining of acid furnaces and acid roof of basic furnaces are essentially silica bricks.
- For basic furnaces magnesite, dolomite bricks are used.

Consumption of Refractories:-

- It ^{is} around 30kg per ton of steel.
- The consumption of refractory can be decreased by the following measures.
 - Using refractories of better quality.
 - Collecting and reusing refractory wastages left from furnace repairs.
 - Running the heat properly.
 - Replacing fully or partially the corroded refractories.
 - Repairing the working layer of refractory lining periodically.
- Refractory are classified into three groups by their refractoriness.

<u>Refractory</u>	<u>Refractoriness</u>
Common refractory	upto 1580 - 1700°C
High refractory	1700 - 2000°C
Highest refractory	Above 2000°C

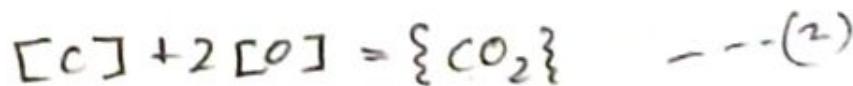
General Principle of Steel Making :-

Carbon Reaction :-

- Pig iron is the main component of the charge for steel making.
- It contains roughly 4% carbon, which is the single largest impurity in pig iron to be eliminated during refining.
- Steel contains much less carbon. For which reason steel making process almost involves the reaction of carbon oxidation, which is called the main reaction of the process.
- During oxidation of carbon (burning off) the metal is said to be boil which is due to the evolution of bubbles of carbon monoxide.
- This bath boiling results in agitation of the metal, equalisation of its composition & temp. and increases the reactions at the slag metal interface.
- Bath boiling also help for the removal of gases, and non-metallic inclusions from the metal.
- Carbon that is dissolved in iron is designated as $[C]$. This dissolved carbon is oxidised by oxygen to form CO . The rxn being,



- But at lower concentration of carbon, the following reaction take place.

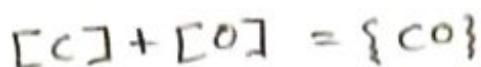


- The reaction ① is called the main reaction of the carbon oxidation.

$K = \text{Equilibrium constant}$

$$= \frac{a_{\text{products}}}{a_{\text{Reactants}}}$$

Equilibrium constant of Reaction ①



$$K_1 = \frac{a_{\{CO\}}}{a_C \cdot a_O} = \frac{P_{\{CO\}}}{a_C \cdot a_O}$$

- Since activity of a gas phase is considered as its partial pressure.

If $P_{CO} = 1$

$$\text{then, } K_1 = \frac{1}{a_C \cdot a_O}$$

$$= \frac{1}{[C] \cdot [O]}$$

$$\text{or, } [C] \cdot [O] = \frac{1}{K_1}$$

- From the above correlation between carbon and oxygen, concentration of oxygen in the bath can be determined by the concentration of carbon that is dissolved in iron.
- During bath boiling the reaction $[C] + [O] = \{CO\}$ proceeds intensively.
- since the rate of the carbon oxidation $(\frac{dc}{dt})$ increases with an increase in bath temp. The temp. rise during bath boil decreases the oxygen content in the metal and the following reaction tends to occur.



- Therefore at a higher temp. there will be higher value of $\frac{dc}{dt}$:

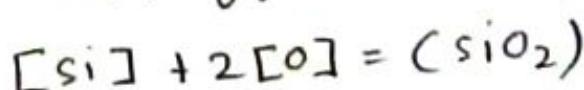
- But when there is no bath boiling, the oxygen from the gaseous phase enters into the metal bath and increases its content in the metal and increases FeO content in the slag.
- If such a situation created for a long time, i.e. when there is no bath boiling, all the iron melt will be oxidised and pass to the slag.

Silicon Reaction :-

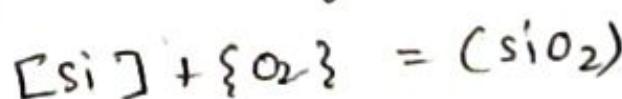
- Silicon can be melted with the iron in any proportion and when dissolved in iron liberates a noticeable quantity of heat.
- Silicon dissolved in iron is designated as $[Si]$.

- Silicon is an element which is oxidised easily.
- The oxidation of dissolved silicon can occur due to its interaction with,

- a) Dissolved oxygen in the metal



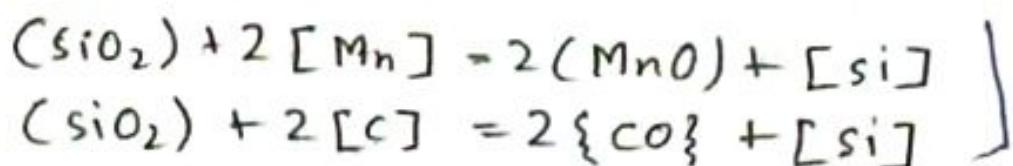
- ① Oxygen in the gaseous phase



- ② Iron oxides in the slag.



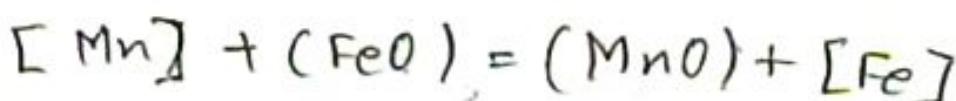
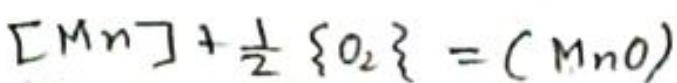
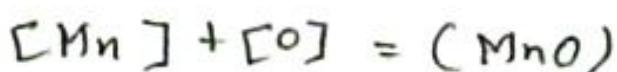
- All the reactions occur with evolution of much heat and oxidation of silica can occur in the presence of an oxidant, in the whole range of steel making temp..
- In basic steel making, the reaction of silicon oxidation occurs practically to the end.
- If there is no intensive supply of oxidant to a melt under an acid slag, the slag is saturated with silica and can occur the following reaction.



- These reaction occurs with absorption of heat.

Manganese Reaction:-

- Manganese is soluble in iron in any proportion.
- It forms ideal solutions in iron.
- It is oxidised readily, especially at relatively low temp. and can form the following oxides like, MnO_2 , Mn_2O_3 , Mn_3O_4 & MnO .
- Among these Oxides only MnO is stable at steel making temp. The reaction being,



- a) All the reaction of manganese oxidation occurs with heat evolution.
- b) The reduction of manganese from slag becomes possible at a rise of temp.
- Under favourable conditions, manganese of the slag can be reduced by iron, carbon or silicon.
- ~~Palverized coal is added to facilitate volatilization at 500°C to remove almost all MnO.~~
- Considering reaction ③



The equilibrium constant of the reaction,

$$K = \frac{a_{(\text{MnO})} \cdot a_{[\text{Fe}]}}{a_{(\text{FeO})} \cdot a_{[\text{Mn}]}}$$

$$K = \frac{a_{(\text{MnO})} \cdot 1}{a_{(\text{FeO})} \cdot a_{[\text{Mn}]}} \quad [\because [\text{Fe}] = 1]$$

Simplifying, the equilibrium quotient,

$$k' = \frac{\gamma_{(\text{MnO})}}{\gamma_{(\text{FeO})} \cdot [\gamma_{\text{Mn}}]}$$

- Which means that the content of Mn at a given temperature is determined by the ratio of the activity of MnO and FeO in the slag.

Sulphur Reaction:-

Sources of 'S':-

- The main source of sulphur is the charge, especially its pig iron.
- A certain amount of Sulphur may be present in the steel scrap.
- Some source of sulphur from the fuel. (If the furnace is fired by high sulphurous fuel like oil and cokeoven gas, which is produced from high sulphur fuel / coal)

Desulphurising Elements:-

- All elements whose reaction with sulphur have lower value of ΔG° ; then the reaction of iron & sulphur can serve as desulphurising elements.
 - These elements are Mg, Mn, Ce, Ca, Na etc.
- Na - in the form of soda
- Mg - in the free form or alloy form

Mn - Alloy form

Ca - As CaO or CaCO_3 form
mind that

- It should be kept in mind that Mn and Ca can interact with dissolved impurities of the steel with liberation of much heat, for that reason safety precautions can be taken before adding desulphurising elements.

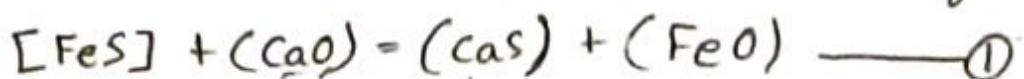
- There are two types of desulphurisation,

1. Furnace Desulphurisation
2. Laddle Desulphurisation

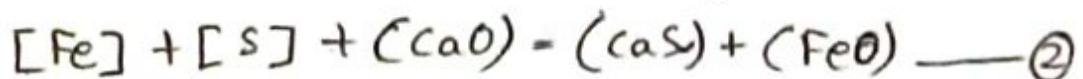
1. Furnace Desulphurisation:

- Lime or limestone is the most cheap and available desulphuriser.
- The interaction between CaO dissolved in the slag and sulphur dissolved in the metal, may be written in the following form.

* Transfer of sulphur from metal to slag.



* Interaction on the metal-slag interface



- Now equilibrium constant equation ①

$$K = \frac{a_{(\text{CaS})} \cdot a_{(\text{FeO})}}{a_{[\text{FeS}]} \cdot a_{(\text{CaO})}}$$

$$\Rightarrow a_{[\text{FeS}]} = \frac{a_{(\text{CaS})} \cdot a_{(\text{FeO})}}{K \cdot a_{(\text{CaO})}}$$

- The higher the activity CaO and the lower the activity FeO and sulphur in the slag, the less sulphur will remain in the metal.

- Equilibrium quotient

$$\text{or } K_1 = \frac{(\%) \cdot (\%) \text{ FeO}}{[\% \text{ S}] \cdot [\% \text{ CaO}]}$$

$$\frac{(\gamma_s)}{[\gamma_s]} = \frac{k' (\% CaO)}{(\% FeO)}$$

- Where, $\frac{(\gamma_s)}{[\gamma_s]}$ is called Desulphurisation index (γ_s) or Sulphur distribution co-efficient, which is

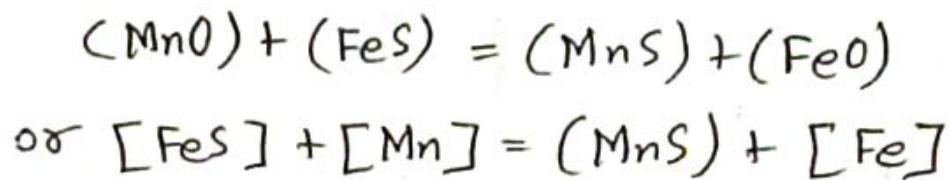
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$$\frac{(S)}{[S]} \propto (\% CaO)$$

Dissolved sulphur removal: - $\frac{1}{(\% FeO)}$

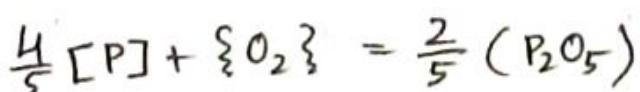
- Thus the principal conditions essential for successful desulphurisation are,
 - ✓ 1. High activity of CaO in the slag.
 - ✓ 2. Low activity of FeO in the slag.
 - 3. Low activity of oxygen in metal (i.e must be deoxidise properly)
 - 4. Low activity of sulphur in the slag.
 - ✓ 5. High temp.
 - 6. Large surface of contact between metal and slag.
- In practical these condition can be provided by the following techniques,
 1. Addition of lime or limestone.
 2. Addition of substances such as Al_2O_3 , CaF_2 , MnO etc. which lower the slag viscosity.
 3. Renewal of slag.

- ④ Desulphurisation is carried out during heats, when the metal is at the highest temp.
- ⑤ Treatment of the metal with liquid or solid synthetic slag with high CaO or low FeO.
- Manganese plays a special part in neutralising the harmful effect of Sulphur -
 - It removes sulphur as per the following reaction,

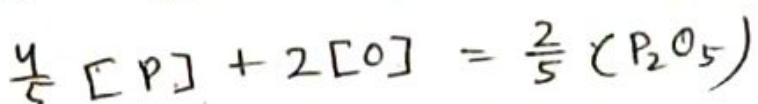


Phosphorus Reaction :-

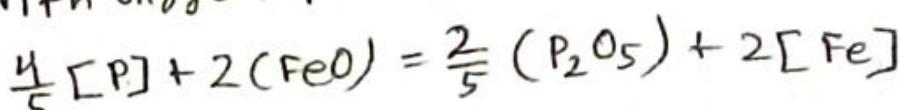
- Phosphorus can be dissolved in iron in any proportion.
- Dissolution of phosphorus proceed with evolution of certain quantity of heat.
- Oxidation of dissolved phosphorus in the metal can occur due to its interaction;
 - With oxygen of the gaseous phase -



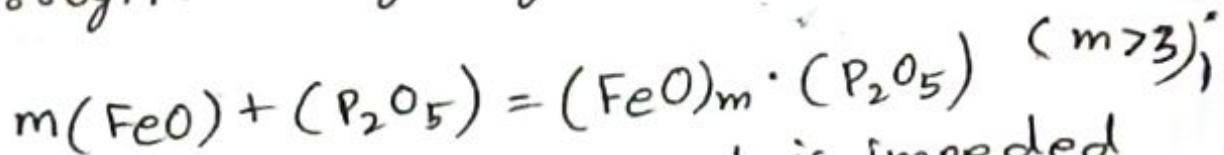
- With oxygen dissolved in metal



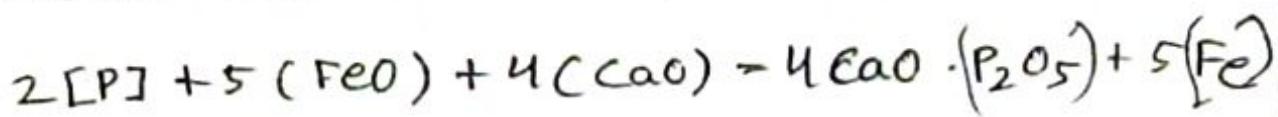
- With oxygen produced in iron oxides of the slag

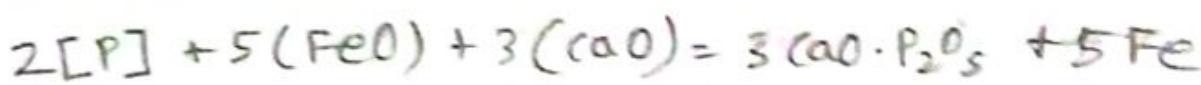


- In all cases the oxidation of dissolved 'P' is associated with heat evolution.
- Especially much heat is liberated when it is oxidised by gaseous oxygen.
- With increase in the temp, favorable conditions may appear for the reduction of the phosphorus.
- At relatively low temp. a certain quantity of 'P' can be removed with strongly ferroginous slags by the following reaction.



- The process of P removal is impeded when the metal has an elevated concn. - tration of easily oxidisable impurity such as Si, Mn, C etc, since they can interact with iron oxide and thus diminish the oxygen content of the slag.
- In order to remove 'P' from the metal and retain it in the slag, the activity of P_2O_5 in the slag must be decreased.
- This can be achieved by forming a basic slag by adding lime or limestone.
- The interaction between the metal and a slag containing Fe and calcium oxides involve the reaction,





- The equilibrium constant,

$$K = \frac{\alpha^a (3\text{CaO} \cdot \text{P}_2\text{O}_5)}{\alpha^2 [\text{P}] \cdot \alpha^5 (\text{FeO}) \cdot \alpha^3 (\text{CaO})}$$

$$= \frac{(\gamma \cdot \text{P}_2\text{O}_5)}{[\gamma \cdot \text{P}]} \quad \text{or} \quad \frac{(\text{P})}{[\text{P}]}$$

- The above ratio is known as dephosphorising index (D_p), which has a higher value for higher basicity, and higher oxidising power of the slag.

Different Between acid and Basic Process :-

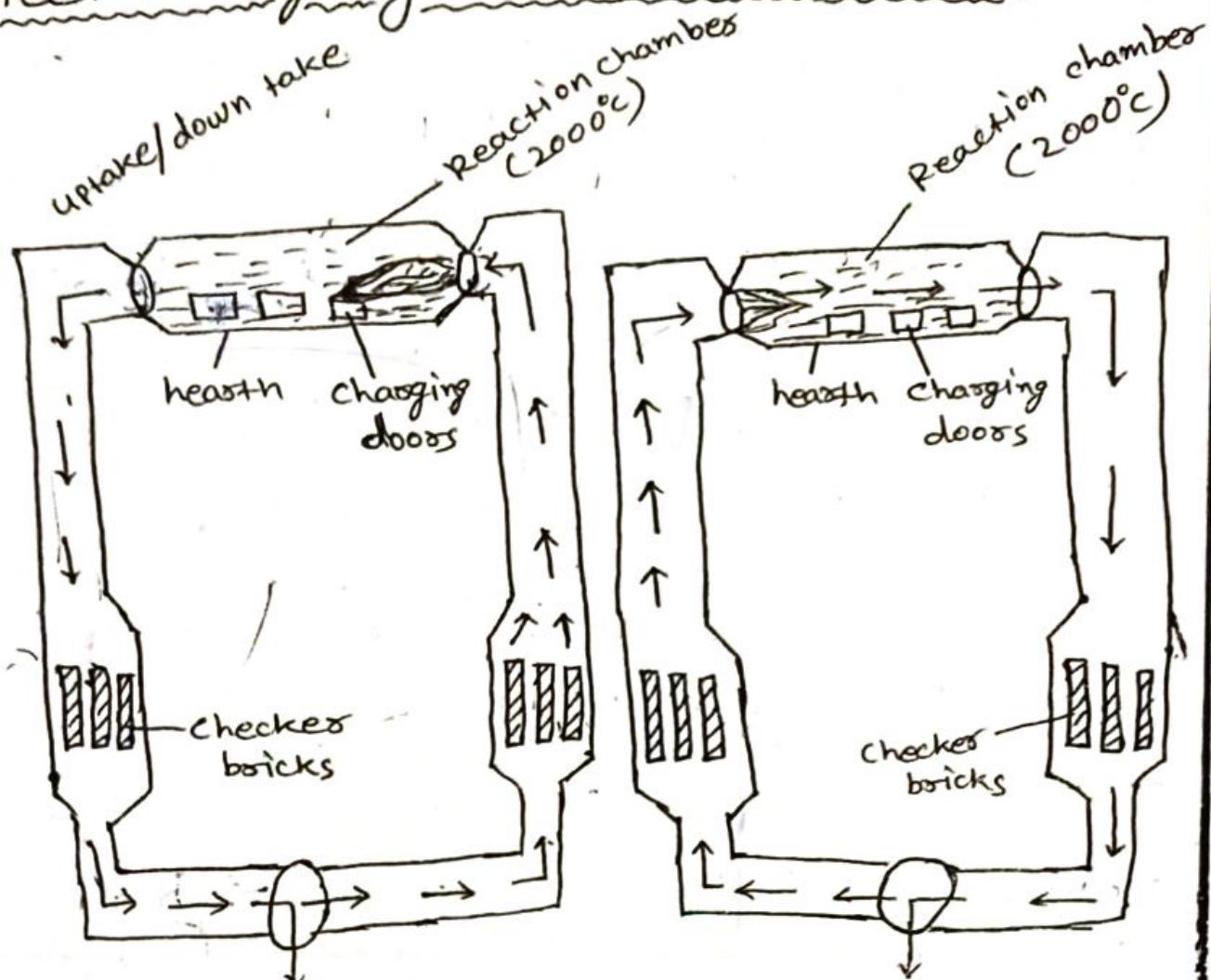
acid

- If the pig iron contain $\text{P} < 0.5\%$; then the acid pig iron is used and the process is called acid process.
- It remove C, Si and Mn.

Basic

- If the pig iron contain $\text{P} > 0.5\%$; then the basic pig iron is used and the process is known as basic process.
- It remove C, Si, Mn and most 'P' and 'S' from the pig iron.

Steel Making By Open Hearth Process (OHP) :-



General Principle

- The open hearth process of steel making consists essentially in melting metal on the hearth of a reverberatory furnace provided with regenerators in which the air for combustion is pre-heated.
- Air and gas are heated to $1000 - 1200^{\circ}\text{C}$ in the pre-heated checker bricks of regenerators.
- Air passes through an air regenerator and gas through gas regenerator and enter the furnace.
- The fuel flame in the furnace has a temp. of $1800 - 1900^{\circ}\text{C}$.

- The hot combustion products are withdrawn through the other end port of the furnace into another pair of regenerators and pass through a system of flues to the stack.
- Thus the second pair of regenerators is heated up when the first is cooled.
- At the moment when the first pair of regenerators stop to heat of the air and gas to the desired temp. the second pair is super heated.
- This is done by means of reversing valve.
- After a certain time the cycle is repeated, the valves are reversed again and so on

Types of Open Hearth Furnaces:-

- open hearth furnace is classified by a number of features.

* By their principal design

1. Fixed type

2. Tilted type

- Most of the furnaces are of fixed type.

* By the type of refractory used in the hearth.

1. Acid open hearth furnace

2. Basic open hearth furnace.

* Depending upon the type of fuel and its calorific value.

1. Two pairs of regenerators
(Low calorific value)
2. Single pair regenerator
(high calorific value)

* According to their capacity.

1. Low capacity ^{OHF} (upto 125 tons)
2. Medium capacity ^{OHF} (125 - 300 tons)
3. Heavy capacity ^{OHF} (upto 900 tons)

Fuels For Open Hearth Furnace :-

- The condition of fuel combustion can be characterised by the co-efficient of heat utilisation.

$$\eta = (Q_c - Q_w) / Q_c$$

Q_c = heat of fuel combustion

Q_w = heat of waste gases

- For OHF $\eta = 0.5 - 0.55$. It increases if the heat of waste gases partially recovered in a waste heat boiler.
- The heat rate depends on many factors, such as,

Furnace capacity (In large furnace the loss of heat for heating the refractory lining or cooling water)

• Fuels used for firing OFH can be classified as,

① By the physical state

(a) Liquid fuel (Heavy fuel oil, tar etc)

(b) Gaseous fuel (Blast furnace gas, Producer gas, coke oven gas & natural gas)

(c) Solid fuel (coal dust)

② By the calorific value

(a) Low heating value fuel's (Blast furnace gas - 900 kcal/Nm³ & Producer gas - 1400 kcal/Nm³)

• Producer gas was used as a fuel in the well developed early OFH.

• In an integrated steel plant a mixture of blast furnace gas and coke oven gas is used as these are easily available.

• Producer gas is used as a stand by or is mixed with the mixture.

• Liquid fuels are invariably used in recently constructed furnaces.

• The use of liquid fuel in preference to gaseous fuel has several advantages,

① High calorific value.

② High melting rate and increased production rate.

③ Since liquid fuels are not pre-heated the checker capacity is fully and better utilised for preheating air only.

④ The furnace design is simple as it has only air port.

- ⑤ A substantial amount of fuel is saved during reversal period since the liquid fuel is put off easily.
- ⑥ The flame is very luminous and long and controllable.
- ⑦ There is less danger of over heating of the roof.
- In an OFH process initially the furnace was used to melt steel scrap alone but for economic reasons it was developed to take a mixture of scrap and pig iron as a charge.
- It could be operated either as an acid or basic process depending upon the charge composition and also with or without hot metal charged at equal ease.

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Furnace Construction:-

- The furnace consists of the following main parts:
 1. Reaction chamber (i.e. the hearth, the furnace wall, the roof, the ports)
 2. Gas and air uptakes and downtakes
 3. Slag pocket
 4. The regenerator and the stack
 5. The reversing valves.
 6. The launder.

1. Reaction Chamber:-

- The reaction chamber is confined by the roof on top, by the hearth of the bottom, by walls at the sides.
- Tapping is effected through the tapping hole

provided at the joint between the back wall and hearth.

- The front wall has charging doors through which solid charge is given into the furnace and molten iron is poured along a spout.
- The reaction chamber is the most critical part of the furnace and operates under the most severe conditions, since this is the place where melting of steel occurs.
- The refractories for the reaction chamber should satisfy the following characteristics
 - 1) High refractoriness
 - 2) High chemical stability against the action of slag, molten metal and furnace gases.
 - 3) Sufficient mechanical strength at high temp.
 - 4) High thermal stability.

(A) Hearth:-

- This is a steel pan made from 15-30 mm thickness steel plate, rectangular in shape with the length about twice as much as the width.
- Chill boxes are provided at each end of the pan for facilitating water cooling.
- The pan is lined inside with a layer of insulating or fire bricks and then atleast three layers of acid or basic bricks. (acid bricks for acid furnace and basic bricks for basic furnaces)

(B) Walls:-

- The front and back walls of a furnace operate under the same condition as the hearth and are in contact with molten metal

and slag.

- The front and back walls in acid furnaces are made of silica bricks and in basic furnaces, it is made of magnesite bricks

(C) Roof:-

- The roof of an open hearth furnace does not contact with the slag and therefore can be made of either acid or basic refractories, irrespective of the type of process.
- The roof of an open hearth furnace are made of either silica or magnesite-chromite bricks.

(D) Ports:-

- Ports are openings at the end of the reaction chamber through which the air and fuel enter the furnace and combustion product are removed.
- The earlier open hearth furnaces use gaseous fuels only and hence had independent ports for air and fuel, but many of the furnaces are fired with oil alone and hence have only the air port through which oil burner is inserted.
- The ports should perform the following functions:
 - ① Ensure good coverage of the whole length of bath by the flame, so that the heat transfer to the bath is at a maximum and that to the walls and roof at a minimum.
 - ② Ensure good intermixing of the air and the fuel, which is essential for the complete combustion of the fuel in the reaction chamber.
 - ③ Offer the least resistance to the flow of

the flue gases removed from the furnace.

- To satisfy the 1st two conditions, the cross-sectional of the port should be as narrow as possible; so as to have the highest speed of air and fuel at the entry to the furnace.
- On the other hand it should be as possible in order to satisfy the third requirement.

2. Gas uptake and Downtake:-

- These are the vertical passages connecting the ports to the regenerators.
- These alternately act as an uptake (to carry fuel and air up) and a down take (to carry furnace exhaust gases down)

3. Slag Pocket:-

- The lower base part of an uptake is called a slag pocket. Its function is to collect slag and other particle carried away from the furnace.

4. Regenerator:-

- The flue gases at a temp. of $1500^{\circ}-1600^{\circ}\text{C}$ pass from the slag pockets into the checkered work of regenerator.
- Sensible heat of the furnace gases is stored in the checkers works of the regenerator.
- There are two pairs of regenerator, one pair on each side to preheat air and gaseous fuel.
- The furnace is fired alternately from each end.

5. Reversing Valve:-

- An open hearth furnace is a plant in which the

direction of moving gases is reversed i.e it is changed periodically ; which is done by means of a reversing valve . -

6. Launder :-

- This is a channel which is connected to the tap hole for directing the metal to the teeming ladle.

Types of Open hearth Practices :-

{ ① All steel scrap practice (If pig iron not available and are quite costly)

{ ② Pig iron + steel scrap practice
 40% 60%

③ Hot metal + steel scrap Practice
 50% 50%

④ Pre-refined metal + steel scrap Practice
 60% 40%

⑤ Hot metal + pre refined metal Practice
 80% 20% - (Rarely use)

⑥ All hot metal practice (Rarely use) 1

- All the six types can be used in basic open hearth process but generally the type 3-6 are applicable for this process .

- Types 1 and 2 - cold metal practice
 Types 3-6 = hot metal practice

Charge One :-

- If around 65% . scrap and 35% . pig iron are included in the charge , the furnace gases provide adequate oxygen to oxidise the

Small proportion of the impurities in the melt.

- There is no necessity for addition of iron ore or coke.
- On the other hand, if the pig iron proportion is more ($>35\%$), i.e. the level of impurity is more and the furnace gases do not provide enough oxygen to oxidise and iron ore has to be incorporated in the charge to oxidise these excess impurities.
- This iron ore is called the charge ore.

Feed Ore:-

- Since the rate of oxygen transfer from furnace gases to the metal bath is extremely low, oxygen supply to the bath is hastened during refining by adding lumpy iron ore. This ore is called feed ore and the practice is known as oreing practice.

Steel making By Acid Open hearth Furnace Process :-

- It is an acid lined furnace generally Silica, to carry out refining under acid slag.
- It could not eliminate 'P' and 'S' from the hot metal.
- Charge material for acid open hearth process;

1. Solid pig iron (Hematite grade)

$$C = 3.0 - 4.0 \%$$

$$Si = 1 - 2.5 \%$$

$$Mn = 0.75 - 1.5 \% \text{ (deoxidation)}$$

$$P = 0.05 \% \text{ (Max)}$$

$$S = 0.5 \% \text{ (Max)}$$

2. Steel scrap

- 3. Iron Ore, mill scale (a low grade iron ore, Fe₃O₄)
- 4. Limestone - increase the fluidity of the slag
- 5. Fluorspar
- 6. Mn
- 7. Deoxidisers
- 8. Alloying addition if required
- 9. Fuel - Producer gas is used as a fuel, since it has low sulphur content.
- Acid open hearth process can take either 100% scrap or 40% pig iron and 60% scrap.

Process or the Sequence of Operation:-

An open hearth heat can be divided into various stages or periods as,

① Hearth Fettling:-

- Upon tapping, the furnace is inspected visually and all defects are amended.
- Special care is needed when inspecting the hearth.
- The positions of the front and back wall which are in contact with slag and metal, are often eroded and thus requires a certain amount of repair. This operation is called the fettling of the hearth.
- It is necessary of the hearth.
- If the steel makers detects other defect in the hearth they also be eliminated.
- The exposed surface of the hearth is built by throwing in refractory material through the charging doors.
- The operation of fettling continues for 10-15 min depending upon the furnace capacity, conditions of the hearth and fettling technique.

② Charging, melting and Refining:-

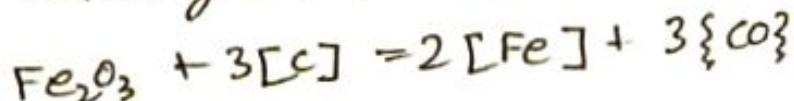
- It comprises the following operation,

① Pig iron followed by steel scrap and lime stone are charged into the furnace through charging doors.

② The charge is melted by burning gaseous fuel such as producer gas and air blowing through the ports 20-25 min from each end of the hearth.

- At this stage the hearth attains a temp. of about $1520 - 1570^{\circ}\text{C}$.

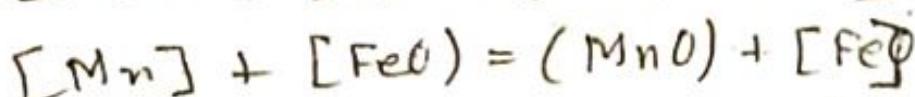
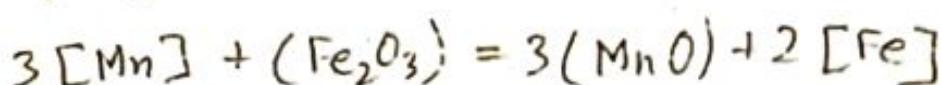
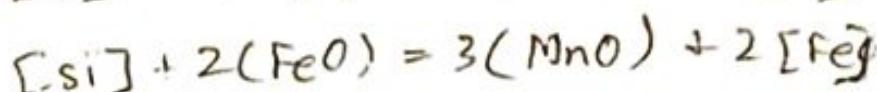
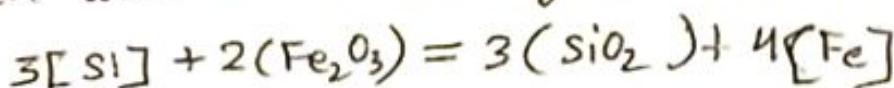
③ Lumpy iron ore is charged through the charging door as an oxidising agent to carry out refining as per the reaction.



- Due to evolution of CO, the bath starts to boil. This period is known as carbon boil period.

• During this period almost all silicon and manganese and part of carbon are oxidised as per the following reactions.

• The oxidation of silicon occurs with heat evolution, which accelerates melting of the charge.



④ The progress of refining is assessed by taking out metal and slag samples from time to time.

- Carbon content of the metal is assessed by observing the fracture of the metal sample, silica content is estimated by measuring the viscosity of the slag, FeO content in the slag is estimated by the colour and fracture of the sample.

③ Deoxidation:-

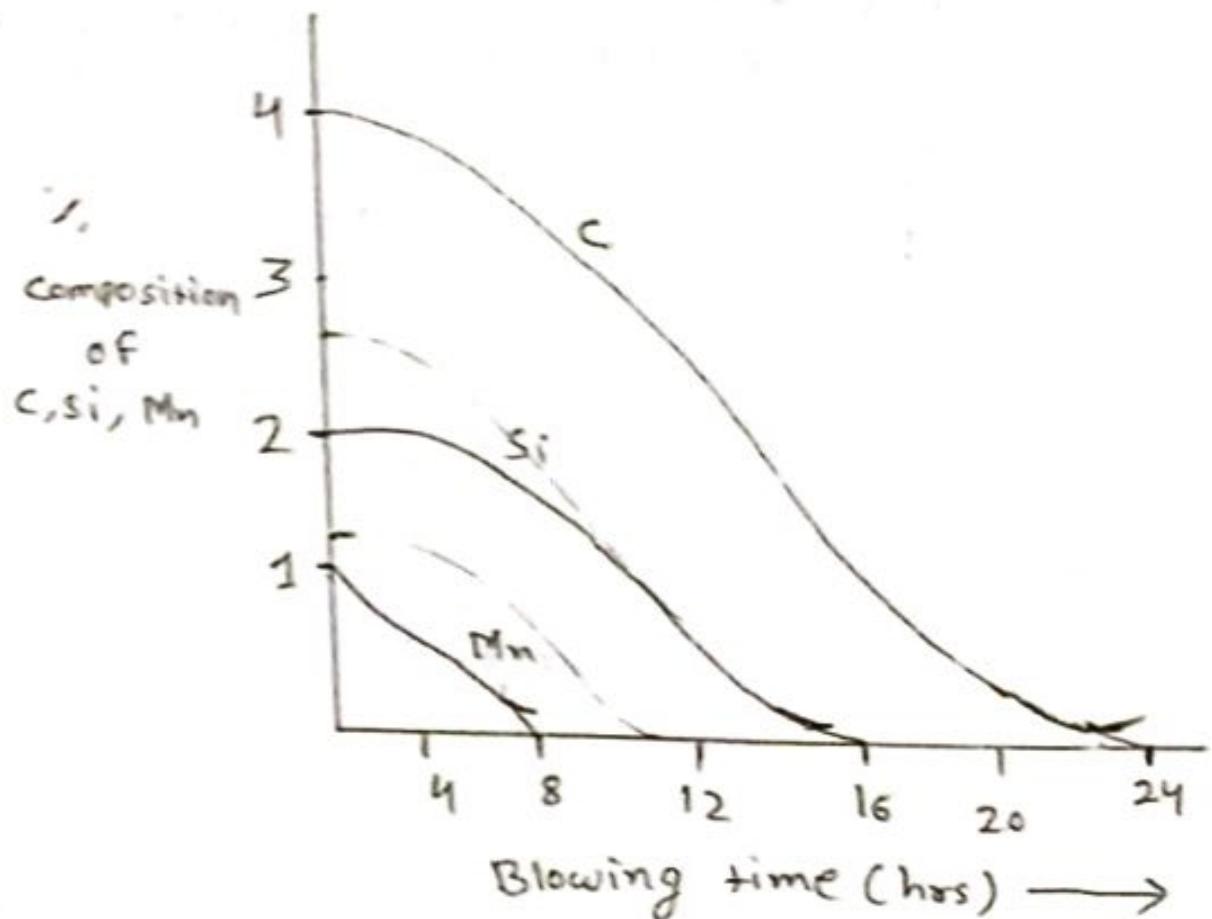
- By the end of the refining some deoxidisers such as Fe-Si, Fe-Mn etc are charged into the hearth to stop boil temporarily.
- Metal sample is taken out at this stage to assess the carbon content.
- If it is correct, the bath is deoxidised to the required extent.

④ Alloying:-

- After deoxidation alloying addition if required are made in the form of Fe₂O₃-alloys in the furnace.
- Laddle addition should be avoided or kept to a minimum in an acid process to produce good quality steel.

⑤ Tapping:-

- The ~~top~~ hole is opened by an oxyacetylene torch and steel is allowed to flow over the launder into the well dried laddle. About 10 min. are required for tapping 80-100 ton of steel.
- The tap-to-tap time for an acid open hearth process is about 12-25 hrs.
- * The following figure shows the sequence of elimination of impurities.



Quality of Acid Open Hearth Steels :-

1. Steel produced by acid open hearth process are very clean and superior quality due to less quantity of dissolved gases and non-metallic inclusions.
2. Low, medium and high alloy steels can be produced by this process, particularly has applications in bridges, railways, heavy vehicle springs, die blanks etc.
3. Acid steel contains less gases than the same grade in a basic open hearth furnace, electric arc furnace or converter process,
 - This is because,
 - The charge is more clean.

- (ii) The quantity of slag formed added to the furnace is not high.
- (iii) Thick high silica slags have a poor permeability of gases.
- (iv) The content of oxygen during a heat in an acid furnace is lower than that in a basic furnace.

4. Acid open hearth steel usually contains
 $0.006 - 0.01\% = \text{oxygen}$, Nitrogen = $0.001 - 0.001\%$
 and Hydrogen $2-4 \text{ cm}^3 / 100\text{gm}$.

5. Acid open hearth steel is used for making
 crank shaft of various motors, rotors of large turbines, large ball and roller bearings, guns and other critical articles.

Steel Production by Conventional B.O.H. furnace Process :-

- Basic open hearth furnace process soon became popular because of high technical and economic indices of the process in terms of output, use of fuel and refractories.
- A basic open hearth furnace can use pig iron and scrap of any composition and in any proportion and make quality steels of any type.
- As such acid open hearth process have now been completely replaced either by basic open hearth or electric arc furnace processes.
- A basic open hearth furnace is lined by basic bricks and basic ramming mass and a basic slag is prepared.

by adding lime or limestone to enable removal of sulphur and phosphorous.

Practices in Basic open hearth Process:-

- The following practices are adopted.

(A) Basic open hearth cold metal practice

(using all cold charges, 30-40% pigs + 60-70% scrap operation is same as A.O.H process)

(B) Basic open hearth hot metal practice.

(using hot metal from blast furnace or pre refined pig iron and scrap.)

Basic Open Hearth Hot metal Practice:-

- A basic open hearth furnace can successfully run with hot metal proportion in the charge of about 35%.
- If the hot metal exceeds or it is more than 50%, the slag formed will not be accommodated in the furnace because of high quantity of impurities present in the pig iron.
- So in order to accommodate high proportions of hot metal in the charge, the following methods have to be done.

① Pre refining of hot metal.

- The hot metal from a blast furnace is pre refined to remove certain amounts of impurities in particular 'Si' is reduced to a low value and Mn, P, and C may also be eliminated to some extent.
- This is achieved by either of the following

means

- (a) Duplexing
- (b) Ladle desiliconisation
- (c) Active mixture practice.

(a) Duplexing:-

- As the name indicates, this process uses two different steelmaking processes (Acid Bessemer and BOH) to carry the required amount of refining.
- First the hot metal is refined in acid Bessemer process to eliminate all the silicon and manganese and a part of carbon after which the predefined metal is charged into a basic open hearth furnace to complete the refine and to produce finished steel.
- Duplex process is adopted where scrap is scarce and surplus hot metal is available.
- It is carried out in two different ways.
 - (i) Dominant pool practice
 - (ii) single heat or small pool practice.

(i) Dominant pool practice →

- It is essentially suited to treat high 'P' iron and where is a steel pool of at least 25% of the furnace capacity is retained to commence the next heat (TISCO, SMS-2)

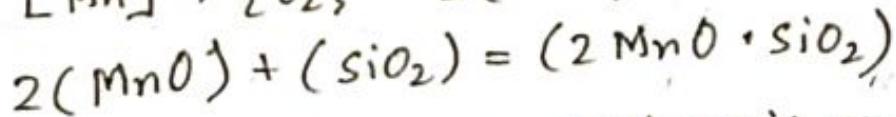
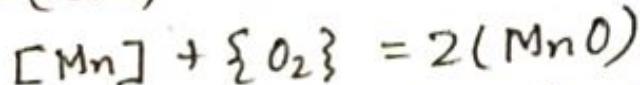
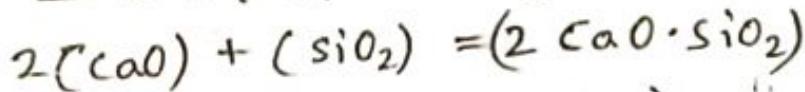
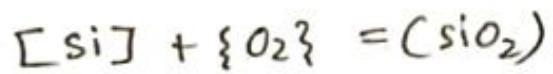
(ii) single heat or small pool practice →

- In this practice the entire amount of heat is tapped out of the furnace and then charging for the next heat begins.
- Sometimes a maximum of 10% steel may be retained in the furnace to act as a heat for the next heat, to melt

flux and for a good initial slag (11ScO, Bumfur)

(b) Ladle Desiliconisation:-

- The excess Siliconic pig iron produced by Indian blast furnaces are treated externally to remove silicon in the hot metal transfer ladle by oxygen lancing.
- This is commonly referred to as ladle desiliconisation.
- In this process, the transfer ladle containing hot metal nearly $\frac{2}{3}$ full, is held under in hood.
- Lime upto 0.5 - 2.0% of the weight of the metal is charged as flux. Ore or scale may also be added.
- Oxygen is blown through a consumable mild steel pipe lance at a pressure of $8-12 \text{ kg/cm}^2$.
- The lance is inserted through the hood at an angle of $75-80^\circ$ to the bath surface.
- The amount of silicon oxidised depends on its own concentration, bath temp, amount of flux, ore or scale added, rate and quality of oxygen blown.
- The main reactions are



- All the above reactions are exothermic and hence the bath temp. rises, unless coolant is added.
- The final silicon content of the hot metal

will be in the range of 0.3-0.5%. The ore-refined metal is charged into a basic open hearth furnace to complete the refining (Durgapur steel plant).

(C) Active Mixture Practice (Adopted first in India)

- | <u>Active Mixture</u> | <u>Malline</u> |
|---|--|
| • Shape & size - same | • Same. |
| • Lining - Basic Lining | • Fire-bricks. |
| • Fired by B/F gas + coke oven gas mixture. | • Fired by B/F gas + oven gas mixture. |
| • Charge with hot metal, cold pig iron, scrap, lime, ore etc. | • Charged with only metal. |
| • Lime equal to 1% of the wt. of metal charge is required to form a basic slag. Iron ore is added to oxidise impurities in particular Si. A certain amount of Mn, P, and S also get eliminated. | |
| • A typical set of data about the performance of the active mixture are: | |

Pig Iron	Composition (%)				
	C	Si	P	S	Mn
From Blast Furnace	3.5	1.0	1.6	0.06	1.2
From Active Mixture	3-3.5	0.4	1.4	0.05	0.05

- These mixture are usually in the range of 400-1200 ton capacity. It is better to use two 500 ton mixtures rather than one of 1000 ton capacity.

Operation/heat of a modern basic open hearth Process:-

① Fettling of the hearth :-

- After tapping the previous heat, the furnace is inspected and repaired for ready of charge material addition.

② Charging and heating of the solid charge :-

- First iron ore is charged in the bottom layer of the furnace.
- It is immediately followed by limestone and scrap.
- A suitable combination of heavy, medium and light scrap in proper proportions is made by an experienced steel maker.
- Heavy scrap pieces are charged at the top above the light scrap, so that the 'liquid' steel drips down and heat transfer to the core is hastened.
- The lime/limestone is charged on the top of the iron ore so that at an appropriate time calcination of lime shall takes place and release lime for the formation of early slag which would be flushed out.

③ Charging of hot metal :-

- When the scrap is heated to the state of incipient fusion, hot metal is poured from the charging doors. So the sequence of charging is,

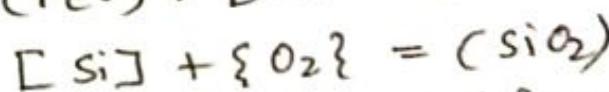
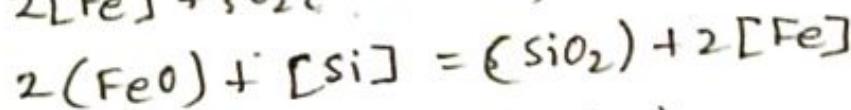
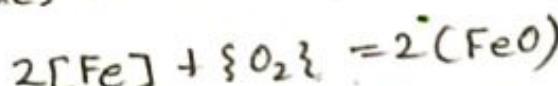
Iron ore — limestone/lime → medium scrap
→ light scrap → heavy scrap → hot metal

(i) Refining:-

- In the modified basic open hearth process oxygen lance is commenced immediately after charging of the hot metal.
- As the lance is progressively lowered, the amount of splashing increased until a point and then decreased to a point of least when the tip is just below the slag surface. This is the correct position of lance.
- Oxygen is blown through the lance at the rate of 12-15 m³/min to keep fuming and splashing of the slag to a minimum.
- At this stage, a slag of low basicity is allowed to flush out.
- The hot metal which is highly oxidising due to furnace gases reacts very violently with the iron ore at the bottom.
- The charge lime joins this to form low basicity slag and is allowed to flush.
- The following is the separation of removal of impurities.

(i) Removal of 'Si'

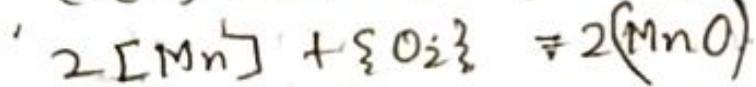
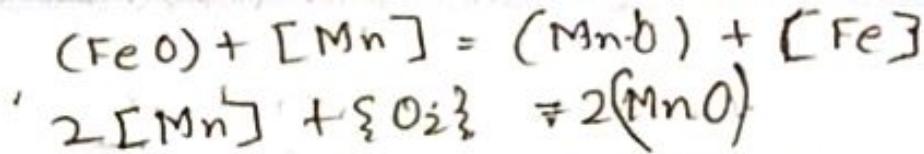
- Silicon is oxidised in a basic open hearth furnace almost fully during melting due to its reactions with oxygen of the furnace atmosphere or iron oxides of the slag.



- The oxidation of silicon and formation of silicates occur with heat evolution, which accelerates melting of the charge.

(ii) Removal of 'Mn'

- Like silicon, Mn is oxidised readily by reacting with oxygen of the atmosphere or with iron oxides of the slag as per reaction



- At higher temp., the condition for manganese reduction are more favorable.

(iii) Removal of 'P'

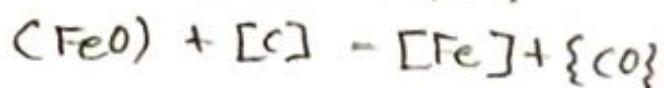
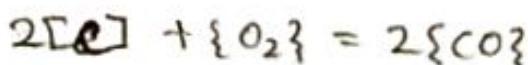
- Phosphorus is oxidised at the same time as silicon and manganese at the beginning of the heat.
- In practice, the steel maker attempts to remove phosphorous from the bath during melting period and the first half of the bath boil, i.e. when the metal is not heated strongly.
- In common practice, single slagging off is sufficient to reduce the concentration of phosphorous to 0.010 - 0.015%.
- If the charge is high in phosphorous, a single slagging off may be insufficient.

(ii) Removal of 'S'

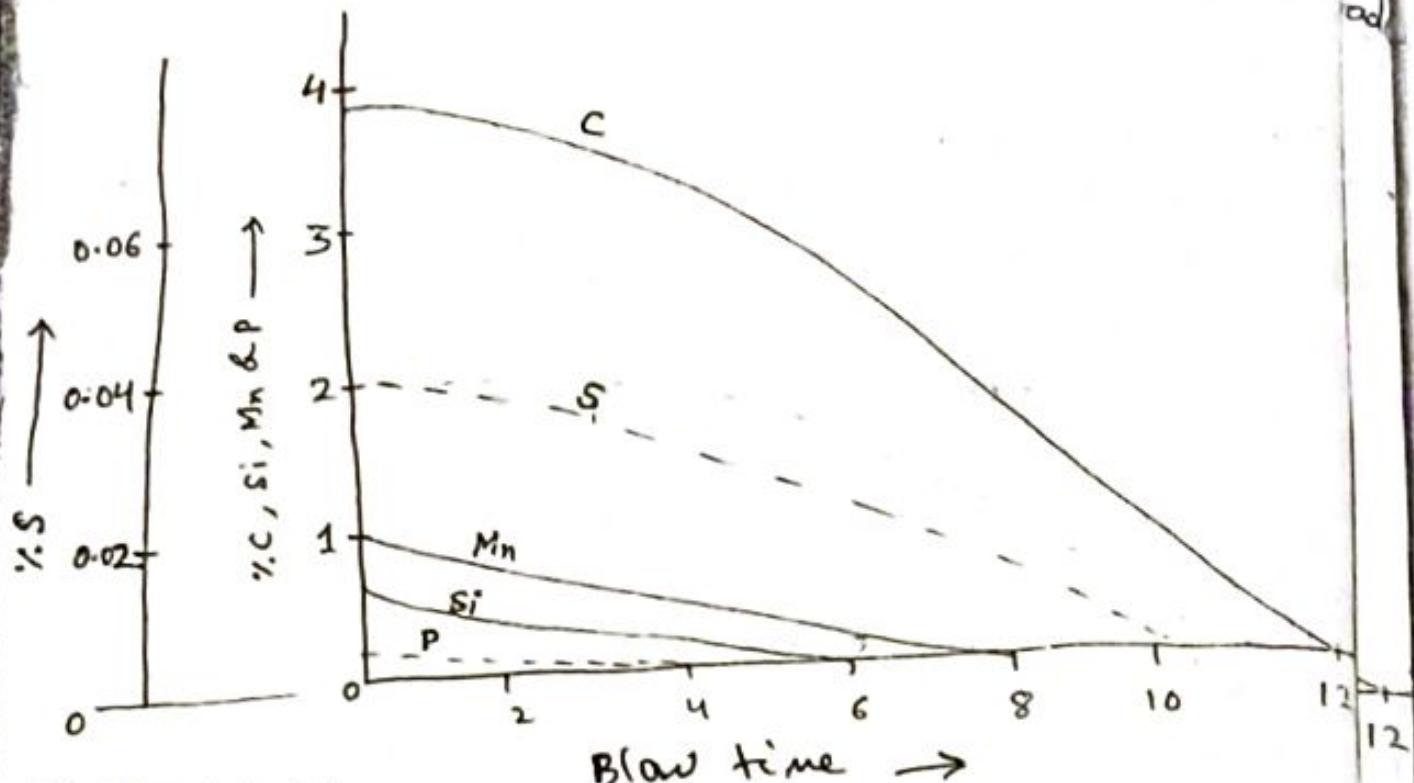
- In view of the high iron oxides in open hearth slags, desulphurisation can only occur to a limited extent with a commonly quality charge, it is not difficult to produce steel with less than 0.04% S.
- But it is substantially more difficult to make steel with a lower content of sulphur (below 0.015 - 0.02%). For this reason, steels very low in sulphur are partially desulphurised in the ladle.

(IV) Removal of Carbon

- The effect of boiling of the bath is due to the evolution of gaseous carbon monoxide (CO) which forms by the reaction of oxidation of the dissolved gases.



• Steels made in basic open hearth, usually contain from 0.05-1.0% carbon depending on the grade



⑤ Blocking:-

- At the end of refining, the oxygen pressure is reduced and is completely stopped to block the heat.
- For blocking the heat Fe-Mn or Fe-Si is added to the bath.
- It raises the manganese content of the bath by about 0.2% and silicon content by about 0.05-0.2%.
- The fuel supply is shut off the sample is taken out for analysis. If carbon analysis is correct, heat is further deoxidised and finished. If it is high, oxygen lancing is again done and the heat is finished.

⑥ Deoxidation & alloying:-

- If carbon analysis is correct, the heat may be deoxidised further and alloying additions are added in the predetermined lot, if required to complete the heat.
- Open hearth steel is usually deoxidised and alloyed in two stages, by adding deoxidants and alloying elements in the form of ferro-alloys partly in the furnace and partly in the ladle.

⑦ Tapping:-

- After deoxidation and alloying, the tap hole is opened by an oxyacetylene torch and the steel is allowed

over the bender into the well dished trolley at the same time the slag is skimmed to the slag.

- The total tap to tap time is around 8 hrs.
- The tap to tap time distribution of a typical plant is,

1. Fettling	30 min (avg)
2. Charging	1 hr 35 min
3. Heat the charge	1 hr 30 min
4. Hot metal	25 min
5. Melting	2 hr 05 min
6. Refining	
7. Deoxidation & alloying	30 min
	7 hrs 35 min

Quality of Modern Basic open hearth steels:-

- It produces all varieties of rimming, semi-killed and low alloy steels owing to slow refining process, its quality is fast better than other products.
- The dissolved nitrogen and oxygen content of these steels are very low.
- The contents of 'P' and 'S' are lower than basic bessemer & LD process.

Natural gas - CH_4 - 95%, propane - 0.2%
 C_2H_6 - 4.2% Butane - 0.02%

Blast furnace gas - N_2 - 55%, CO - 21%, CO_2 - 22%
 N_2 - 48%, CO - 20% H_2 - 3%

producer gas - CO_2 - 12%, H_2 - 14%, CH_4 - 4%,
passed O_2 - 3%

water gas - ~~C_6H_6~~ + $\text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2$ (CO - 45%,
 H_2 - 50%, CO_2 - 5%)
coke steam

coke oven gas - H_2 - 51%, CH_4 - 34%, CO - 10%, ethylene
 C_2H_4 - 5%

Charge Materials :-

- ① Hot metal (50-70%)
- ② Steel scrap (30-50%)
- ③ From ore
- ④ Lime stone
- ⑤ Deoxidisers
- ⑥ Alloying addition
- ⑦ COKE

Finished Steel

C - 0.12
Mn - -
P - 0.02
S - 0.02
Si - --

Advantages of BOH Process (Features of Modern BOH)

- It is matched with the electric arc furnace practice to consume even 100% scrap in the charge.
- It can also operate on any hot metal scrap proportion.
- As compared to LD process, Modern BOH are not economical in terms of installation and running costs.
- In near future, these furnaces will be replaced by ultra modified practices by
 - (i) Improving the regenerative capacity.
 - (ii) Allowing increasing gas volume by widening the port ends and slag pockets etc.
 - (iii) Minimising the leakage of cold air.
 - (iv) Improving the melting efficiency by controlling the flame characteristics.
 - (v) Using new oxy-fuel burners and oxygen
 - and (vi) Using computerised control for material and thermal balance of the charge, spectrochemical analysis methods of analysis.
- The total fettling, charging etc will be cut down and the tap to tap time will be nearly of 4-5 hrs. There are two type of ultra modified furnace ① SIP
② Twin hearth process.

Steel Ingots :- Chapter - 7

- Depending upon the degree of deoxidation and solidification phenomenon, steel ingots are classified into the following types.

1. Killed Steels - • Steel that is fully deoxidised by strong deoxidiser, is called killed steel since no activity is observed by way of gas evolution during solidification.

- It remains quiet in the mould as if it is dead and hence the term killed.

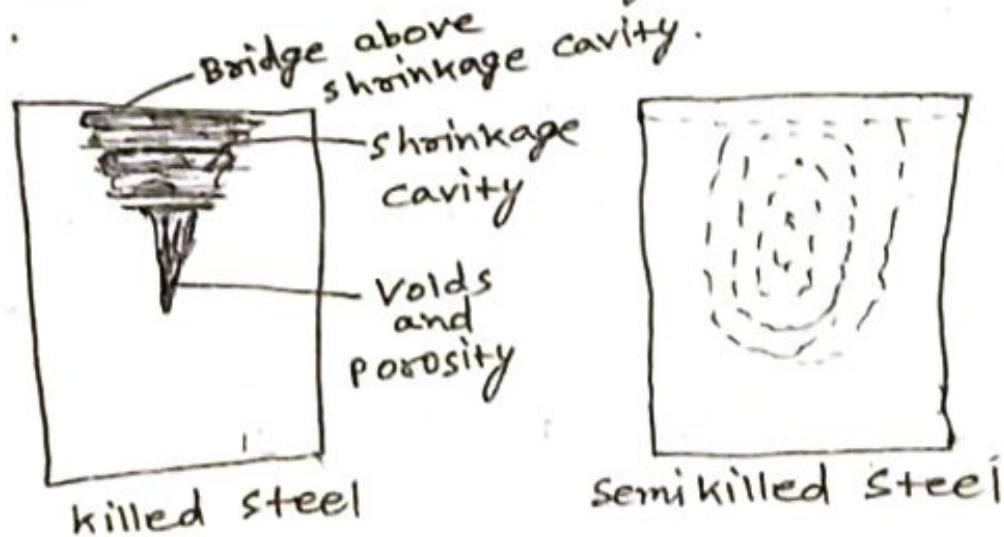
Killed steel solidifies progressively from the sides and bottom of the mould till finally a shrinkage cavity, known as pipe, is formed in the top central portion of the ingot.

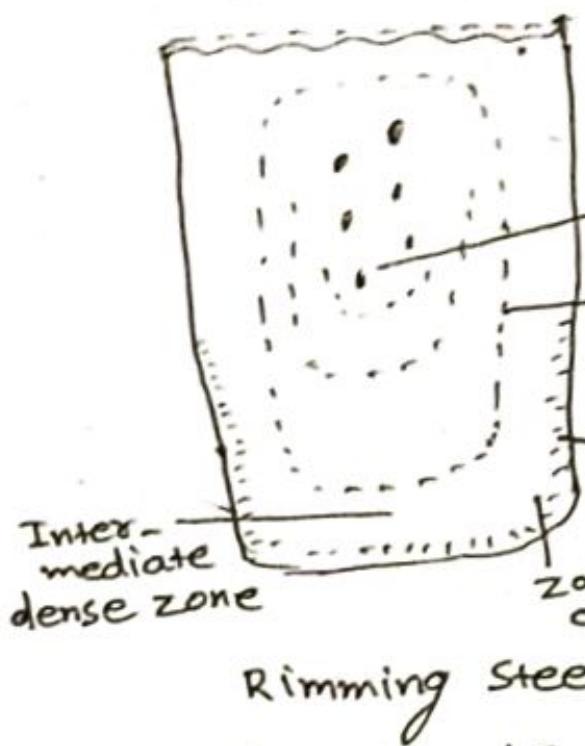
2. Rimming Steels - • Steel that is not deoxidised fully and the evolution of gases is appreciable during solidification such a steel is known as rimming steel.

- During solidification it gives the appearance of boiling action. This boiling action is known as rimming.

3. Semi-killed steel - • Steels that are partially deoxidised and some gas evolution takes place during the later stage of solidification are known as Semikilled steels.

4. Capped steels - • A special variety of rimming steel in which the rimming action is less violent.





Rimming Steel



Capped Steel

1. Rimming Steel :-

- Rimming steels require a lot of gas evolution during solidification.
- The steel must contain enough oxygen derived oxygen which only possible in low C. Steels.
- Hence rimming steels are produced only carbon is less than 0.15%.
- The heat must be finished in a furnace with respect to iron oxide content of the slag in such a way that the bath contains desired level of oxygen at a carbon level less than 0.15%.
- In general no deoxidation is carried out inside the steel making furnace only a small amount of deoxidation, if needed, is carried out using Fe-Mn or Al as deoxidizers; in the ladle or in the mould itself.
- In a properly cast rimming, primary blow holes formed next to the ingot skin of adequate thickness and the necessary blow holes are formed still inside.
- The ingot has a minimum of pipe.
- The zone between primary and secondary blow holes is known as a rim.

- Rimming steel ingot has a smooth surface.
- Rimming steels are cast in narrow-end-up moulds and wide application of flat products.

2. Semikilled Steels:-

- These are partially deoxidised steels such that only a small amount of gas is evolved during solidification.
- The carbon content has to be in the range of 0.15 to 0.3%.
- The required deoxidation may be carried out in the furnace itself.
- Fe-Mn, Fe-Si or Al may be used as deoxidisers.
- Fe-Mn is not evolved immediately after pouring of steel in a mould but it is evolved towards the end of ingot solidification.
- Semi-killed steels are cast into big-end-down moulds and find very wide use in the manufacture of structural shapes, plates and merchant products.

3. Killed steels:-

- No gas evolution takes place in killed steels during solidification. All steels containing more than 0.3% C are killed steel.
- The heat is worked in such a way that by the time of carbon level drops close to the specification level, the refining should be over.
- In general the heat is then blocked by addition Fe-Si, wish silicon pig iron or silicon-manganese to the bath in the furnace.
- Blowing stops the carbon-oxygen reaction by lowering the oxygen content of the bath.
- Killed steel are cast in wide-end-up moulds with hot tops and particularly suitable for furnaces.

4. Capped steels:-

- This is a special variety ofrimming steel in which gas evolution is less pronounced.
- The steel is cast in bottle shaped narrow-end-up moulds in which the constricted top facilitates mechanical capping of the ingots.
- Early gas evolution is prohibited by adding some aluminium shots in the mould during teeming.
- The gas evolved in the later stages raises the metal level which is stopped by tapping.
- A cast iron cap is mechanically fastened down on the mould top. The capping stopsrimming.
- Capped ingots are produced from steels containing compound 0.15% C. These are used for producing flats, wires and bars.

Ingot Moulds:-

- Molten steel is poured into moulds to produce ingots for rolling, forging etc.
- These moulds are massive castings of more uniform shapes with cross-section like square, rectangular, round, polygonal etc.

Square moulds— Ingots with a square section are used for rolling into billets, rails, structural section etc.

Rectangular moulds— ingots with rectangular cross-section are used for rolling into slabs, flat products etc.

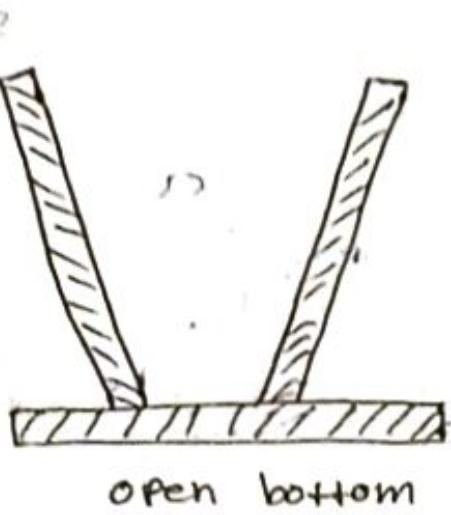
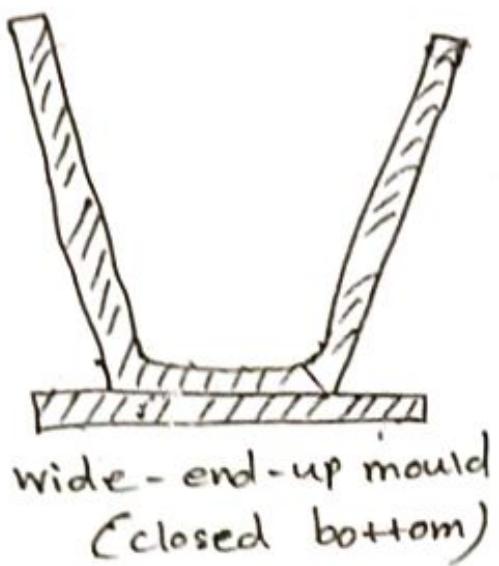
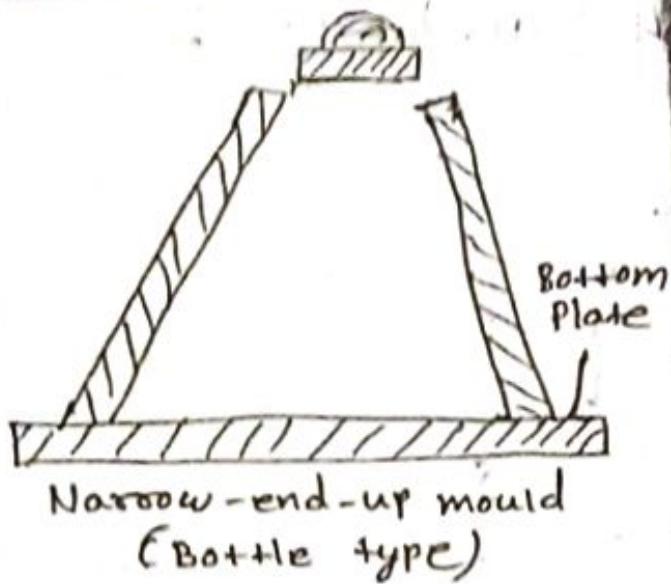
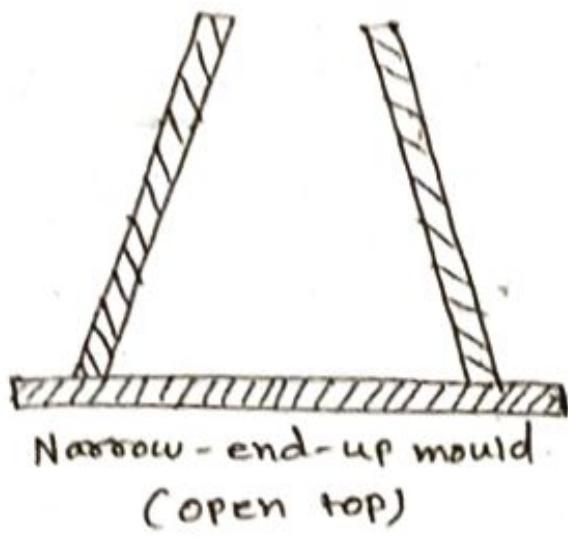
Round moulds— Round ingots are used for tube making.

Polygonal moulds— Polygonal ingots are used for type wheels, forgings etc.

- To help strip the mould off the ingot; the mould walls are tapped from one end to the other end, which divides the moulds into two basic types.

(1) Narrow-end-up / Big-end-down mould

(2) wide -end-up / Narrow-end-up mould.



Methods of Teeming of Steel :- Chpt 8

(1) Direct / TOP teeming

(2) Tundish Teeming

(3) Bottom / indirect / uphill teeming.

- Teeming is the pouring of liquid steel into an ingot mould.

(1) Direct / Top Teeming:-

- The liquid metal is teemed directly from the ladle into the mould.
- The rate of pouring can be controlled by the use of different sizes of nozzles.
- The rate of teeming increases as the nozzle diameter increases.
- It has a no. of advantages.
 - ↳ Teeming can be organised more simply.

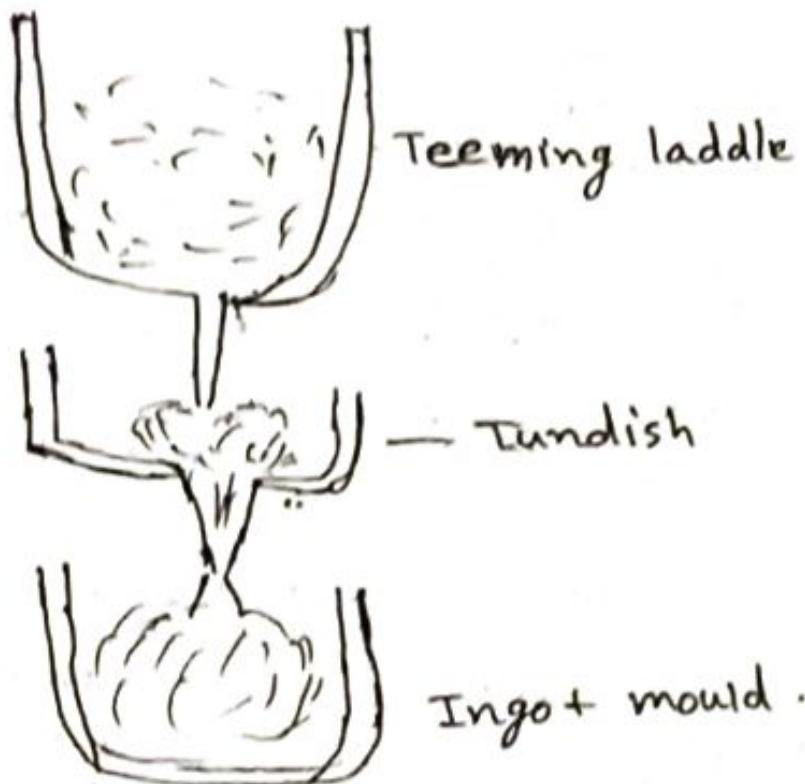
Disadvantage

1. When the metal jet strikes the bottom plate or mould bottom, the metal is splashed, stick to the mould walls, react with the rising metal and form blow holes and other surface defects.
2. Top poured ingots usually have a poorer surface than bottom poured.
3. The procedure takes much time.

(2) Tundish Teeming:-

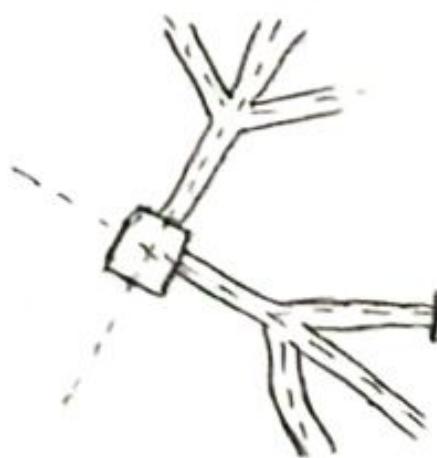
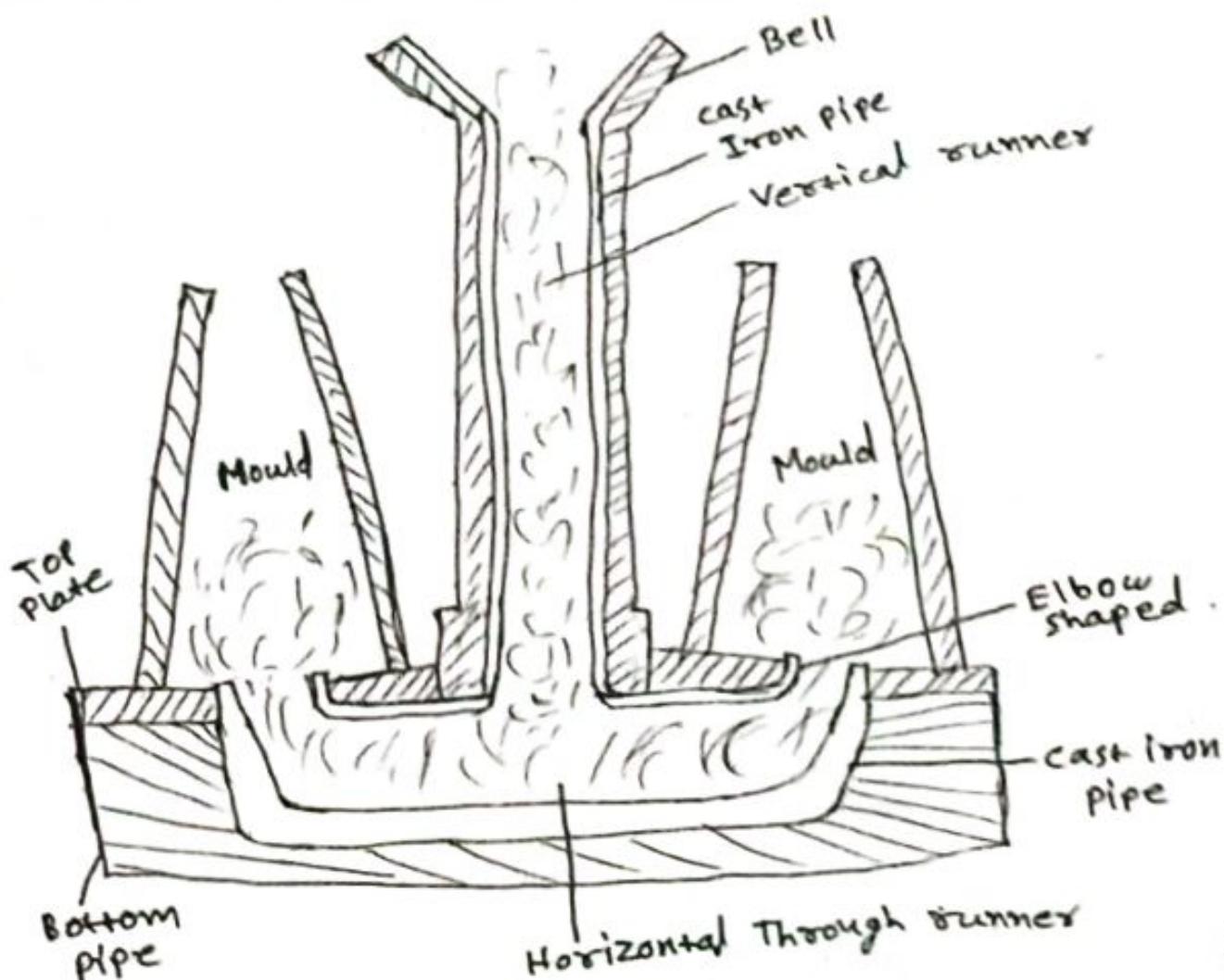
- The tundish is an auxiliary link in the process sequence i.e., steel making Plant — teeming, ladle ingot.
- A tundish is provided between the ladle and ingot mould to ensure uniform flow of metal while top teeming and minimises ingot defects.
- A tundish has its own nozzle to regulate the flow.
- The nozzle diameter in case of tundish is slightly larger than the teeming ladle.
- Tundishes with one or more upto eight nozzles are employed to distribute the metal.

- everly in that many moulds at a time.
- This reduces the total time of a teeming laddle and the available super heat in the metal can be fully utilized.
 - Tundish teeming is used for teaming of forging ingots and special alloy steel ingots.

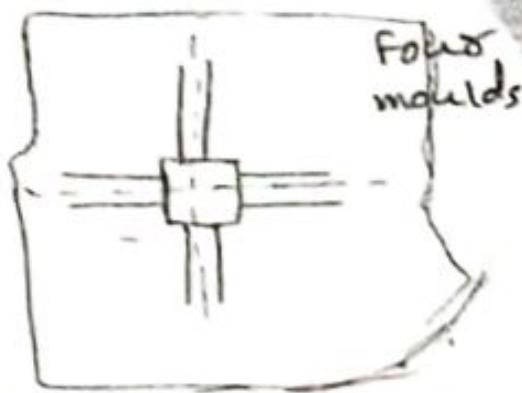


(3) Bottom Teeming / uphill teeming / Indirect Teeming:-

- Here steel is teemed from this teeming laddle into a vertical runner which is connected at the bottom to a horizontal runner, the end of which opens up in the bottom of the mould.
- The top of the vertical runner is shaped like trumpet or bell to make teeming easy.
- The height of the vertical runner is more than that of the mould to ensure complete filling the mould.
- One vertical runner can feed at least two and as many as twelve moulds at a time. In such cases, all the moulds are set on the same bottom plate having the required



moulds
can be
filled at
a time



bottom plate

Advantage

- ① Mould filling can be carried out at a low date since several moulds are being filled at once.-
- ② It is possible to observe from the top how the metal rise in the moulds.
- ③ It is possible to cast simultaneously a large number of small ingots . This circumstance is of special importance in cases when the works has no powerful cogging mill .

④ The quality of bottom teemed ingot is much superior and the bottom plate wear is much less as compared to top teemed ingots.

Disadvantage

- ① The principal draw back of bottom pouring is that the work organisation is more complicated and requires more hand labor for the preparation of the bottom plates, for eg, Placing of runners, risers, trumpets etc.
- ② Shaped runner bricks should be stored in proper places, dried, assembled before casting, cleaned from dust etc. with careless work, cast steel can be contaminated by inclusions from runners.

Ingot defects, their causes and remedies:-

1. All ingots are subjected to careful inspection upon reducing in a cogging mill, before being rolled in the mill.
2. There are various types of ingots, defects. Their probable causes and remedies are given below.

1. Shrinkage cavity/pipe :-

- A cavity not filled with metal, appears mainly in the top portion of killed steel steel ingots.
- It amounts 2.5-3.0% of the total apparent volume of ingot.

Causes — • A particular steel composition, ingot taper, teeming, temp., composition of fillers, addition of metal to the filled moulds.

Remedies

- ① Using hot top feeder head.
- ② Pouring little more metal after solidification.

2. Blow holes:-

- The entrapment of gas evolved during solidification of steel produces cavities known as blow holes in all except killed steels.

Causes — ① Increase gas saturation action of the heat

② Thick fatty lubrication of moulds

③ Improper deoxidation

④ Low temp. of teeming → Proper teeming → Proper deoxidation

3. Porosity:-

- Loose str. in the form of fine pores all over the metal volume.

- Detected in unetched or weakly etched macro-sections.

Causes - ① Over heated metal at tapping.
 ② Improper deoxidation
 ③ Saturation with gases.

4. Shrinkage porosity:-

- Fine pores in the core portion of ingot under the shrinkage cavity, which can be detected in unetched or weakly etched macro sections.

Causes - ① Low temp. of steel
 ② improper method of steel casting.

5. Columnar Structure / Ingotism:-

- After the formation of initial chill layer, further solidification results in the formation of dendrites which grow along their principal axis perpendicular to the mould walls.
- If the length of these is appreciable it is known as columnar structure and in an exaggerated form as ingotism.
- Ingots possessing ingotism tend to crack during rolling.

Causes - ① High temp & speed of teeming
 ② slow freezing of steel in the core portions of the ingots.

6. Honey Comb blow holes:-

- Gas bubbles in the form of honey combs at a very small distance from the surface of rimming and semikilled steel ingots.

Causes - ① High speed of mould filling
 ② Increased gas saturation
 ③ Over oxidized heat.

7. Segregation:-

- Chemico-physical inhomogeneity in certain zones of ingot due to precipitation of impurities in molten steel during its passage from liquid to solid state in the presence of interdendritic crystals.

Causes - ① High temp & speed of teeming.
 ② slow freezing of steel in the core portions of ingots.

8. Non metallic inclusions :-

- Inclusions are of two types.

(a) Endogenous inclusion - Non-metallic substances formed by physico-chemical process occurring during melting, casting and solidification.

- causes -
- ① Over oxidation of the bath
 - ② Elevated concentration of sulphur.
 - ③ Low metal temp. at tapping.
 - ④ Presence of viscous slag in tapped metal.
 - ⑤ Prolonged tapping and teeming.
 - ⑥ Repeated oxidation.

(b) Exogenous inclusions - Particles of refractories, slag, sand and other substances which can occasionally enter the metal during tapping and teeming.

- causes -
- ① Poor cleaning of the launder, ladle, runners and moulds.

- remedies -
- ① Use of strong refractories.

9. Internal Fissures / clinked ingot :-

- The term clinked ingot is used to denote internally cracked ingot. These cracks or fissures are due to:

- Causes -
- ① Too rapid reheating of an ingot
 - ② Too rapid cooling of an ingot.

- Remedies -
- ① Preventing too rapid cooling and reheating of the ingot.

10. Hairline Cracks :-

- Metal discontinuities stretched along the direction of deformation, originate from budding of gas bubbles or more often non-metallic inclusions.

- Causes -
- ① Gas saturation in steel and contamination with non-metallic inclusions.

11. Boxhat ingot :-

- A hollow top portion of rimming steel ingots, having a thin outer crust and open at the top.

Causes - ① Excessive deoxidation of rimming steel
② Excessive teeming rate.
③ High gas saturation, especially with nitrogen.
④ High temp. of steel.

12. Belt :-

- Welding of two metal layers in ingot, detected in hot ingots as a darker band.

Causes - ① Interruption of steel jet during teeming.

13. Surface cracks :-

- These are the defects that are apparent on the surface of an ingot after solidification or are visible in some form after mechanical working.
- Some of the surface defects are

① Ingot cracks - are four types

(i) Longitudinal cracks :- These are parallel to the vertical axis of the ingot and are caused due to the development of lateral tension in the skin found at the bottom position of the ingot.

(ii) Transverse cracks :- These are parallel to the base of ingot and are formed due to longitudinal tension in the skin.

(iii) Restriction cracks :- These are longitudinal or transverse in direction and are located at the corners of the ingot are due to the friction between the mould and ingot of a small radian of curvature.

(iv) Sub-Cutaneous cracks :- These are internal fissures close to the surface and caused due to thermal shocks.

Remedies - ① By proper designs of the mould.

② Control of temp of teeming, teeming rate etc.

14. Other surface defects :-

- ① Lappiness - It is a fold ingot skin caused by freezing of slowly rising top-surface of the metal in the mould before the pouring is over.
- ② Seam - Metal droplets are thrown off due to the impact of metal stream on the mould bottom. These drops stick to the mould wide and they form seams in rolled products.
- ④ Crazing or crocodile skin - A large no of cracks present in the mould will cause crocodile skin in the ingot.

Steel production by LD Process:-

Cold pig iron :-

Raw materials for LD process

- In some cases, cold pig iron is included in the charge material to consume the excess of iron produced in the plant.
- Big pieces of pigs (3-4% of charge) can be included along with the scrap.
- However, cold pig iron charging tends to prolong the blow, hence it is not recommended.

Steel scrap :-

- It is used in the charge as coolants to utilize.
- The excess heat energy available during refining.
- LD process can take upto 25% of the metal charge as scrap.

Lime/Limestone :-

- These are added as fluxes.
- Use of limestone is discouraged, since the thermal energy available during the heat is best utilized for melting scrap & at times of disintegration of iron ore and so limestone is not recommended to be utilized for calcination.
- Therefore lime is added straight way as flux.
- If limestone is added as flux, lime will available only after the calcination, i.e. slag formation will be delayed.

Bauxite & Fluorspar :-($\text{Al}_2\text{O}_3 \& \text{CaF}_2$)

- These are added as fluxes to bring lime quickly in solution.

Dolomite :-

- It is used as flux and to help early formation of slag and safe guarding of the lining.

Iron Ore

- Use of iron ore in charge is to the formation of early slag.
- And also it acts as a coolant, if scrap is not available.
- In its cooling effect, 1% ore in the charge is nearly equivalent to 3.5% steel scrap.

gaseous Oxygen :-

- It is used as oxidizing agent to carry out the oxidizing reactions.
- Generally 99.5% purity oxygen is blown through the water cooled lance.
- The consumption of oxygen per tonne of steel made varies with proportions of scrap and ore added as coolants and also with single or multi hole lance designs.

LD Plant :-

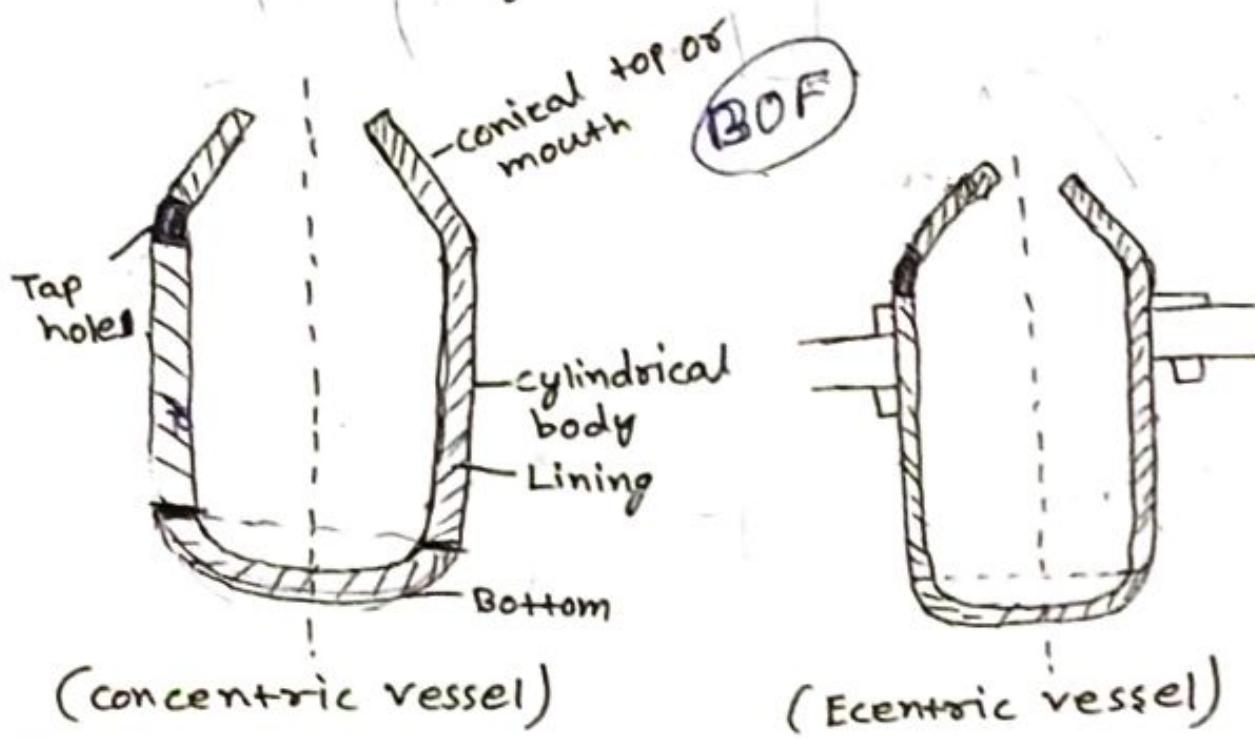
- A LD plant consists of the following major constituents.
 - ① LD vessel including foundations, rotating gears etc.
 - ② The O₂ lance
 - ③ The hood and waste gas treatment plant
 - ④ Material handling and storage facilities.
 - ⑤ Instrumentation & control pulpit
 - ⑥ The vessel lining & wrecking accessories.

The LD vessel :-

Construction :-

- The refining carried in a vessel known as LD vessel or LD converter or basic oxygen furnace (BOF).
- A modern oxygen converter has a cylindrical body or shell, conical top and the spherical bottom.
- Each of these is a welded construction of non-ageing steel plates.
- The converter shell is usually of the solid-bottom type and welded structure.
- In some cases, detachable or removable bottom are used instead of the solid type.
- Detachable - bottom converters can be repaired more quickly, since the lining is cooled more rapidly if the bottom is removed.
- Detachable bottoms, however, increase the risk of metal penetration through their joints with the shell.

- The top may be concentric or eccentric to the rest of the body.



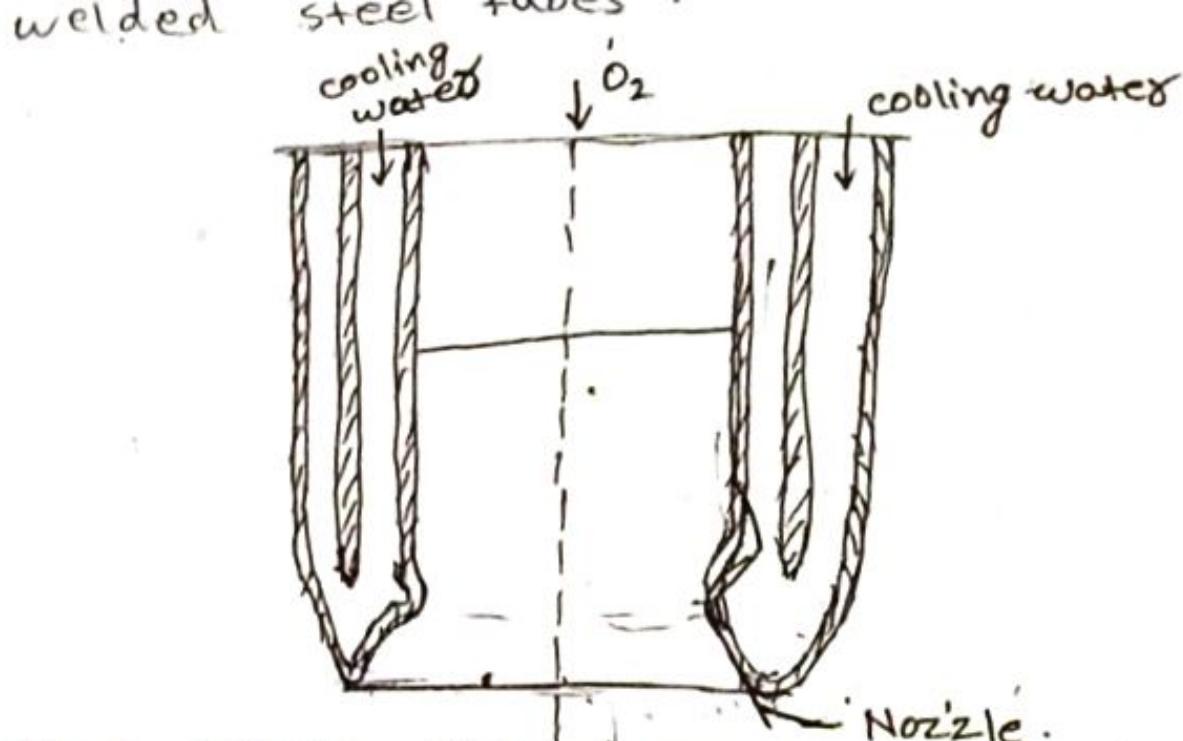
- The eccentric shape has the following adv.
 - The slag as well as metal removal is easy.
 - The gases, ejections etc. come on one side and regular cleaning of only that side is needed.
 - The construction of hood and insertion of a lance is easy.
 - The lance is protected and controlled in a better way since the hood is inclined.
- However, it has some drawbacks as,
 - The lining is not symmetrical and hence it is more difficult to lay.
 - The shop is congested since the charging and tapping are carried out on the same side.
- Inspite of these disadvantages, the eccentric shape is still almost universal, adopted because of the above mentioned advantages.
- In early designs, the converter was tapped from the mouth.
- In modern designs, a tap hole is provided at the junction of cylindrical body and the conical top.

The heavy weight of the vessel including the charge is uniformly taken over by a steel ring which is either welded or attached.

- These funions are attached to the ring to support the vessel freely in split & bearings.
- The vessel is capable of rotation through 360° but in practice it rarely exceeds 220° .
- It is rotated by an electric motor through a system of reduction gears.
- The capacity of oxygen converters varies within wide ranges.
- The ratio of the inner volume of a converter to the mass of metal charge is taken close to $1\text{m}^3/\text{t}$.
- The height to diameter ratio $H/D = 1.2 - 1.5$.
- The depth of the metallic bath is usually $= 1.6 - 1.9\text{m}$ and its unit surface area $= 0.12 - 0.18\text{m}^2/\text{t}$.
- The height of the vessel $= 7$ to 8m and the thickness $= 60 - 100\text{cm}$.
- The early vessels had capacities around 30-50t but the modern vessels are up to 400t capacity.

The oxygen lance:-

- The combination of devices for top blowing of oxygen including the lance, a stand by lance and lifting and transfer mechanisms, is rather complicated structure.
- For instance, the mass of a lance (together with cooling water & hoses) of a modern large converter is roughly 1.5 ton.
- The lance is made of three concentric steel tubes to circulate water around the central tube and pass oxygen through the most inner tube.
- Since the tip of the lance is exposed to very high temp., water cooling is necessary.
- The lance is made up of copper tip with

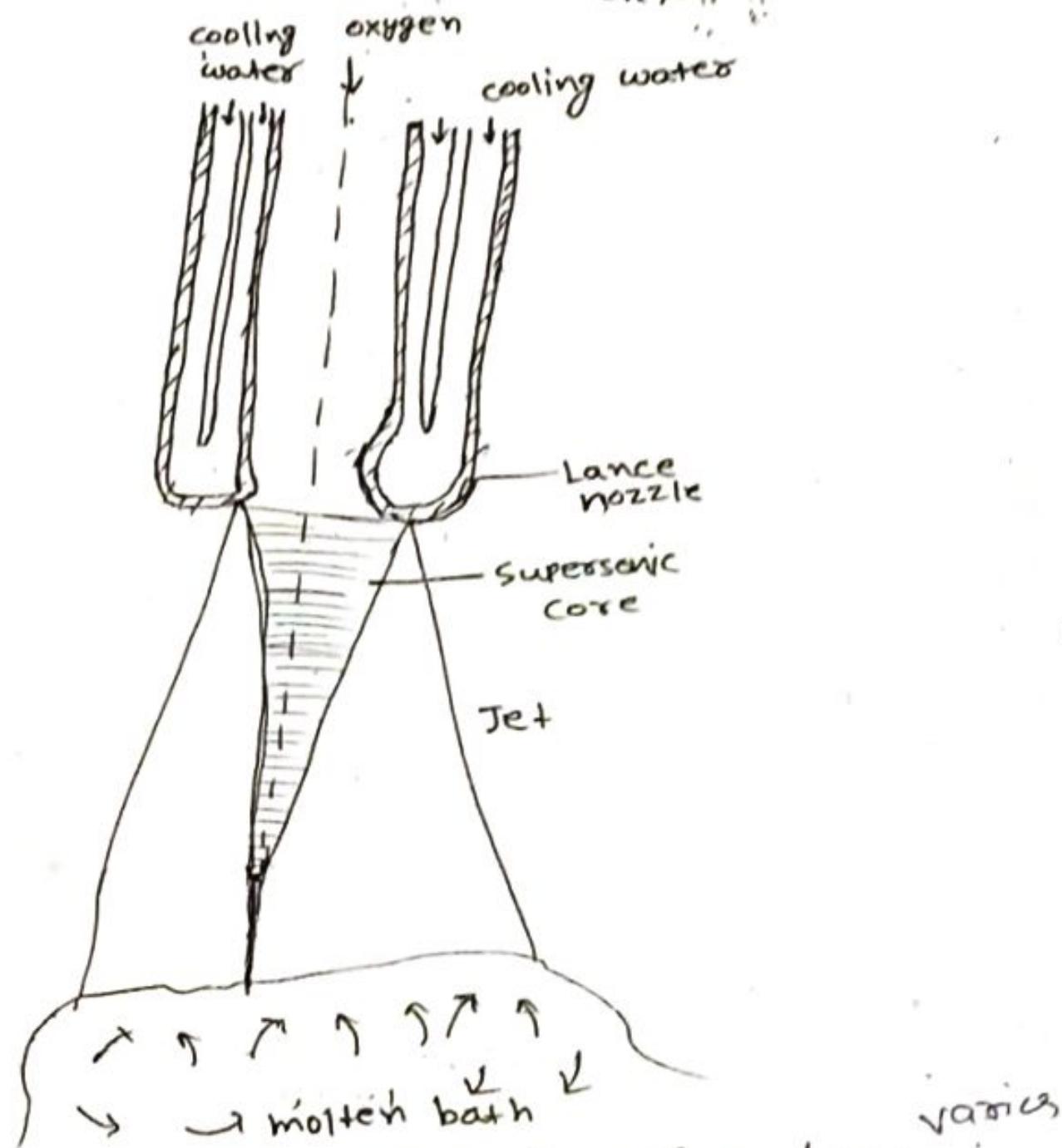


- It is nearly 8-10 metres long and its diameter varies with furnace capacity in the range of 20-25 cm., water requirements are around 50-70 m³/hr at a pressure of 5-7 kg/cm².
- The lance is suspended by a wire rope and can be inserted in or withdrawn from the furnace by means of an electrically operated lance gear.
- Jigs are used to hold the lance in a fixed blowing position.
- An additional lance is provided as a stand by to immediately replace a faulty one, to continue the blow.
- An oxygen lance should supply oxygen at the specified flow rate and form the jet of desired shape and have a sufficiently high durability and simple in design.

Oxygen lance design:-

- Earlier the LD process was developed using in lance with a cylindrical nozzle.
- Now it is replaced by a convergent-divergent laval shaped nozzle lance.
- The resultant bath penetration is more in case of laval shaped nozzle than that due to a cylindrical nozzle.
- Laval shaped nozzle is therefore universally adopted.

- Oxygen is generally blown at 8-10 atm pressure so that the jet issuing at the nozzle exit is supersonic and generally has a velocity between 1.5 - 2.5 times the velocity of sound.
- During blow, the jet should be expanded to obtain maximum impact area at the bath surface.
- At the same time it should also penetrate the bath surface to a maximum extent.



- The depth of penetration of a jet is inversely with the impact area at the bath surface.

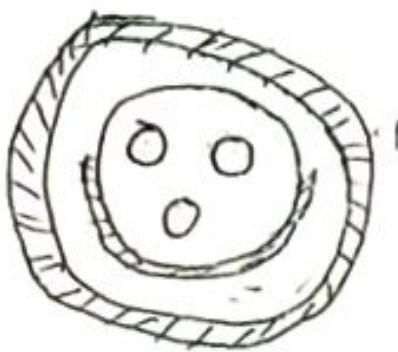
- The requirements therefore can only be met at the optimum.
- The depth of penetration of a jet in a bath can be assessed in terms of the jet force number as

$$JFN = \frac{\text{Gas pressure} \times \text{Nozzle throat dia}}{\text{Height of nozzle}}$$

- For greater value of JFN, decarburation is faster and dephosphorisation is faster faster for lower value of JFN.
- Oxygen lances may have a single nozzle (in small converters) or the multi nozzle (for bigger converters).
- Lances for high capacity furnaces have 5 to 7 nozzles. The blowing action of a multinozzle lance is quite different from that of a single nozzle lance.



Single nozzle lance design



Multinozzle lance design.

- The axes of nozzle in a multinozzle lance are inclined to the vertical axis of the lance by nearly 10° , so that they do not interact with each other.
- Hence 10° inclination is used to obtain non-interacting jets without lowering the Penetration Power.
- The impact area is considerably increased by use of a multinozzle lance.
- Therefore, multinozzle lance has fairly become popular for bigger converters.
- The dimensions, number and shape of nozzles are selected on the following considerations :
 - During particular period of the heat, the oxygen jet must penetrate as deep as possible

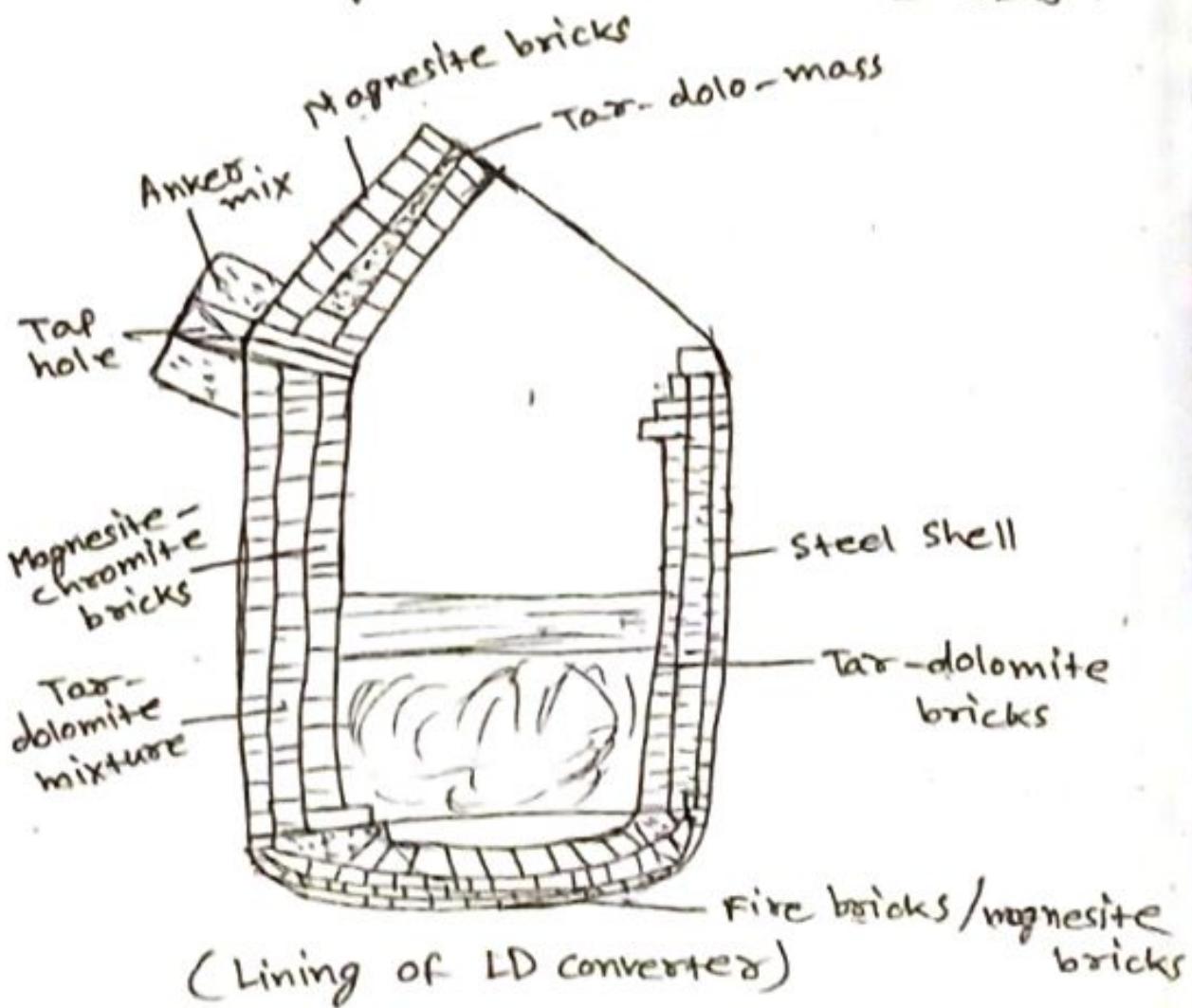
- (1)
- the metal bath (oxidation of carbon and better agitation of bath)
- (2) During other periods, the jet must act on the bath surface so as to accelerate the dissolution of lime in slag and form free running slag of the desired basicity.
 - (3) The effect of oxygen jet on the bath surface should not envalue splashing of metal and slag.
 - (4) The lance should be preferably simple in construction and reliable in operation.

Vessel lining:-

- The lining of oxygen converters operates extremely severe conditions, especially that is the cylindrical portion near the slag line, where it is in contact with the slag-metal emulsion formed by the oxygen jet acting on the bath surface.
 - The life of lining is usually measured by the no. of heats between capital repairs.
 - Without periodic repairs, the lining can withstand upto 1000 heats.
 - The consumption of refractories in poorly organised converters is less than 3kg/t.
 - In modern practice, tar-dolomite and tar-dolomite-magnesite refractories, which have a relatively low cost and sufficiently high durability, are the most popular materials for making oxygen converters lining.
 - The lining of a converter usually consists of a no. of layers.
- (a) Intermediate layers — usually made of tar-dolomite mixture.
- (b) Inner side of the converter — It is made of magnesite-chromite or roasted dolomite bricks.
- (c) The working layer — Which is in direct

Contact with Slag, metal and gases — It is made of tar-dolomite bricks.

- ④ The mouth — It is lined by high stable tar-dolomite or magnesite-chromite bricks.
- ⑤ Bottom — Magnesite bricks or Fire bricks.



- The life of lining depends on a no. of factors:
 - ① Method of charging of solid materials
 - ② The temp. conditions of heat.
 - ③ The slag conditions
 - ④ Temp. changes between heats.
- With all other conditions being identical, the life of lining is determined by the composition and quality of refractories.

Operation / Heat of a LD Converter :-

- The sequence of operation is as follows
- 1. After the previous heat is tapped and slag is drained, the vessel is brought to inclined position. The scrap is then charged from the charging chute in 1 lot (3-5 min)
- 2. It is brought back to horizontal position. Hot metal is charged (3-5 min)
- 3. The vessel is rotated to vertical position. Lance is lowered and oxygen is blown through the lance (1-1.5 min).
- 4. As soon as ignition takes place, a part of lime is charged along with other fluxes to form early slag. (3-5 min)
- 5. The blow continues for nearly 15-25 min. All this time lance height is altered. The oxygen is put off and the lance is raised up. (15-25 min)
- 6. The vessel is brought to inclined position. Metal and slag samples are taken for analysis. Alloying addition, if any may be added during this time 2-3 min. is allowed for homogenization. (5-8 min)
- 7. If analysis are correct, the vessel is turned to tapping position and steel is tapped into the laddle. Laddle additions may be done here. (4-7 min)
- 8. This gives a tap-to-tap time of 30-50 min. Delays due to tap hole repair, cleaning of tip etc may increase the heat time by a few minutes. The most efficient plants have an average tap-to-tap time of 30-32 min, whereas 40-50 min is considered as a good average time for most of the plants.
- If analysis are not correct, the vessel is reblown for a short duration.

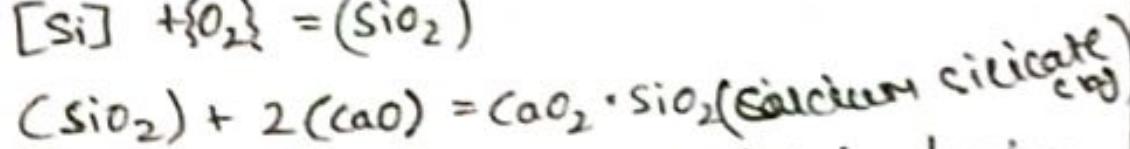
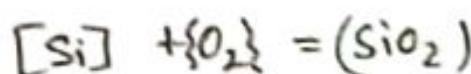
Chemistry of refining reaction :-

- The melting process in an oxygen converter may be divided into two periods.
- In the first period, the concentration of impurities in the bath are rather high.
- In the second period there remain almost no impurity in the bath.

- Oxidation of 'Si', 'Mn', 'C' & 'P' begins almost immediately as the blow is started.

① Oxidation of Silicon:-

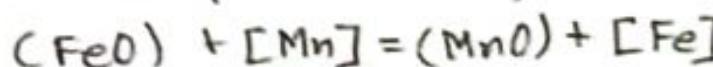
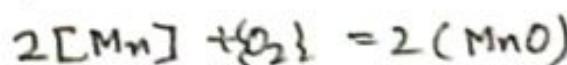
- It occurs intensively during a few minutes at the beginning of blow. Silica, which forms on oxidation reacts with CaO into silicates.



- Silicon is oxidised practically completely during a few minutes upon starting the blow.

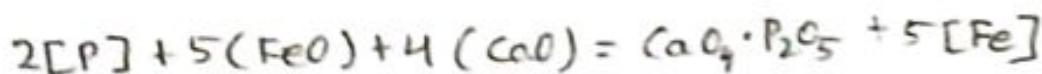
② Oxidation of Manganese:-

- The oxidation of manganese results in the formation of MnO. The concentration of manganese in the metal is determined by the following reaction.



③ Dephosphorisation:-

- The process of dephosphorisation develops as the basic slag is being formed. It is oxidised by iron oxides and CaO.



- This reaction is exothermic so that moderate temp. are favourable for its oxidation. Successful removal of phosphorous to slag is favoured by a high activity of iron oxides in the slag and high basicity of slag.

④ Oxidation of Carbon:-

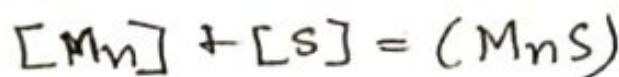
- The oxidation of carbon takes place during the whole period of blowing.
- The rate of carbon oxidation is determined by the intensity of oxygen supply and by the conditions of formation of CO.

- Therefore, carbon oxidation depends substantially on the shape of oxygen jets and on their depth of penetration into the bath.
- A jet penetrating deep into the bath forms many gas bubbles.
 - For that reason, blowing of the converter bath is usually carried out in two stages.
 - At the first stage, oxygen lance is raised an appreciable distance above the metal, which is favourable for the intensive oxidation of iron and formation of favourable for the intensive oxidation of iron and formation of ferruginous tiny slag.
 - At the second stage, the lance is lowered so that the jet penetrates deep into the metal bath which favours separation of CO and therefore the rate of carbon oxidation increases.

⑤ Removal of Sulphur:-

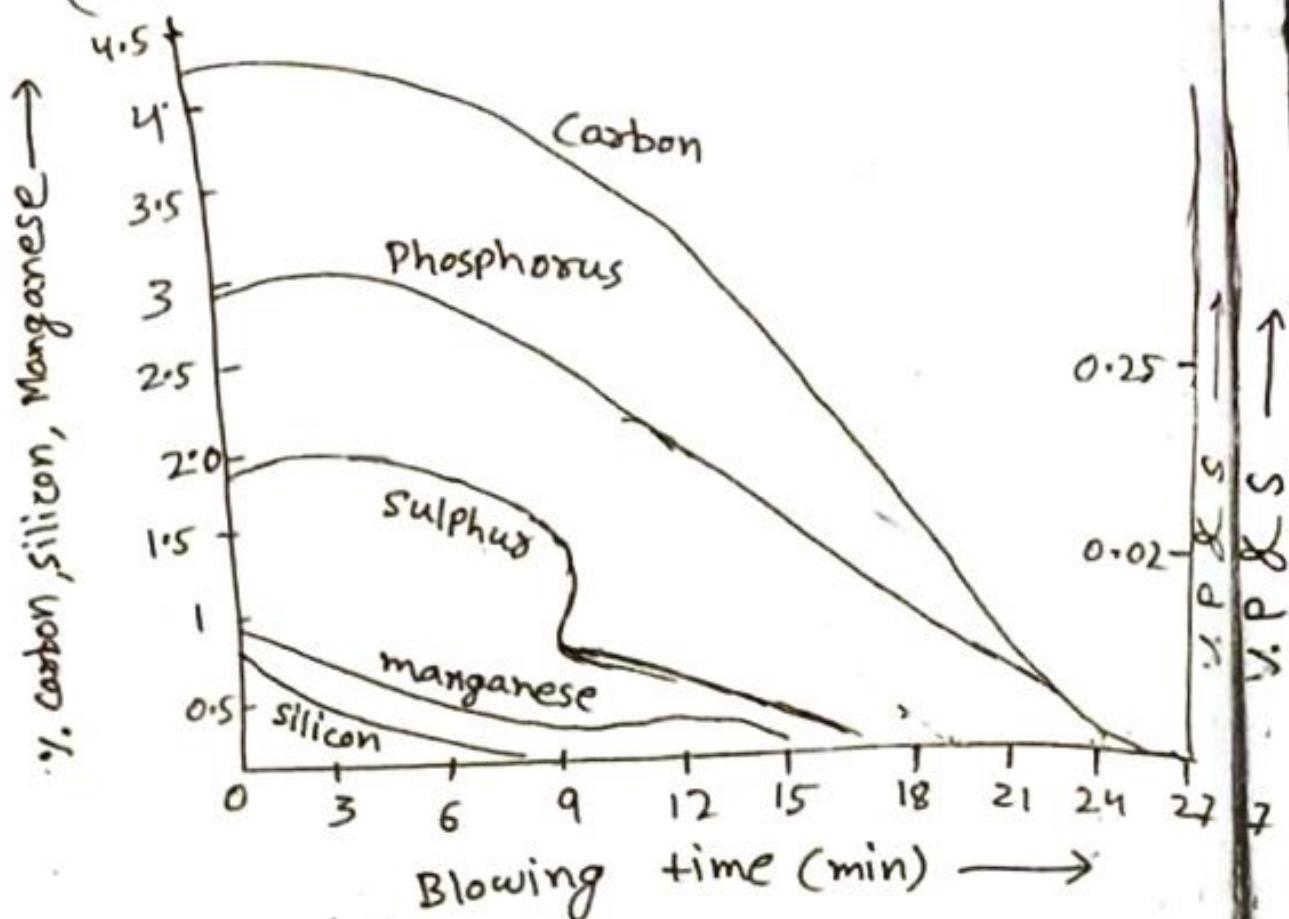
(K)

- In LD process, a certain portion of sulphur is removed in the course of heat, partially to slag and partially to gaseous phase.
- The most favourable conditions for sulphur removal exist in the bath at the very beginning of the process, when the metal is still high in carbon and silicon.
- In case when pig iron has a noticeable concentration of manganese, a definite positive role is taken by the reaction between the manganese and sulphur which are present in pig iron.



- Thus, almost all the silicon and carbon of the charge, most of the manganese and a definite portion of the phosphorus and sulphur are removed from the metal.
- The following figure shows the sequence

(Bath composition with blowing time)



Metallic yield :-

- The metallic yield is often 90% more of phosphorus and silicon contents in the hot metal generate large volume of slag and the yield decreases due to its increased loss of iron in the slag.

Converter slag :-

- The slag is basic in nature.
- Slag composition varies continuously during the blow.
- A typical composition of slag of dead soft steel is as follows.

$$\text{CaO} = 48 - 52\%$$

$$\text{FeO} = 16 - 22\%$$

$$\text{SiO}_2 = 10 - 16\%$$

$$\text{MnO} = 3 - 5\%$$

$$\text{MgO} = 2 - 5\%$$

$$\text{P}_2\text{O}_5 = 1 - 3\%$$

Composition of blown metal / quality of LD Steel :-

- LD process was earlier meant to produce only soft steels but now it has successfully been used to make even high carbon and alloy steels, including stainless steels.
- LD steels are characterized by their low phosphorus, nitrogen and carbon contents.
- The following is a typical composition of LD steel .

P - 0.012 - 0.017 %.

N - 0.003%.

C = 0.04%.

H = 3-4 cm³ /100 gm metal.

O = negligible .

Residual elements - very negligible .

- LD steels are generally cleaner than BOF steel .

Advantages of LD Process :-

- ① For comparable output , an LD installation requires much less investment than does an open hearth furnace .
- ② It is about 10 times faster than the OPH process .
- ③ Instead of air , pure oxygen is blown . This eliminates the harmful effects of nitrogen .
- ④ It produces steels with exceptionally low sulphur content .
- ⑤ It does not use an external source of heat or fuel .
- ⑥ LD process is operationally more efficient than OPH or electric process of making steel .
- ⑦ Over oxidation of the bath not take place .
- ⑧ It is very suitable for Indian pig irons as they contain an average of 0.3% P.

Limitation / Disadvantages :-

- The major disadvantage of LD Process is that the charge must include a considerable quantity of molten pig iron , thus limiting the amount of scrap that can be used .

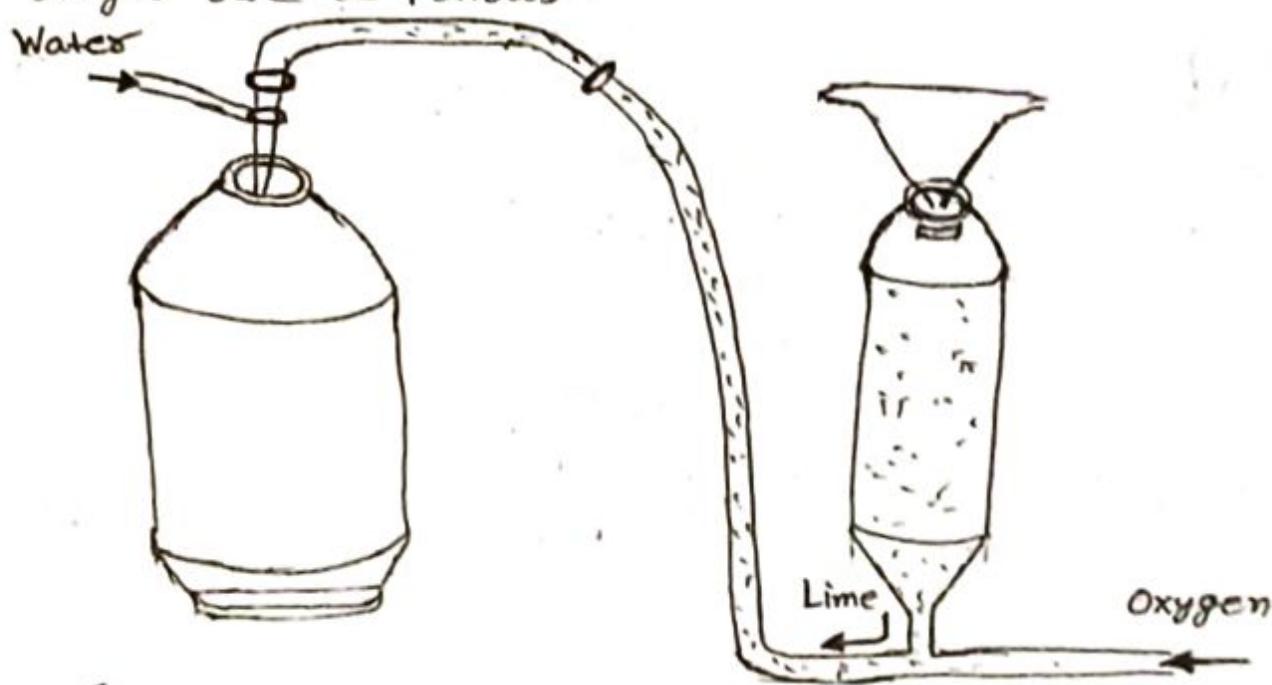
Development of LD Process :-

- LD process was originally designed to refine basic pig iron containing less than 0.4% P, to consume around 25% of the metal charge as scrap as coolant, to produce soft steel.
- As a result of wide applications, the process has undergone improvements in various ways.
- Some of the developments are as follows:
 - ① Capacity of the converter has increased from 30t to 400t and even 500t.
 - ② Height to diameter ratio has increased to 1.5.
 - ③ Single hole nozzle lances have universally been replaced by multi hole lances.
 - ④ Productivity has been increased.
 - ⑤ Blowing time has been cut in.
 - ⑥ Lining life has increased upto 2000 heats using better refractories.
 - ⑦ The operation has been fully automated.
 - ⑧ Product quality has been improved.
 - ⑨ Thermal input has been improved to take higher proportions of scrap (40%).
 - ⑩ Gas handling system has been improved to recover CO to use as a fuel.
- Some of the developments are described below in detail.

LD-AC or OLP Process:-

- Countries like Germany, France, Belgium, Luxembourg, UK etc produce Thomas grade iron (high 'P' content)
- Thomas grade pig iron - C = 2.2 - 3.5%
P = 1.5 - 2.0%
Mn = 0.7 - 1.0%
Si = 0.4 - 0.6%
S = 0.05%.
- LD process was modified by the CNRM in Belgium to refine Thomas iron and put into commercial practice at the ARBED-dulange works in Luxembourg.

- The process is known as LD-AC (A stands for ARBED, the Belgian concern and C for CNRM (Centre National des Recherches métallurgiques of Belgium and Luxembourg).
- One was called the OLP Process (Oxygen Lime/Lance process) and the other OCP Process (by the initial letters of the French words oxygen-chaux-pulverise - oxygen powdered Lime)
- The essence of the process and the sequence of stages are as follows.



(Diagram of a converter plant for OLP Process)

- The process is based on the use of ferruginous lime slag that is left in the converter from the previous heat.
- Pig iron is poured into the slag.
- Powdered lime is blown with the oxygen jet through the lance. The position of the lance is changed in course of blowing. At the initial stage it is held high (2m above the bath level) in order to accelerate slag formation and to remove phosphorus to a maximum. After that the lance is lowered to roughly 1 metre above the bath level for decarburisation. The period of blowing is usually continued for 14-16 min.
- The vessel is turned down for taking samples of metal & slag and for slagging off. The metal at this moment usually contains around 1.0% carbon.

and $0.11 - 0.13\%$. P and has a temp. near 1600°C . The slag contains roughly 55% CaO , 20-25% SiO_2 , around 23% P_2O_5 and very little of FeO (6-8%).

- ⑤ Scrap or iron ore is charged and the second blowing (with addition of powdered lime) is carried out for 6-8 minutes.

- ⑥ The vessel is turned down again for sampling of metal and slag. The metal at the end of the process-use has $0.04 - 0.05\%$. C and $0.015 - 0.017\%$. P and the slag is high in FeO (25%). The total consumption of powdered lime is 100-125 kg/ton pig iron.

- There is a lot of similarity between LD-AC and LD plants in design and operation.

- The vessel shape is however altered to a tulip shape with two tap holes diametrically opposite positions.

- The vessel volume is nearly 20% more than that of LD to accomodate extra slag volume generated in the process.

- With properly run heat are well organised slag cutting-off, the final steel will not contain more than 0.02% . P.

- Quick formation of a high basic slag is also favourable for desulphurisation of the metal.

The Sulphur content in the final metal is usually $0.01 - 0.015\%$.

- Time distribution between the stages of the OLP process is roughly as follows.

Iron pouring & scrap charging	—	1-6 min
First blow	—	14-16 "
Slagging off	—	4-5 "
Sampling & temp. measurement	—	2-3 "
Addition of scrap & iron ore	—	2-3 "
Second blow	—	6-8 "
Sampling & temp. measurement	—	2-3 "
Tapping	—	2-4 "
		Roughly 45 min.

- The tap-to-tap time is around 45 min.

Steel Production by Electric Furnace Processes:

Originally the electric furnace was used for the production of relatively small amounts of high grade tool steels and alloy steels. In modern integrated steel plants, however, it is widely used to produce high quality steels of special compositions from charges of 100% scrap.

Electric furnaces are of three types:

such as

- A. The electric resistance furnace *
- B. The electric induction furnace
- C. The electric arc furnace.



The electric resistance furnace is not used in steel making for a variety of reasons. The arc furnace process and induction furnace processes are described briefly below:

(C) Electric Arc furnace process of steel making

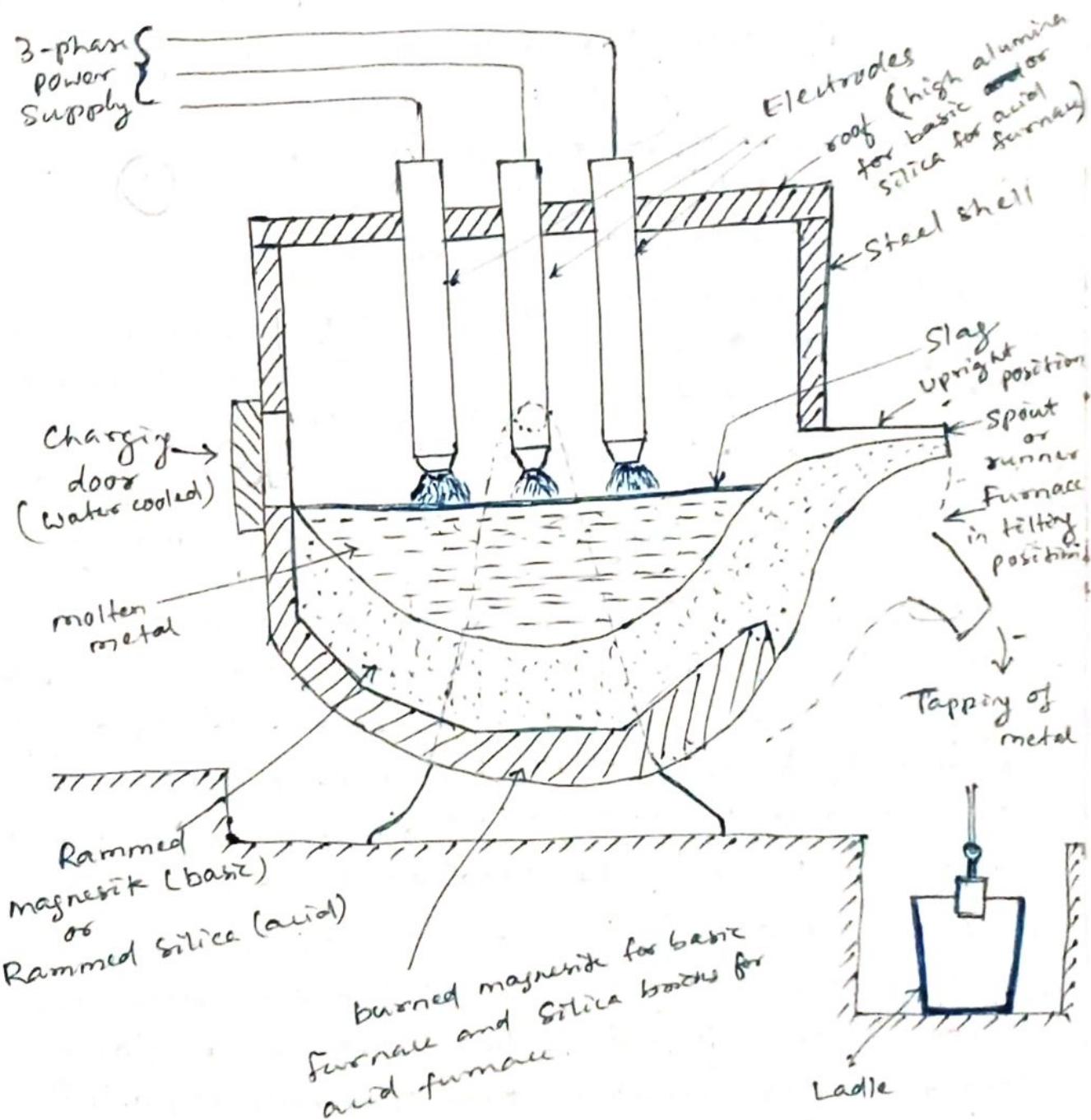
1. Direct arc furnace → In a direct arc furnace, current flows from the electrode to the charge and heat is transferred from the arc to the charge primarily by radiation; but a part of heat is also generated in the charge itself. A temperature of about 4000°C can be attained by direct arc f/c.

2. Indirect arc furnace → In indirect arc furnace, arc is struck between two carbon electrodes and heat is transferred to the charge by radiations.

Indirect arc furnaces are of small capacities and do not develop steel making temperatures readily. These are generally used for non-ferrous foundries.

A direct or an indirect arc furnace may be lined with acid or basic refractories. Acid lining is preferred when good steel scrap low in 'S' and 'P' is available so that removal of these two elements is not required. Acid lined furnaces are used

in steel foundries. A basic lined furnace is advantageous because inferior scrap may be used to make good steel. The basic process removes 'S' and 'P' from the melt. However, the heats take longer time than in acid lined furnaces. The following figure shows a direct arc furnace, with construction & operation.



(Direct Arc furnace)

The furnace the furnace proper looks like a saucepan covered with from top with an inverted saucer. The electrodes are inserted through the ~~top~~ cover from top. Arc furnaces are of two designs:

- (i) The roof along with the electrodes swings clearly off the body to facilitate charging and from top.
- (ii) The roof is tipped a little and the furnace body moves to one side clearly off the roof to facilitate charging.

The furnace ~~body~~ consists of the following parts:

- 1. furnace body - i.e shell, the hearth, the walls, the spout, the door etc.
- 2. Gears for furnace body movements.
- 3. Roof & roof lifting arrangements
- 4. The electrodes, their holders & supports
- 5. Electrical equipments ; e the transformer, the cables, the electrode control mechanisms, etc.

1. furnace Body

(a) Furnace Shell → The furnace shell is a welded or riveted steel plate construction and has a cylindrical saucepan like shape with spherical bottoms. The spout for tapping the metal is welded to the bottom and the main door is situated directly opposite the spout. The furnace shell is lined from inside with suitable refractory bricks.

(b) hearth → The bottom or hearth is the bottom of the furnace is called hearth. It is lined with magnesite bricks or rammed ~~to~~ with ~~to~~ dolomitic ~~brick~~ The contours of the hearth should be such that when tapping all the metal and slag should freely flow out. Newly rammed hearth is slowly dried and brought to the working temperature by placing coke on the bottom and striking an arc against it.

(c) Side walls → It is the cylindrical part of the shell, extends vertically from the slag line to the top of the shell. Side walls are lined with suitable bricks, generally magnesite brick. The thickness of the sidewall ranges from 35 to 50 cm.

(d) Tap hole → A tap hole of ramming mass is provided directly opposite to the door to tap the metal after heat is over.

(e) Door → For small size furnaces, a door is provided directly opposite to the tap hole for charging

Slagging off is also done by this ~~close~~ door. Bigger furnaces have another additional door at right angles to this door. The door is lined with basic bricks and generally water cooled.



Operation of Electric arc furnace

The heat of the arc furnace can be done in the following steps:

- (1) Preparation of the charge furnace Preparation.
- (2) Charging
- (3) melt down
- (4) Refining
- (5) Finishing and tapping of single slag heat
- (6) Slagging-off and mainly reducing slag
- (7) Reducting Period
- (8) Finishing and tapping of the heat.

(4)

1. Preparation of the furnace → EAF

After tapping the previous heat, the slag is completely drained out and lining is inspected. The ~~eroded~~ portion are repaired in hot condition using granular dolomite or magnetite. Fettling may be done manually or by machines. The tap hole is repaired and plugged before patching the slag line. The door sill, spout are cleaned and then patched. Door charged furnaces need more extensive repairs than top charged furnaces.

2. Charging →

In order to avoid mechanical damage to the hearth, first light scrap is charged. Then heavy scrap followed by light scrap. Bentonite and fluor spar are charged for the early formation of slag. (If refining is carried out during melting, lumpy iron ore or mill scale is included in the charge). Broken electrode pieces, cone etc are added to obtain required carbon in the bath, if required.

The furnace is charged from the basket held by an overhead crane. As a rule 40% heavy, 40% medium and 20% light scrap are incorporated to make up the charge which minimizes back charging. Heavy scrap pieces should be of such sizes and be charged in such a way that they do not cause bridging and short-circuiting of the electrodes.

3. melt down →

After the charging is over, the roof is replaced in position, the electrodes are lowered manually, the arc is struck and the electrodes are put on automatic control. As the metal just below the arc melts and drops down, the electrodes travel automatically further down to maintain a stable arc. The voltage is raised and the electrode is again allowed to bore until there is no danger of short circuiting. This is repeated till the electrodes travel to the bottom and a pool of molten metal is formed at the bottom. Hereafter, maximum power is fed to the furnace for melting the charge.

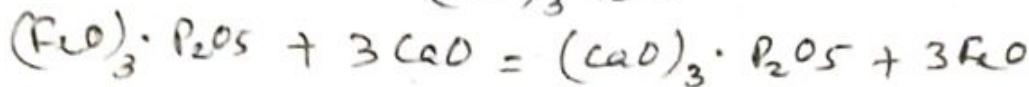
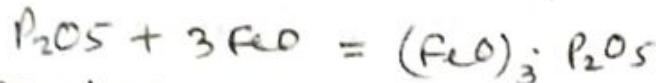
The presence of lime and fluor spar in the charge helps to form slag during melting. If ore is incorporated in the charge, most of phosphorus and silicon will be oxidized by the time of melt out.

4. Refining →

Refining continues even during melting. Actual amount of impurities to be oxidized from the charge is generally very small in coke furnaces. The oxidation reactions are:



~~Mn + FeO~~



The oxidizing slag at the melt out may have the composition like

$$\text{CaO} = 38-45\%$$

$$\text{SiO}_2 = 10-15\%$$

$$\text{FeO} = 13-20\%$$

$$\text{MnO} = 10-15\%$$

Refining can be commenced by the addition of ore

At the end of melting, control of phosphorus is necessary. Phosphorus can be eliminated by keeping the slag oxidizing and the basicity ~~up~~ of the order of 2.2 - 2.5. Since phosphorus is prone to removal at high temperatures it must be fully eliminated before the bath picks up temperature. If the bath temp rises before phosphorus is lowered, the bath has to be cooled down by adding ~~some~~-some scrap and refining iron ore.

During refining bath samples are periodically

taken out to assess the progress of refining. Once the chemistry of the bath and temperature are at the desired level, the heat is ready to be deoxidized by Fe-Mn, Fe-Si and finished for tapping.

4. Finishing and Tapping of a single slag heat →

Low carbon heats are tapped open without blocking which otherwise is a bath temperature at the time of blocking should be on the high side. Alloying additions can be made out to a properly blocked steel heat. Final deoxidation by Fe-Si, Fe-Mn and Al and other alloying additions can be made in the Saddle rodle.

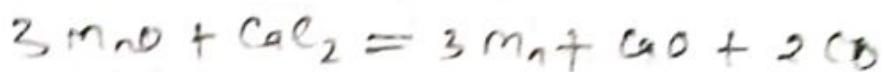
The heat is tapped by opening the tap hole, by tilting the furnace.

5. Slagging off and making reducing slag →

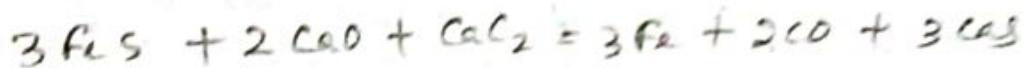
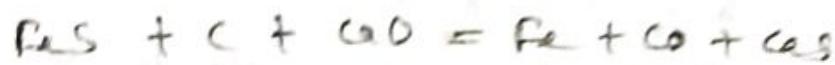
In a double slag practice, at the end of oxidizing period, slag is removed from the furnace by tipping it on the back side. Small additions of spar thin down the slag which flows over readily. Reducing slag is formed by adding fresh charge of lime and spar in which a little of sand may be mixed to help form the slag. Strongly reducing carbide slag can be formed by putting coke on the slag after it has melted. It forms carbide as

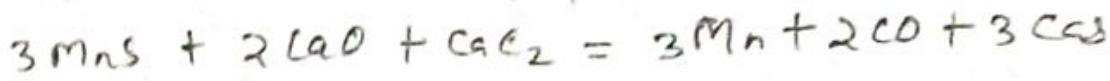


which is quite effective in desulphurizing the heat, further deoxidation occurs when FeO and MnO react with CaC₂



Sulphur which is present in the molten bath as either FeS or MnS is eliminated in the following way





7. Reducing period → for heats containing less than 0.15% C reducing slag is made by adding lime, Fe-Si and Al. No coke is added because it would carbonize the bath. The reducing slag compositions are approximately

(8)

$$\text{CaO} - 55-60\%$$

$$\text{SiO}_2 - 25-30\%$$

$$\text{FeO} - 1.0\% (\text{max})$$

$$\text{MnO} - 5-10\%$$

After the reducing refining is over, the bath is fully deoxidized by adding Fe-Si and Al.

8. Finishing and tapping of a double slag bath →

If the analyses are correct, ~~the it is tapped & the heat is tapped~~

Advantages of Electric Steel making →

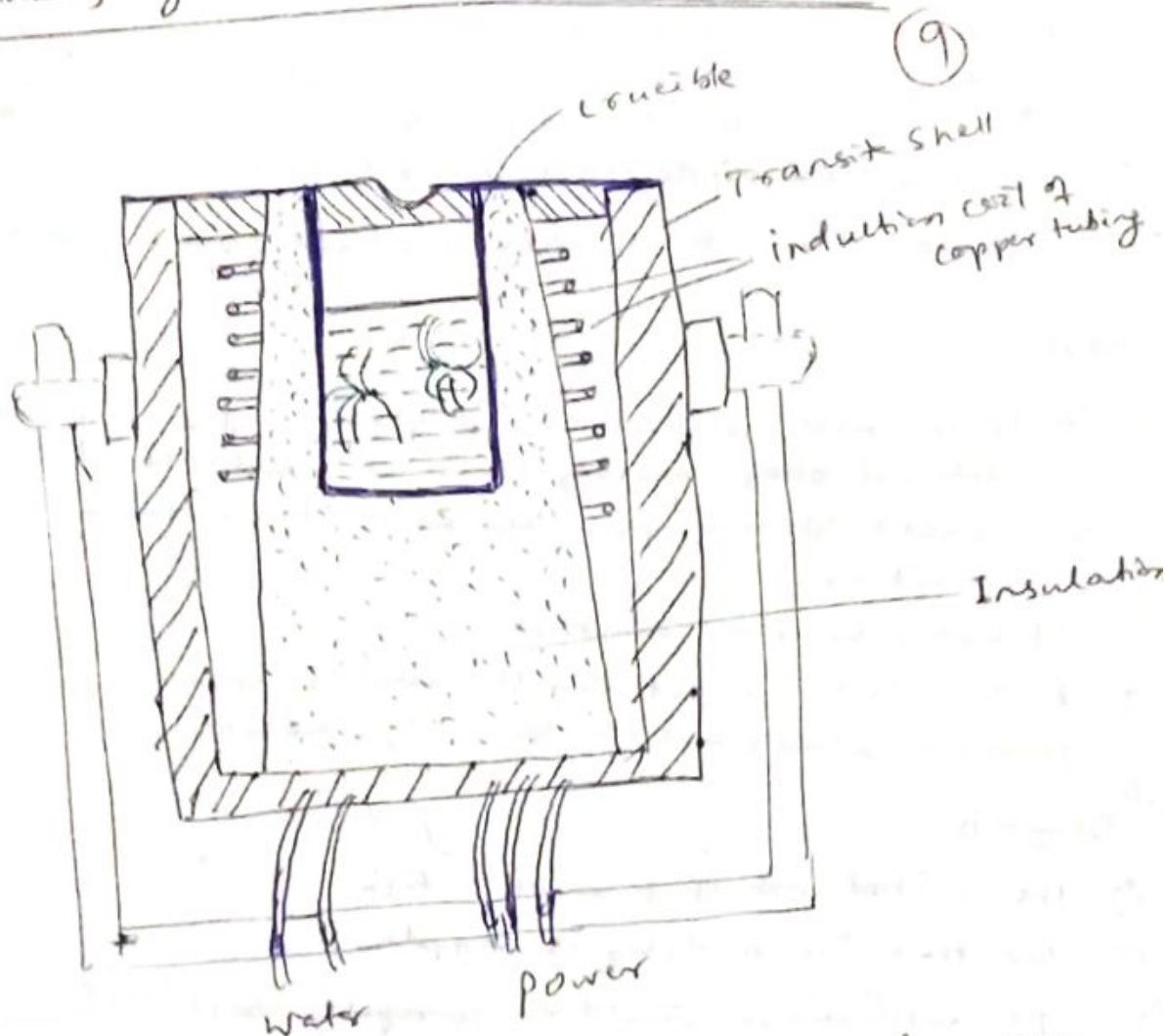
- ① Electric furnaces melt steel readily available, attain much higher temperatures and greater efficiency
- ② Temp. & atmosphere can be kept under strict control
- ③ The furnace has flexibility of operations. It can be operated ~~with~~ ^{at} cold as well as hot charges.
- ④ Charge is not contaminated as there is no gaseous fuel and air
- ⑤ Furnace conditions are cleanliness class.
- ⑥ High alloying steels can be manufactured with little or no loss of costly alloying elements. Alloying elements may be charged in the steel itself.

Disadvantages of electric steel making →

1. The power is not so fast as basic oxygen furnace processes.
2. It is ~~more~~ uneconomical unless electric power is available at a cheaper rate and in plenty.
3. Its cost is more than that of O.H or Bessemer process.
4. Many furnaces have small capacities.

Applications/uses → (1) manufacture of all stainless steels, carbon steels, heat resisting, engg alloy steels, tool steels and special alloy steels.

Steelmaking by Induction furnace Process



construction - A high frequency induction furnace consists of a refractory crucible placed centrally inside the water cooled copper coil and packed into position by dry refractory (insulation) tightly between the copper and crucible. The crucible has a sprout for pouring.

Principle of operation -

- ① light scrap is charged at the bottom ~~at~~ and hear at the top ~~at~~ to prevent atmospheric oxidation of the scrap.
- ② A high frequency current is passed through the water cooled copper coils which acts as the primary of a transformer and the metal charge becomes the secondary.
- ③ Heavy alternating secondary currents thus induced in the metal charge by electromagnetic induction create heat because the metal charge offers resistance to the passage of secondary currents.
- ④ The heat developed in the skin of metal charge reaches

inside by conduction and melts the charge.

- ④ The secondary current associated with it a ~~reg~~ magnetic field which provides a magnetic stirring action on the molten metal, speeds up the melting process.
- ⑤ The time taken by the charge to melt is short.
- ⑥ Once melted, the metal is deoxidized and poured into ladle.

(10)

Adv/Adv

- ① It can melt relatively small quantities of a wide variety of metals and alloys quickly, conveniently and cleanly.
- ② Magnetic stirring produces excellent uniformity of melt composition.
- ③ It has a simpler construction.
- ④ Rate of energy input can be readily controlled.
- ⑤ Furnace atmosphere can be easily controlled.

Demerits

- ① The initial cost of furnace is high.
- ② No time for analysis of sample.
- ③ The metal charge should be carefully selected.

Applicability

For melting several, special, high and low alloy quality steels.

Recent Steelmaking Processes

Ch-10
Page 1

1. Ajax process

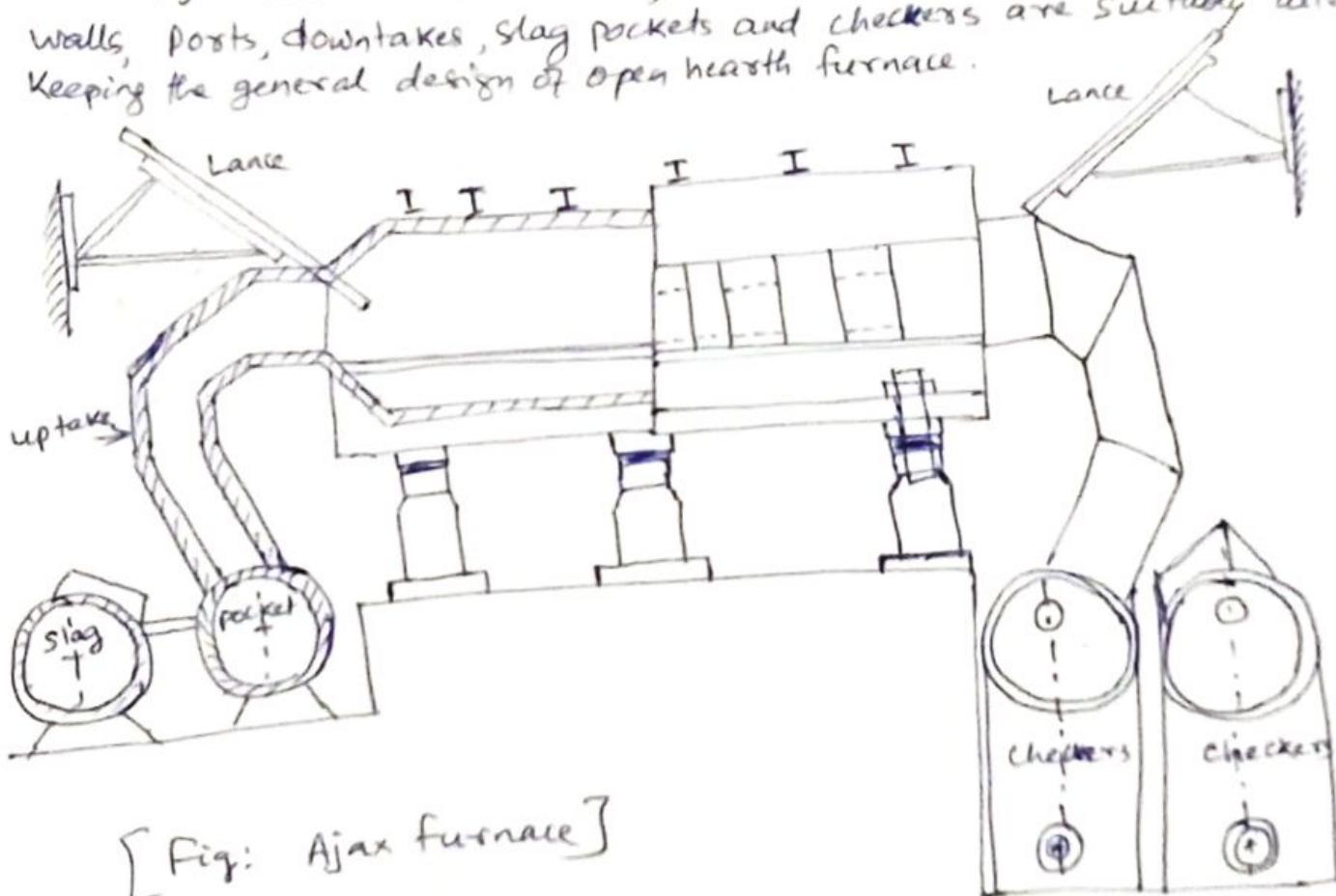
2. OBM process
Spray refining or steel or spray steel making Process

3.

1. Ajax Process of Steelmaking: →

Ajax process is the modification of the tilting open hearth furnace process in which oxygen lances are introduced through the ports instead of the roof in case of open hearth furnace process. The process was developed in UK and popularly known as Ajax process and the furnace employed as Ajax furnace (shown in the following figure).

Ajax furnace is essentially a tilting open hearth furnace. The end walls, ports, downtakes, slag pockets and checkers are suitably altered keeping the general design of open hearth furnace.



The downtime, slag pocket and checkers are cylindrical in shape. Each one of these are encased in cylindrical steel shells with appropriate openings and flanges. The slag pocket has its axis horizontal and that of the checker as vertical. The furnace is fired with coke oven gas provided on each end. It is used alternatively in conjunction with the direction of fuel firing and are completely withdrawn when not blowing. The lance is held at an angle of $27-34^\circ$ to the surface during blowing and has usually three nozzles. Oxygen is blown at 5-6 atm pressure.

Scrap is charged in the furnace and is preheated by fuel firing as in the open hearth practice. Hot metal is poured in and fuel supply is turned off. Oxygen lancing is immediately started from one end by lowering the lance inside the furnace. At the end of usual fuel cycle time it is withdrawn and the one on the other side is used. It works ~~alternatively~~ alternately.

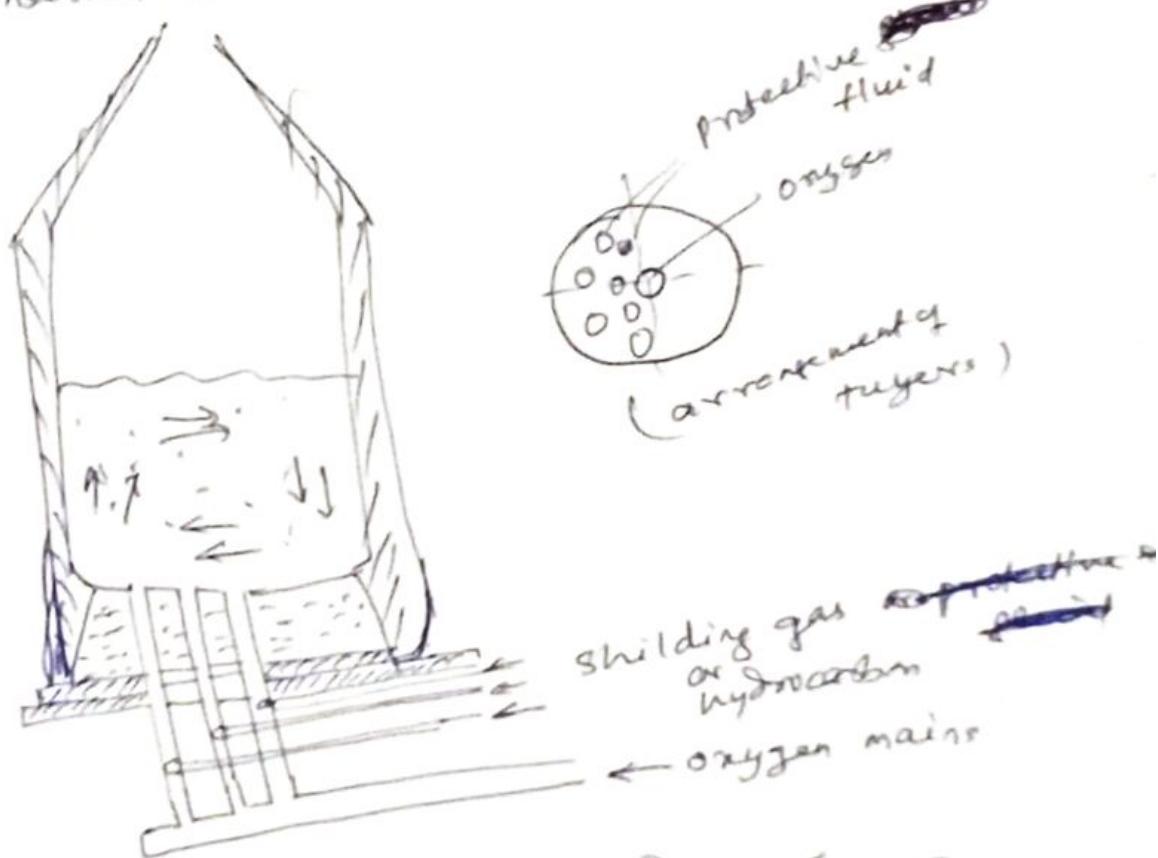
This process is meant to refine Thomas iron. Therefore, the blowing continues till the carbon drops to 1%, and phosphorous to 0.1 - 0.15%. By this time, the fertiliser grade slag is ready and is removed. Fresh lime and ore are charged to form second slag. Blowing is continued again till carbon is down to 0.4%, and bath temperature is upto 1570°C . At this time, oxygen lancing is stopped and the heat is finished. The tap-to-tap time is nearly 5-6 hours.

2. Oxygen Bottom blowing Process (OBM)

2. Oxygen Bottom Blowing processes (OBM Process)

In bottom blowing processes, oxygen is introduced from the bottom through tuyere holes with a peripheral shield of protective fluid. The tuyere is therefore made of two concentric tubes, oxygen being blown through the inner tube and protective fluid through the annular space between the tubes. The process was developed by the Maximilianshütte Iron & Steel Co. in West Germany in 1967 and was named as OBM process. It used propane or other gaseous hydrocarbon as protective fluid. The US Steel developed a similar process using a gaseous protective fluid and named it as Q-BOP (Quiet, Quick).

OBM process → The OBM vessel is a Bessemer like converter fitted with a special bottom. The tuyeres are inserted from the bottom in such a way that oxygen



would be surrounded by a protective hydrocarbon gas like propane. In order to promote turbulence in the bath, and ensure good slag-metal contact, the tuyeres are arranged only on half the converter bottom.

Operation — Thomas grade iron (1.8% P) is usually refined by OBM process. After charging scrap and hot metal, blowing is started. Lime is added immediately

from an overhead chute. The blow is divided into three distinct parts. The first part lasts for 16-17 minutes and at the end of which a high phosphoric slag ($18-22\% P_{2}O_5$, $12-15\% FeO$) is raked off. The carbon and phosphorus are analysed by taking a sample. The analysis is generally 0.3% C and 0.08% P, at this stage. Fresh lime is added and blowing continued for about a minute when the carbon comes down to 0.1%, and phosphorus 0.025%. The final blowing is of nitrogen without protective gas and thereby the bath averages finally 0.0004% H₂ and 0.005% N. The tap-to-tap time - 40 minutes.

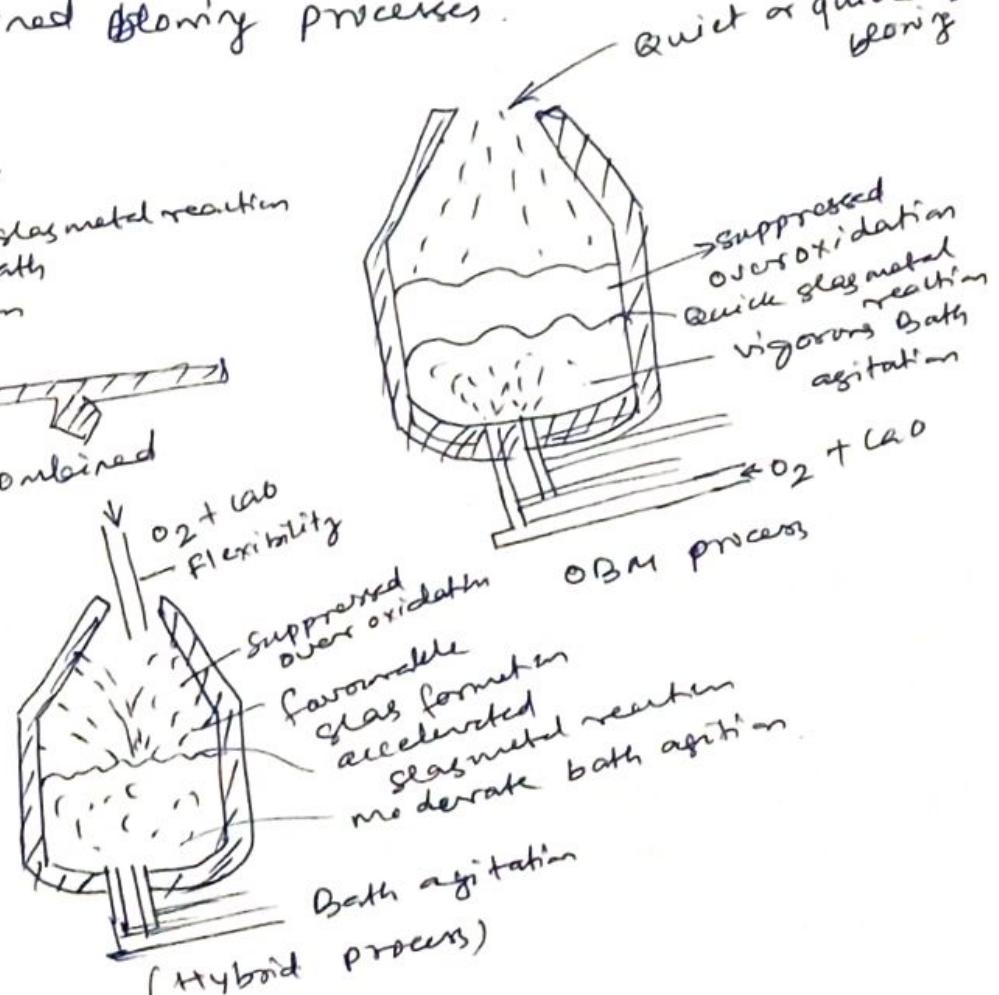
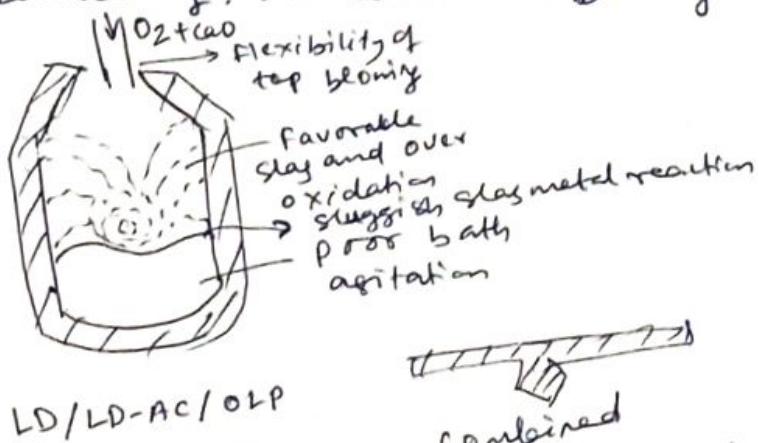
Metallic yield - 90-92%.

The process is capable of producing all variety of plain carbon steels.

(A nitrogen rinse is given at the end of refining to absorb dissolved hydrogen)

Combined blowing / Hybrid processes

All such processes where in gas phase is introduced from both top and bottom of the vessel are known as hybrid processes of steel making, or combined blowing processes.



Some Hybrid processes

- 1) LD-KG - ~~heat gas~~ + oxygen from top + bottom inert gas blowing
- 2) NK-CB - , , , + ~~heat gas~~ bottom inert gas
- 3) LD-OTB - , , , + , , "
- 4) LBE - " , , + " , "
- 5) STB - , , , + inert gas + oxidising gas
- 6) BSC-BTA ϕ - " , " + Air and nitrogen
- 7) LD-OB - " , " + O₂ and hydrocarbon
- 8) K-BOP - " , " + " , "
- 9) KMS - " , " + " , "
- 10) OBM No ~~top~~ + O₂ and hydrocarbons

LBE = Lance Bubbling Equilibrium

LD-KG = Kawasaki Steel Corporation, Japan.

LD-AB = Argon Blowing

LD-OB - oxygen blowing

STB - Sumitomo Metal Industries, Top and Bottom

K-BOP - Kawasaki, Basic, oxygen process

combined blowing process \rightarrow When oxygen is blown both from top and bottom.

more logically it is called hybrid process.

Bath agitated process \rightarrow If inert gas stirring is carried out from bottom only, with top oxygen blowing.

Characteristics of combined blowing processes \rightarrow

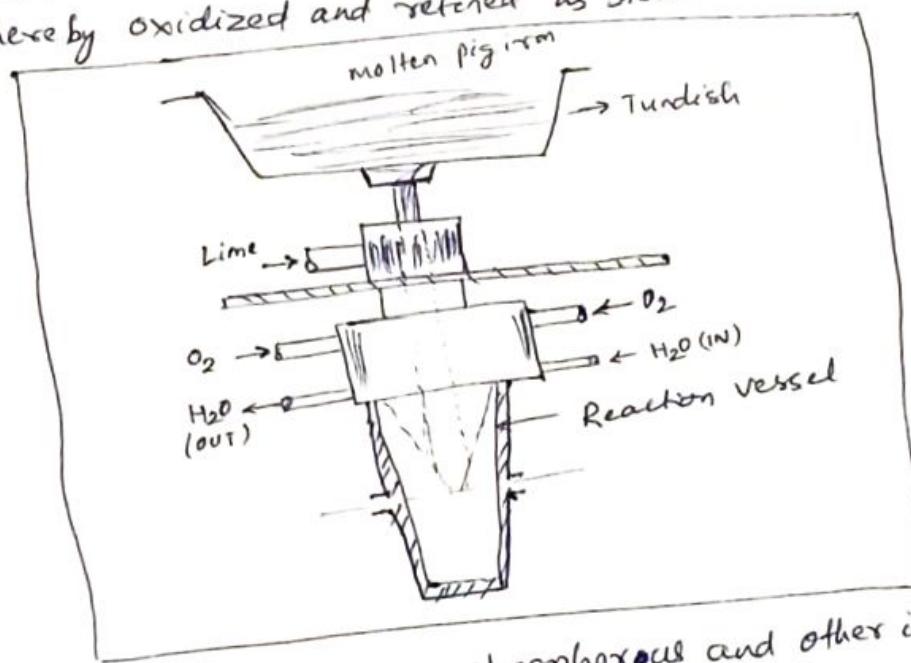
1. In bath agitated processes, bath stirring is caused by a neutral gas introduced below the metal bath.
2. In combined blowing process, oxygen is introduced from both top and bottom, bottom oxygen being protected by hydrocarbon shield. The proportion of oxygen blown from each end varies from process to process.
3. A small amount of inert gas (3%) (N or Ar) ~~about~~ of the volume of oxygen blown from top, introduced from bottom, agitates the bath effectively that slopping is almost eliminated.
4. If 20-30% of the total oxygen blown from bottom can cause adequate stirring of the bath. The increase beyond 30% contributes negligible addition of benefit.
5. However at 30% oxygen blowing from bottom leads to formation of very dry slag and possibility of its ejection during refining.
6. Blowing of inert gas from bottom has a chilling effect on bath and hence should be minimum.
7. As compared to top blowing, the hybrid blowing eliminates temperature and concentration gradients, effects improved blowing control, less slopping, higher blowing rates, reduces overoxidation, improves yield.
8. As compared to bottom blowing,

3. Spray steel making Process

~~Recent Steelmaking Processes~~

Spray steel making is a relatively new process wherein a stream of molten pig iron discharging from a tundish is subjected to jets of lime and of oxygen which oxidise and refine the molten pig iron into steel.

The apparatus used for spray steel making process includes a tundish having one or more elongated slots through which molten pig iron discharges as one or more thin films of metal. The slots are covered and uncovered by a slideable gate and the headers are arranged on opposite sides of the molten metal film. One pair of opposite headers discharge refining materials and another pair of similar headers discharge oxygen as jets that atomize the pig iron. The pig iron is thereby oxidized and refined as steel.



Carbon, Silicon, Manganese, phosphorous and other impurities in the pig iron react with the oxygen to form carbon monoxide, Silica, Manganese oxide, $P_2O_5^-$, and ~~sulfur~~ Sulphur is removed as SO_2 and Sulphide in the slag which to retain such oxides as SiO_2 , MnO , $P_2O_5^-$ and the slag should be oxidising and the flux therefore may be powdered lime. During the run of metal into the vessel, the extractor fan operates to withdraw gas and fume from the vessel. Large quantity of heat is generated by the reaction and may be used to melt scrap. This scrap can be placed in the reaction vessel before a run is started. Alternatively additional scrap or pre-reduced or partially reduced iron ore may fed into the reaction vessel by the chute.

The refining process may be a single-stage process or it may be effected in more than one stage. Thus a first stage spray refining may be effected to desilicorise and partly decarbonise the iron. This pretreated iron may be further spray refined to remove further impurities in second stage.

Continuous casting of steels

Principle: — It is the process of teeming of liquid steel in a short mould with a false bottom through which partially solidified ingot is continuously withdrawn at the same rate at which the metal is poured in the mould.

Advantages of continuous casting:

The continuous casting method has a lot of benefits compared to the older ingot casting methods. The ~~new~~ major advantages are

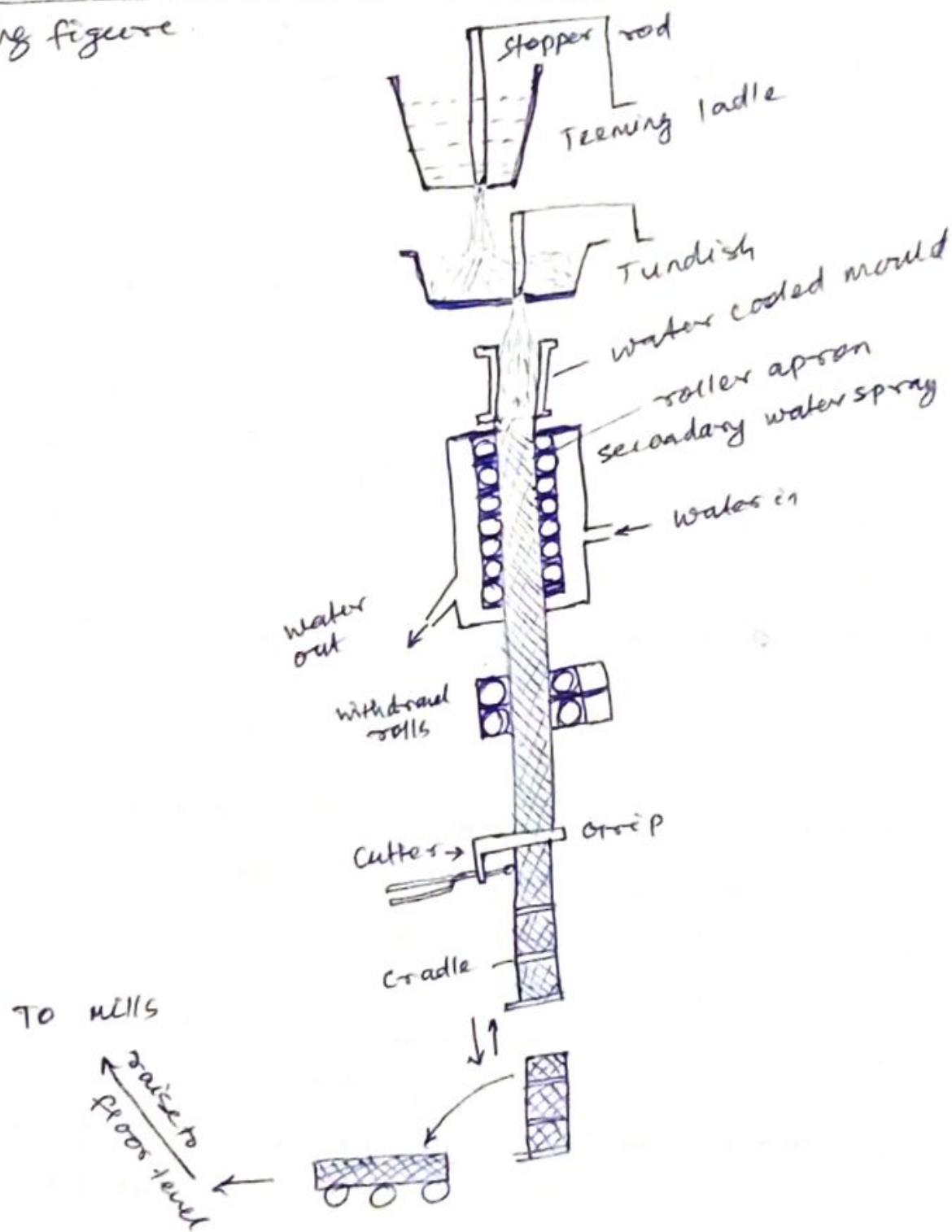
1. Savings of energy and manpower
2. Improvement of steel quality
3. Better yield of metal
4. Lower ~~cost~~ cost of production and large quantities of production
5. More economic than ingot casting.

The equipment for continuous casting of steel consists of

1. The ladle (to hold the 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. withdrawl rolls - (to pull out the ingots continuously from the mould)
5. cooling sprays - (for solidifying the ingot)
6. Bending or cutting devices
7. electrical and mechanical gears (to run the machine)

Types of continuous casting machines: — The main types of continuous casting machines are

1. vertical type continuous casting m/c
 2. vertical-mould and horizontal-discharge type continuous casting m/c
 3. The curved mould or S-type.
1. Vertical Type continuous casting machine. It is shown in the following figure.



This type of continuous casting machine is very tall and needs a tall shop to accommodate the equipment. It must need a high casting speeds and longer cooling zone. Hence this type of plant is used for large and medium sections to produce slabs. It is very simple in construction and most reliable to operate. All steel qualities can be cast out at very high speeds, without any fear of danger.

Construction & Operation →

The continuous casting machine consists of teeming ladle to which liquid steel is poured, a stopper controlled tundish to regulate the flow of liquid steel, a water cooled mould, roller apron to control the water cooling pressure, a water sprays, withdrawl rolls to withdraw the cooled slab and oxyacetylene torch to cut the slab in appropriate length, a cradle to store the slabs and a roller table to raise the slabs to ground floor level where they are sent to the mill.

In operation, the mould is kept ready by fixing the dummy bar in position. The teeming ladle is brought to in position and the temperature of the metal is measured. The teeming ladle must be preheated to the required temperature before tapping steel in it. Teeming commences when the temperature of the steel falls to the required level. The tundish must be preheated to the required level, by this time. The molten steel is allowed to collect to a certain level in the tundish before commencing pouring in the mould. As the level of steel in the mould rises to a certain pre-fixed level, the reciprocation of mould begins and immediately thereafter the dummy bar is withdrawn slowly. The secondary cooling sprays are put on as the dummy bar moves down. The speed of withdrawl should be quickly adjusted to the predetermined speed for the particular steel being cast. Pouring should continue steadily till the ladle is empty.

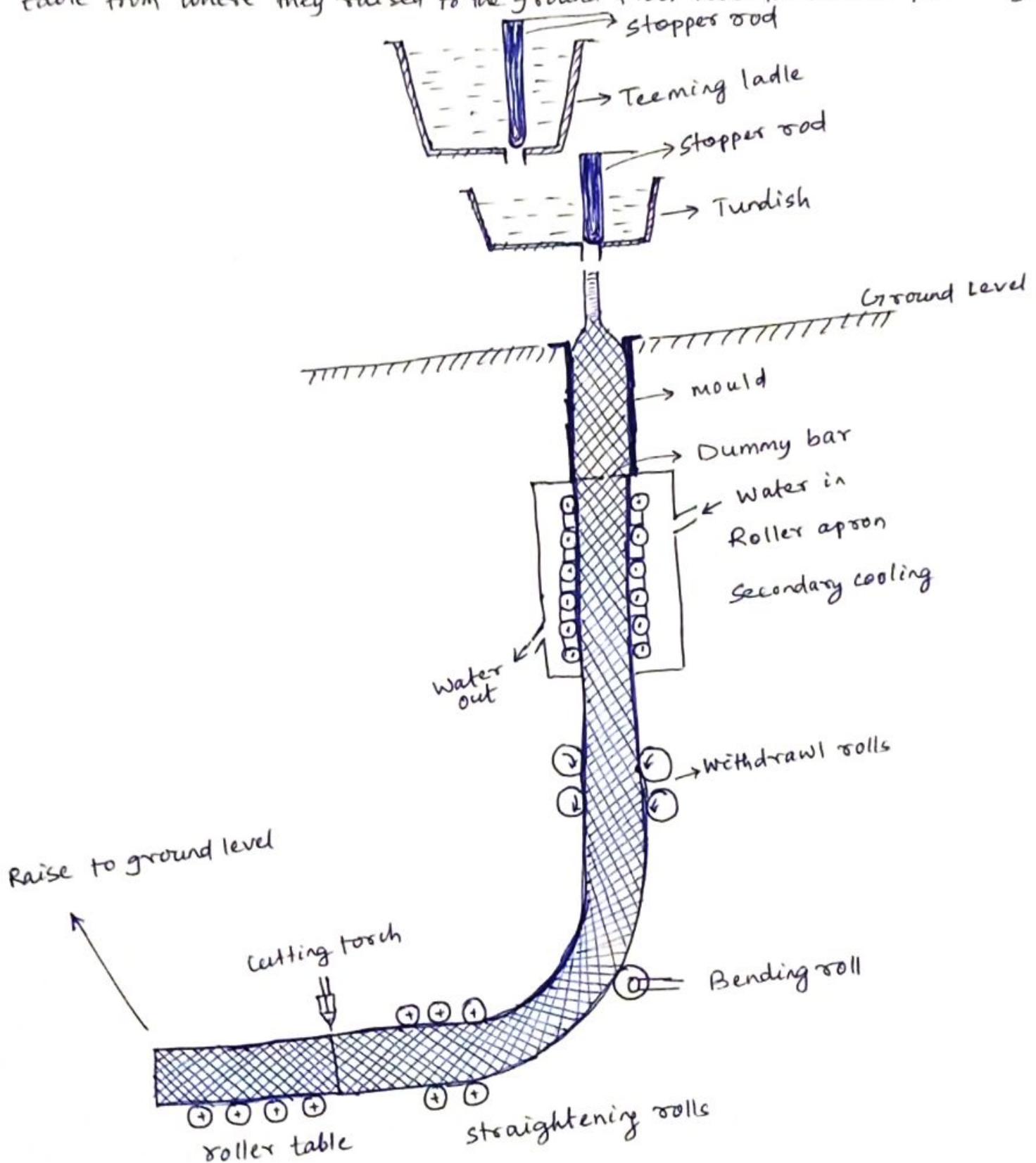
2. Vertical-Mould Horizontal-discharge type continuous M/c → Casting

construction & operation →

It consists of a stopper controlled teeming ladle, a stopper controlled tundish, a water cooled mould, roller apron, secondary cooling system, withdrawl rolls, bending rolls, cutting torch, and a roller table.

In operation, the molten steel is teemed into the teeming ladle in which the stopper rod controls the rate of teeming. Then the liquid steel is poured into the water cooled mould via a stopper controlled tundish. The mould has a false bottom which allowed the molten metal to the roller apron in which a secondary cooling system is provided, and solidification starts there. The solidified steel is moved by withdrawl rolls. A bending

roll is provided to bend the steel ingot to make it discharge horizontal. The bent slab is straightened by the help of straightening rolls. When the slab is fully horizontal, a cutting torch moves at the same speed to cut away in required length. The slabs are then moved to the roller table from where they raised to the ground floor level for further processing.



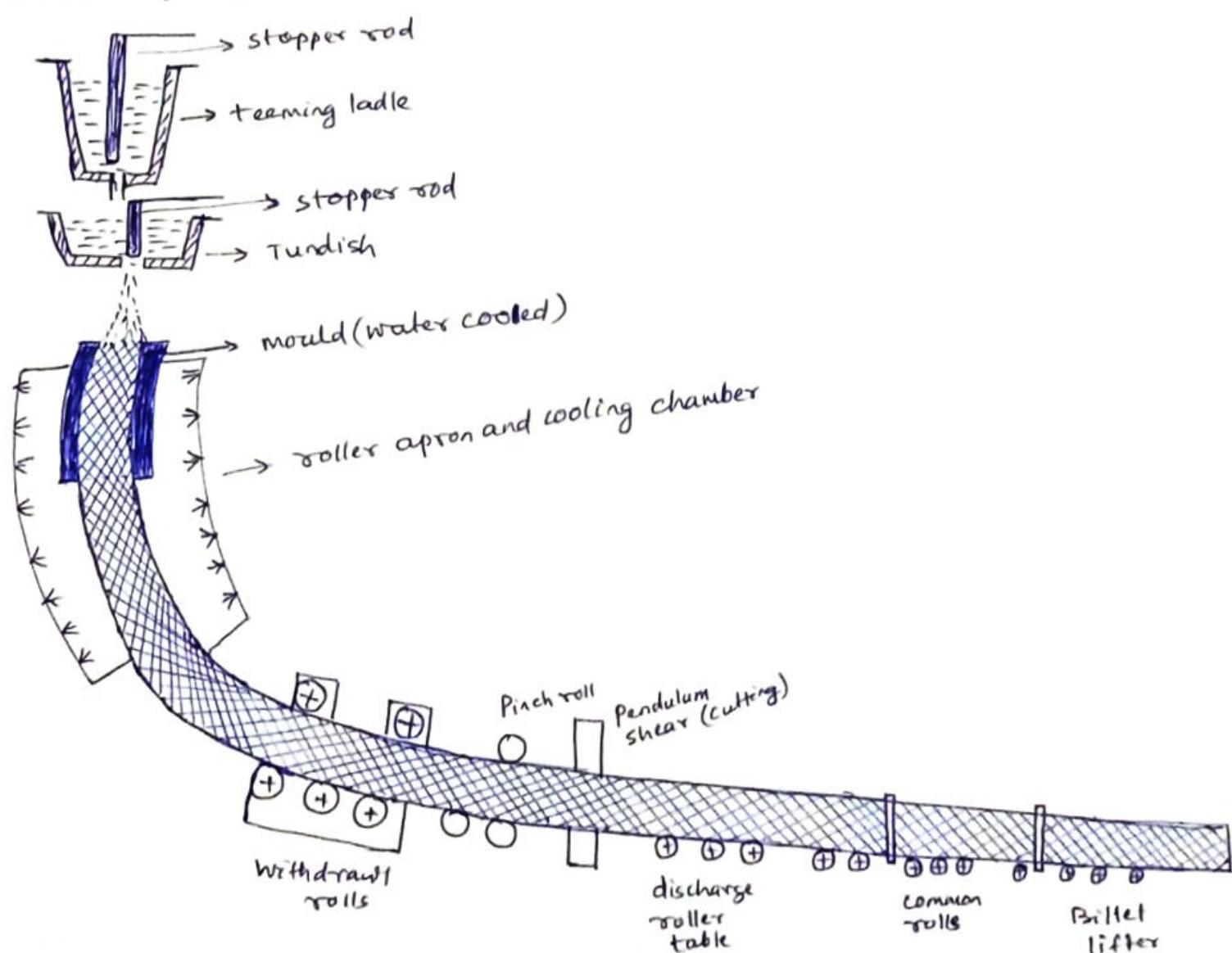
(Fig. vertical-mould Horizontal Discharge
continuous casting m/c)

3. The Curved Mould (S-type) Continuous Casting Machine →

This is the latest design almost universally adopted for continuous casting of almost any section like billets, blooms etc. The characteristics of this machine are:

- (i) The mould is itself curved one.
- (ii) The strands come out of the mould in curvilinear fashion with a fixed radius.
- (iii) It is bent before the entire cross-section is solidified.
- (iv) The curved strand is then straightened after it is fully solidified and cooled to desired extent.
- (v) The height of the shop is minimum.

The following figure shows the S-type continuous casting m/c.



(Fig: S-type continuous casting m/c)

Construction & operation: → It consists of a stopper controlled teeming ladle, a stopper controlled tundish, a water cooled mould (curved), roller apron and cooling chamber, withdrawal rolls, pendulum shear, Pinch rolls and a billet lifter.

In operation, the molten steel is teemed into the teeming ladle in which the stopper rod controls the rate of teeming. Then the liquid steel is poured into the water cooled mould via a stopper controlled tundish. This curved mould has a false bottom which allows the molten metal to the rollers apron in which a secondary cooling system is provided and solidification starts there. It is bent ~~before the end~~ after the entire cross-section is solidified. The solidified steel is moved by the withdrawl rolls. The bent billet is straightened by the pinch roll after which a pendulum shear is provided to cut the billet, at the desired length. It is then discharged horizontally and raised to the ground floor.



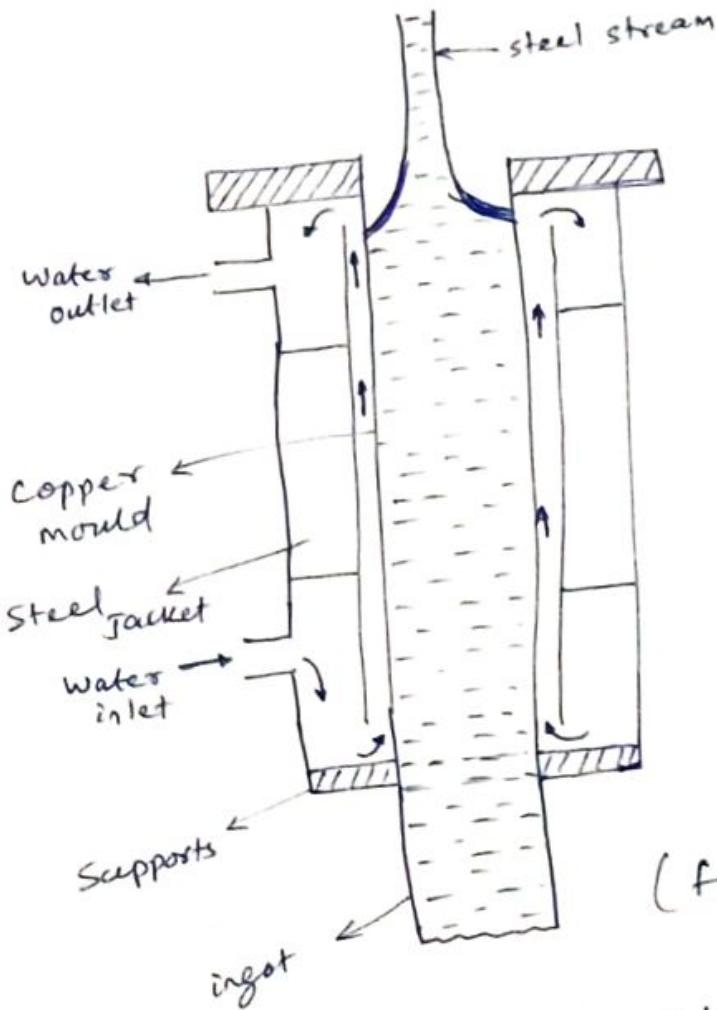
Disadvantages of continuous Casting:

- (1) Continuous and capable cooling of moulds is required, else centre-line shrinkage develops.
- (2) Just simple shapes can cast, which should have a stable cross-section.
- (3) Large capital investment is necessary to set up process.
- (4) Not proper for small amount production.
- (5) Requires a large ground space.

Mould and Mould maintenance in Continuous Casting Process:

In continuous casting, the mould is made out of drawn copper tube or machined out of a solid ~~block~~ block or it is a welded plate construction of high conductivity electrolytic grade copper as shown in the following figure. The mould is water cooled. It has open bottom and hence is closed by a dummy plug bar in the beginning. It is 75-140 cm in length. The modern moulds are tapered to narrow down towards the bottom. Moulds are lubricated to assist stripping. The main function of the mould is to produce and stabilize a solid shell resistant enough to withstand the metallic pressure of the liquid core and thus, contain the liquid phase at the entry of the secondary spray cooling zone. If the mould system does not work properly, a break-out can take place and the hot liquid steel core can

burst open, pouring liquid steel onto the machine and causing a very dangerous situation. As there is a relative motion between the strand and the mould wall, some form of lubrication is needed. A thin film of lubricating oil or of lubricating flux is interposed between the mould and hot liquid phase to prevent its direct contact with the mould, which can potentially endanger and damage the mould itself. Liquid steel in the slab mould is normally covered with a layer of mould powder (casting powder) to protect the steel from reoxidation and absorb inclusions. The powder has a low melting point and flows over the liquid steel to provide mould lubrication and to help control heat transfer. It also serves to protect the liquid steel against reoxidation, thermally insulate the free surface and absorb any inclusion which can float to the surface. Rapeseed oil has typically been used to prevent sticking to the mould in case of billet casting.



(fig. Mould of continuous casting machine)

During continuous casting, the copper mould plates controls the shape and initial solidification of the steel product, where quality is either created or lost. Maintaining a reliable, crack-free mould with close dimensional tolerances is also crucial to safety and productivity.