LECTURE NOTES

On

MANUFACTURING OF STEEL AND STAINLESS STEEL

ORISSA SCHOOL OF MINING ENGINEERING, KEONJHAR
ଓଡିଶା ଖଣି ଯାନ୍ତ୍ରୀକ ବିଦ୍ୟାଳୟ, କେଉଁଝର
GOVERNMENT OF ODISHA | ଓଡିଶା ସରକାର

COURSE COORDINATOR: Smt.PARASMITA BISWAL

Metallurgical Engineering Department

Orissa school Of Mining Engineering ,Keonjhar

Subject code: TH-1(MTPC301)

Session- 2026-27

Vision and Mission of the Department

VISION: To offer quality technical education In the field of Metallurgical Engineering with orientation towards industry, entrepreneurship, higher education and to strive for developing professionally competent technicians meeting the needs of the global economy.

MISSION:

M1 : To develop students in the field of Metallurgical Engineering as highly motivated, skillful and qualified manpower for employment and higher learning

M2 : To promote a conducive environment for all round development of students.

M3 : To promote linkages with external agencies to meet changing needs of industry and society.

M4 : To Improve Laboratories

Program Education Objectives (PEOs)

PEO 1: Diploma professionals will be able to make a successful career in metallurgical industries or higher studies to meet the needs of future requirements.

PEO 2:Diploma metallurgists will have technical and behavioral competencies through adequate exposure to industry.

PEO 3: To impart technological knowledge and skills for solving real-time engineering problems.

PEO 4: To develop human resources with capabilities of effective communication, moral values and social responsible .

Units	Topics/Sub-topics	
Unit-I	**Fundamentals of Steelmaking** Definition and objectives of steelmaking, Role of carbon and impurities (Si, Mn, P, S, O, N), Acid and basic steelmaking processes, Raw materials: hot metal, scrap, fluxes, Basic thermodynamics and kinetics of steelmaking reactions, Conditions for removal of Si, P, S, Mn, and C, Overview of steel grades and their composition, Brief study of obsolete processes: Bessemer process and Open- Hearth process (with limitations)	
Unit-II	**Primary Steelmaking Processes** **Steel Making by LD Converter:** Raw materials of LD process, construction and operation of LD converter, emulsion and refining reactions in LD converter and sequence of elimination of impurity, Mn hump, quality of steel and composition of slag in LD process, advantages and limitations of LD process, importance of lance height, developments in LD process: multi nozzle lance, combined blowing process. **Other Steel Making Processes:** Working principle, process, advantage and limitations of: OLP process, OBM Process. **De-Oxidation Practice:** De-Oxidisers and their use**,** Killed, semi killed and rimming steel.	
Unit-III	**Stainless Steel Manufacturing** **Introduction to Stainless Steels:** Definition and role of chromium (passivation)**,** Classification: Austenitic, Ferritic, Martensitic, Duplex, Precipitation hardening, Properties and applications, **Stainless Steel Making (Primary processes):** Raw Materials for stainless steel making**, Electric Arc Furnace:** Principle, types of slags prepared by electric arc furnace, steps of electric arc furnace heating to produce stainless steel, advantages of electric arc furnace process**,** **Induction Furnace:** Principle and process of induction furnace, advantages and limitations of induction furnace process, **Secondary Steel Making Process:** Objectives of secondary steel making, Principle of operation and advantages of secondary steel making processes such as: LHF Process, VOD Process, AOD Process and RH-OB degassing process, Inclusion Control and Clean LHF Process, VAD Process and RH- OB degassing process, Inclusion Control and Clean Steel Production, Process Control and Automation in Secondary Steelmaking**,** Stainless steel grades and their industrial selection criteria.	
Unit-IV	**Casting, Defects & Green Steel** **Pit Side Practice:** Teeming methods such as: Direct pouring , Tundish teeming and Bottom teeming, Ingot defects, their causes and remedies, **Continuous** **Casting of Steel:** Principle and	

	operation of continuous casting, types of casters, advantages of continuous casting, products of Continuous casting, **Green Steel Technology:** Brief idea on green steel, its advantages**,** Sustainable Practices in Steel Industry**,** Basic idea about Emissions and Effluent Treatment**,** Basic idea about Waste Heat Recovery and By- product Utilization	

Lecture 01

Fundamentals of Steelmaking

Steelmaking is the process of converting molten pig iron or scrap steel into steel by removing impurities and controlling the chemical composition to obtain the desired mechanical and physical properties. Steel is one of the most important engineering materials and is widely used in construction, transportation, machinery, and manufacturing industries.

1. Raw Materials

The main raw materials used in steelmaking are:

- **Hot metal (Pig iron):** Obtained from the blast furnace and contains about 4–4.5% carbon along with impurities such as silicon, manganese, phosphorus, and sulfur.
- **Scrap steel:** Recycled steel used to reduce production costs and conserve natural resources.
- **Fluxes:** Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are added to remove impurities by forming slag.
- **Oxygen:** High-purity oxygen is used to oxidize unwanted elements.

2. Principle of Steelmaking

The fundamental principle of steelmaking is the **oxidation of impurities**. Oxygen reacts with carbon and other impurities present in molten iron. These impurities are converted into oxides, which either escape as gases or combine with fluxes to form slag. The slag floats on the molten steel and is removed, leaving purified steel.

- Steel making is a high-temperature chemical process focused on **melting, purifying, and alloying** molten iron to lower carbon levels and remove unwanted elements. The core principles rely on controlled **oxidation**, **slag formation**, and **reduction**

Key Chemical Principles:

- **Oxidation:** Oxygen is injected into molten pig iron to burn off excess carbon (reducing it usually below 1%), silicon, manganese, and phosphorus into oxides.
- **Slag Formation:** Fluxes like burnt lime (CaO) are added to combine with oxidized impurities (SiO_2, P_2O_5) to form a floating layer called slag, which isolates and removes the waste.
- **Reduction & Deoxidation:** Special agents are added near the end of the process to remove remaining oxygen and sulfur, ensuring the steel does not become brittle.

Alloying: Specific amounts of elements like chromium, nickel, or manganese are mixed in to achieve the exact mechanical properties required for the final grade of steel.

Lecture 02

Definition and Objectives of Steelmaking Definition of Steelmaking

Steelmaking is the metallurgical process of converting molten pig iron or scrap steel into steel by removing impurities such as carbon, silicon, phosphorus, sulfur, and manganese, and by adjusting the chemical composition to obtain the desired mechanical and physical properties.

Objectives of Steelmaking

The main objectives of steelmaking are:

1. **To reduce the carbon content** of molten pig iron to the required level for different grades of steel.
2. **To remove harmful impurities** such as phosphorus, sulfur, silicon, and excess manganese.
3. **To produce steel with the desired chemical composition** by controlling the amount of alloying elements.
4. **To improve the mechanical properties** of steel, such as strength, hardness, toughness, and ductility.
5. **To remove dissolved gases** like oxygen, hydrogen, and nitrogen that can affect steel quality.

Key points of Steelmaking

Carbon Reduction: Lowering the high carbon content from roughly 4% in raw pig iron down to generally less than 1% (or up to 2% max) to remove brittleness.

Impurity Removal: Oxidizing and removing unwanted chemical elements like silicon, phosphorus, sulfur, and excess gases (oxygen, nitrogen, hydrogen).

Precise Alloying: Adding specific elements like manganese, chromium, nickel, or vanadium to achieve targeted mechanical properties such as strength, toughness, and corrosion resistance.

Homogenization: Adjusting and stabilizing the temperature and chemical composition of the molten batch so it meets strict industrial quality standards before casting.

Lecture 03

Role of Carbon and Impurities in Steelmaking

During steelmaking, carbon and various impurities present in molten iron significantly influence the quality and properties of steel. Their levels must be carefully controlled.

1. Carbon (C)

- Carbon is the most important element in steel.
- It increases **strength and hardness**.
- Excess carbon reduces **ductility and toughness**.
- During steelmaking, carbon is reduced to the desired level by oxidation.

2. Silicon (Si)

- Silicon acts as a **deoxidizer** in steel.
- Excess silicon makes steel **hard and brittle**.
- It is removed by oxidation to form **silica (SiO_2)**, which enters the slag.

3. Manganese (Mn)

- Manganese improves **strength, hardness, and wear resistance**.
- It combines with sulfur to form **manganese sulfide (MnS)**, reducing the harmful effects of sulfur.
- Excess manganese is removed by oxidation.

4. Phosphorus (P)

- Phosphorus increases **hardness and strength**.
- High phosphorus causes **cold brittleness**, making steel brittle at low temperatures.
- It is removed during basic steelmaking by forming phosphate compounds in the slag.

5. Sulfur (S)

- Sulfur is a harmful impurity.
- It causes **hot shortness (hot brittleness)**, making steel crack during hot working.
- Sulfur is removed by reaction with lime and manganese during refining.

6. Oxygen (O)

- Dissolved oxygen forms oxide inclusions in steel.
- It reduces toughness and causes defects.
- Oxygen is removed by **deoxidation** using aluminum, silicon, or manganese.

7. **Nitrogen (N)**

- Nitrogen increases strength slightly.
- Excess nitrogen causes **aging**, brittleness, and reduced ductility.
- Nitrogen content is minimized by proper steelmaking and refining practices.

Acid and Basic Steelmaking Process

Steelmaking processes are classified as **Acid Steelmaking** and **Basic Steelmaking** based on the type of refractory lining and slag used.

1. **Acid Steelmaking Process**

- Uses **acidic refractory lining**, such as silica (SiO_2).
- Forms **acidic slag**.
- Cannot remove **phosphorus (P)** and **sulfur (S)**.
- Requires pig iron with **low phosphorus and low sulfur**.
- Produces good-quality steel when pure raw materials are available.

2. **Basic Steelmaking Process**

- Uses **basic refractory lining**, such as magnesite (MgO) or dolomite (CaO–MgO).
- Forms **basic slag** by adding lime.
- Efficiently removes **phosphorus and sulfur**.
- Suitable for pig iron containing higher amounts of impurities.
- Widely used in modern steel plants, especially in the **Basic Oxygen Furnace (BOF)**.

Lecture 04

Raw Materials for steel making

The main raw materials used in steelmaking are:

- **Hot metal (Pig iron):** Obtained from the blast furnace and contains about 4–4.5% carbon along with impurities such as silicon, manganese, phosphorus, and sulfur.
- **Scrap steel:** Recycled steel used to reduce production costs and conserve natural resources.
- **Fluxes:** Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are added to remove impurities by forming slag.
- **Oxygen:** High-purity oxygen is used to oxidize unwanted elements.

Basic Thermodynamics and Kinetics of Steelmaking Reactions

1. Thermodynamics of Steelmaking

Definition:

Thermodynamics is the study of energy changes and the conditions under which chemical reactions occur. In steelmaking, it helps determine whether a reaction is possible and what products will be formed.

Principles of Thermodynamics in Steelmaking:

- **Gibbs Free Energy (ΔG):**
  - Determines the feasibility of a reaction.
  - If $\Delta G < 0$, the reaction occurs spontaneously.
  - If $\Delta G > 0$, the reaction does not occur spontaneously.
- **Temperature:**
  - High temperatures (1600–1700°C) promote the reduction and oxidation reactions required for steelmaking.
  - Temperature affects the equilibrium of reactions.
- **Chemical Equilibrium:**
  - Steelmaking reactions continue until equilibrium is reached.
  - Changing temperature, pressure, or composition shifts the equilibrium according to Le Chatelier's principle.
- **Oxidation Reactions:**
  - Oxygen reacts with impurities such as carbon, silicon, manganese, phosphorus, and iron to form oxides.
  - Examples:
    - $C + O \rightarrow CO$
    - $Si + O_2 \rightarrow SiO_2$
    - $Mn + O \rightarrow MnO$
    - $4P + 5O_2 \rightarrow 2P_2O_5$

- **Slag Formation:**
    - Oxides combine with lime (CaO) to form slag, which removes impurities from molten steel.
    - Example:
        - $CaO + SiO_2 \rightarrow CaSiO_3$

    - If **$\Delta G < 0$**, the reaction occurs spontaneously.
    - If **$\Delta G > 0$**, the reaction does not occur spontaneously.
- **Temperature:**
    - High temperatures (1600–1700°C) promote the reduction and oxidation reactions required for steelmaking.
    - Temperature affects the equilibrium of reactions.
- **Chemical Equilibrium:**
    - Steelmaking reactions continue until equilibrium is reached.
    - Changing temperature, pressure, or composition shifts the equilibrium according to Le Chatelier's principle.
- **Oxidation Reactions:**
    - Oxygen reacts with impurities such as carbon, silicon, manganese, phosphorus, and iron to form oxides.
    - Examples:
        - $C + O \rightarrow CO$
        - $Si + O_2 \rightarrow SiO_2$
        - $Mn + O \rightarrow MnO$
        - $4P + 5O_2 \rightarrow 2P_2O_5$

2. Kinetics of Steelmaking

Definition:

Kinetics is the study of the speed or rate at which chemical reactions occur. It explains how fast impurities are removed during steelmaking.

Factors Affecting Reaction Rate:

1. **Temperature**
    - Higher temperature increases reaction rate.
2. **Oxygen Supply**
    - Efficient oxygen blowing accelerates oxidation reactions.
3. **Mixing of Molten Metal**
    - Good stirring improves contact between metal, slag, and oxygen, increasing reaction speed.
4. **Surface Area**
    - Greater contact area between reactants increases reaction rate .

5. **Slag Composition**
    - Proper slag basicity enhances impurity removal, especially phosphorus and sulfur.
6. **Diffusion**
    - The movement of atoms and molecules from one phase to another controls many steelmaking reactions.

Important Kinetic Steps:

- Transport of reactants to the reaction site.
- Chemical reaction at the interface.
- Removal of reaction products.

Lecture 05

Condition of removal of Si, P,Mn and C Overview of steel grades and their composition

1. Removal of Silicon (Si)

Silicon is the first impurity to oxidize because it has a high affinity for oxygen.

Reaction:

$Si+O2\rightarrow SiO2$

Conditions for Removal:

- High oxygen availability.
- High temperature (about 1600–1700°C).
- Basic slag containing lime (CaO).
- The silica (SiO_2) formed combines with lime to form slag:

  $CaO+SiO2\rightarrow CaSiO3$

2. Removal of Phosphorus (P)

Phosphorus makes steel brittle, so it must be removed effectively.

Reaction:

$4P+5O2\rightarrow 2P2O5$

Conditions for Removal:

- Highly basic slag (high CaO content).
- High oxygen potential.
- Low to moderate temperature during the early stage of refining.
- Low FeO loss and good slag-metal contact.

Slag Reaction:

$3CaO+P2O5 \rightarrow Ca3(PO4)2$

3. Removal of Manganese (Mn)

Manganese is oxidized after silicon but before carbon.

Reaction:

$Mn+12O2 \rightarrow MnO$

Conditions for Removal:

- Adequate oxygen supply.
- Basic slag to absorb MnO.
- High temperature.
- Good mixing of molten metal and slag.

4. Removal of Carbon (C)

Carbon content is reduced to obtain the desired steel grade.

Reaction:

$C+1/2O2 \rightarrow CO$

$C+O2 \rightarrow CO2$

Conditions for Removal:

- High-temperature molten steel.
- Pure oxygen blowing (Basic Oxygen Furnace).
- Good bath agitation for efficient gas removal.
- Carbon is mainly removed as carbon monoxide (CO) gas.

Sequence of Impurity Removal

1. Silicon (Si)
2. Manganese (Mn)
3. Phosphorus (P)
4. Carbon (C)

Overview of Steel Grades and Their Composition

Steel is classified according to its carbon content and alloying elements.

Steel Grade	Carbon Content (%)	Typical Composition	Applications
Low Carbon Steel (Mild Steel)	0.05–0.25	Fe + 0.05–0.25% C, small amounts of Mn and Si	Structural work, pipes, automobile bodies
Medium Carbon Steel	0.25–0.60	Fe + 0.25–0.60% C, Mn (0.6–1.5%)	Shafts, gears, railway tracks
High Carbon Steel	0.60–1.00	Fe + 0.60–1.00% C	Springs, cutting tools, high-strength wires
Low Alloy Steel	0.10–0.50	Fe + C + Cr, Ni, Mo, V (up to 5%)	Pressure vessels, machine parts
Stainless Steel	0.03–1.20	Fe + ≥10.5% Cr, Ni, Mo	Kitchenware, chemical plants, medical equipment

Steel Grade	Carbon Content (%)	Typical Composition	Applications
Tool Steel	0.50–1.50	Fe + C + W, Cr, V, Mo	Cutting tools, dies, molds
High-Speed Steel (HSS)	0.70–1.00	Fe + W, Mo, Cr, V, Co	Drills, milling cutters, lathe tools

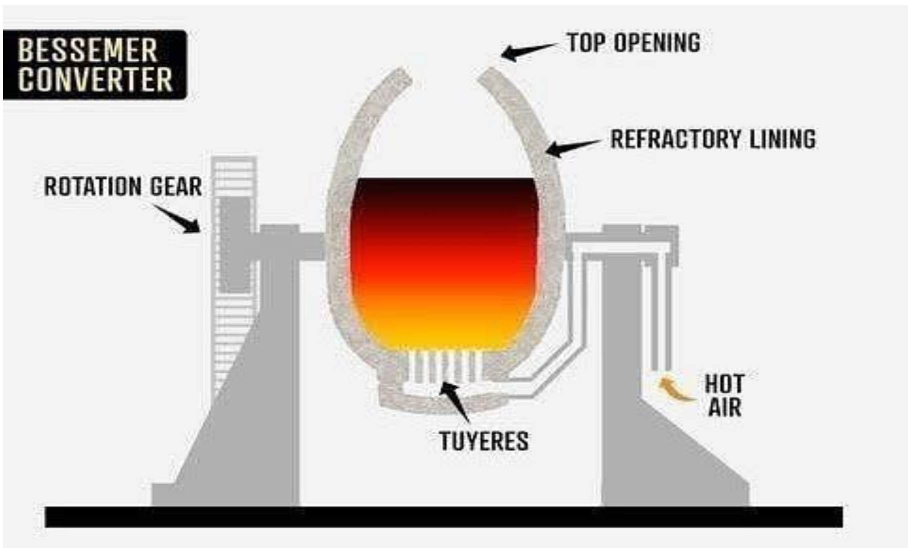
Classification Based on Carbon Content

- **Low Carbon Steel:** 0.05–0.25% C
- **Medium Carbon Steel:** 0.25–0.60% C
- **High Carbon Steel:** 0.60–1.00% C

Lecture-6

Brief study of obsolete processes Bessemer process and open-Hearth process(with limitations)

Obsolete steelmaking processes are older methods that have largely been replaced by modern technologies such as the **Basic Oxygen Furnace (BOF)** and **Electric Arc Furnace (EAF)** because they are more efficient, economical, and produce better-quality steel.



2.Bessemer Process

It was developed by Henry Bessemer in 1856.
The Bessemer process uses a cylindrical vessel, and the entire vessel can be turned from vertical to horizontal position.
The vessel is fitted with tuyeres at the bottom.

Hot metal from the blast furnace is charged into the vessel while it is in the horizontal position.

The vessel is then moved back to the vertical position, and air is blown through the tuyeres.

Oxygen in the air reacts with the impurities and oxidizes them. The process is autogenous because the oxidation reactions are exothermic and generate enough heat.

The refining time is 15–20 minutes, and the tap-to-tap time is 30–40 minutes.

However, steel produced by the Bessemer process suffered from high nitrogen content, as nitrogen dissolved into the molten steel from the injected air.

2. Open-Hearth Process (Siemens-Martin Process) Open

Hearth Furnace (OHF)

Heat making in OHF steelmaking involves the following unit operations:

1. Fettling
2. Charging of solids
3. Melting
4. Refining
5. Tapping liquid steel

1. Fettling

Inspection and repair of the lining after the previous heat is tapped
Repair the damaged area of the refractory lining .

2. Charging

The charging sequence of solids is:
Iron ore at the bottom,
Then limestone .

Finally scrap on top of the limestone.

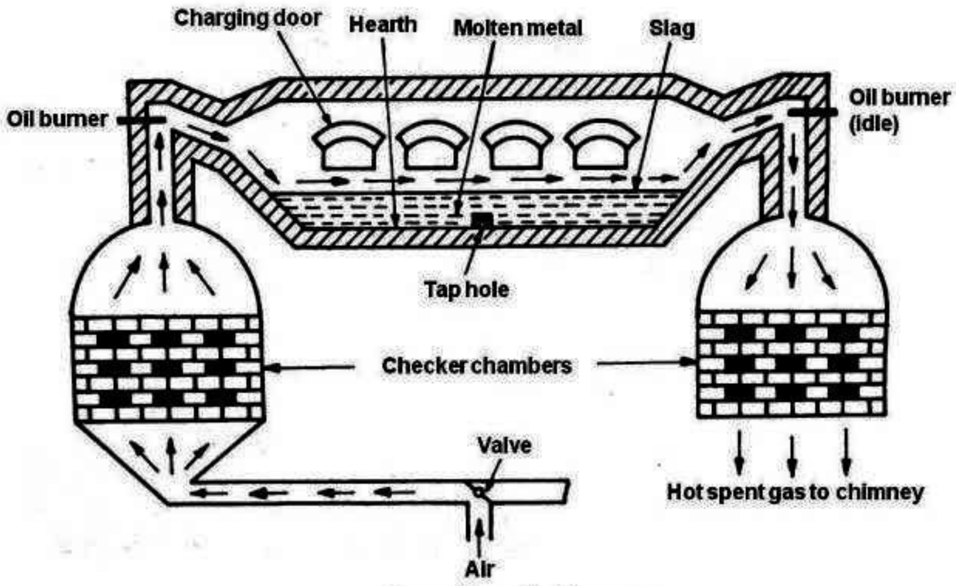
3. Refining

In this stage, all the steelmaking refining reactions occur.
Oxidation of impurities is carried out by adding iron ore or by an external supply of oxygen.
As the impurities are oxidized, the amount of slag on the top of the horizontal bath keeps increasing, and the chemical composition of the metal bath changes continuously.

Slag and metal samples are withdrawn throughout the refining period (lasting 90–120 minutes) to monitor the oxidation of carbon, manganese, and phosphorus.

4. Tapping of Steel

Tapping of the Open Hearth (O-H) furnace is similar to blast furnace tapping.
Tapping is done by opening the tap hole present at the hearth



Lecture-7

Primary Steelmaking Process – Steelmaking by LD Converter (Basic Oxygen Furnace - BOF)

- Plain carbon steels constitute about 90% of the world's total steel production.
- Today, the production of plain carbon steels follows two major routes— the integrated BF (blast furnace)–BOF (basic oxygen furnace, which is the new name for the LD process) and the scrap/DRI (direct reduced iron or sponge iron)—EAF route. Alloy steels are generally made in EAFs and electric induction furnaces.
- L-D process is a primary steel making process.
- L-D stands for "Linz" and "Donawitz", two cities of Austria. It was first developed and installed in Austria in 1952.
- In India it was first adopted by RSP (previously known as Hindustan Steel limited) in 1960.

Raw Materials for L-D furnace

- The charge material consists of Hot metal, Coolants (Scrap, Pig cast, Iron ore and Mill scale), Flux (Lime, Dolomite and CaF_2) and gaseous oxygen (99.9% pure). Hot metal

- The product of blast furnace i.e. hot metal is directly feed into L-D furnace.
- Generally the hot metal charged consists of impurity in the following range:

C - 3.5-4.5%
Si - 0.5-1.5%
P - 0.05-0.25%
S - 0.02-0.06%
Mn- 0.4-0.9%

- Hot metal charged should have temperature 1250-1350^{0}C.

Coolants

- Various coolants like: Scrap, Mill scale, sponge iron and iron ore are charged in L-D furnace in order to utilize the excessive heat generated during the refining processes.
- Coolants also prevents wearing out of refractory.
- These are used in limited quantity, maximum scrap that can be consumed by L-D is 25%. Flux

- Generally calcined lime is used as flux in L-D furnace than lime stone, as decomposition of limestone requires thermal energy.
- Except lime, dolomite is also used as flux. Sometimes CaF_2 and bauxite is also used as flux.
- The amount of flux added is 2-5% depending upon the wt % of impurities.

Oxygen

- In L-D 99.9% purity oxygen is used for refining.

- If the purity decreases then it will lead to addition of impurities like N_2, Which adversely affect the quality of steel.

Lecture-8

Construction and Operation of LD Converter (Basic Oxygen Furnace - BOF)

The L-D furnace mainly consists of:

1. Vessel
2. Oxygen lance
3. Vessel lining
4. Hood

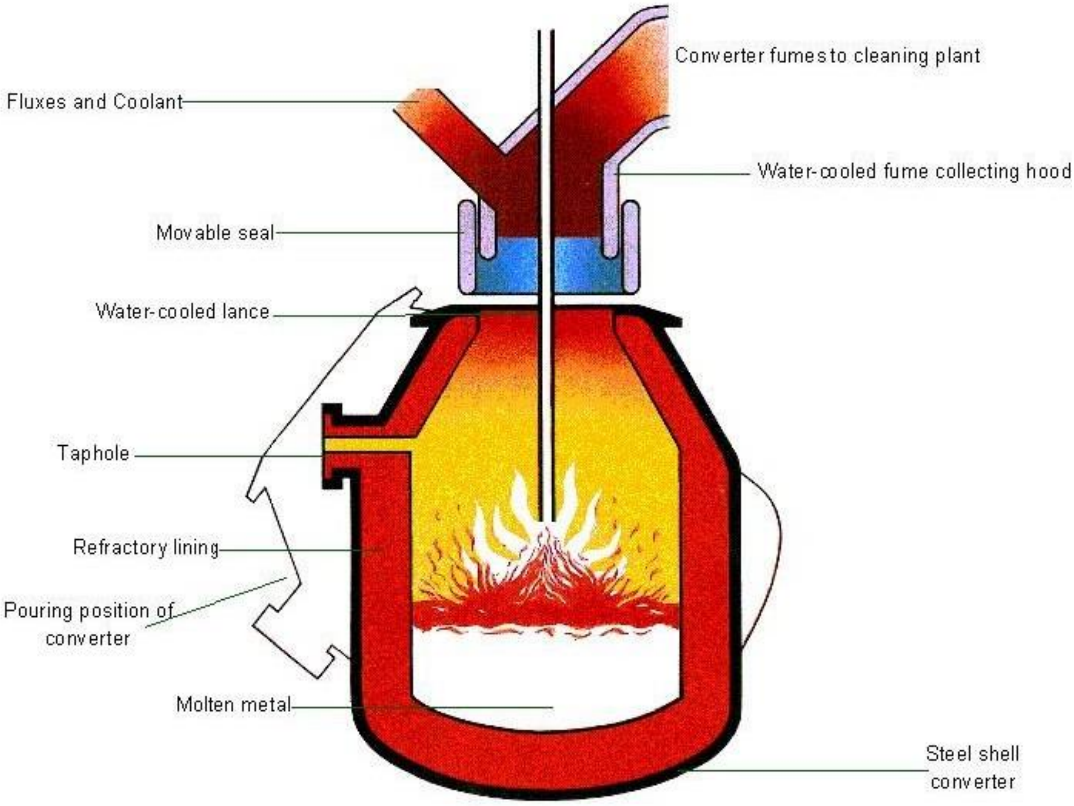


Fig: L-D Converter

1.Vessel

- Vessel is divided into 3 parts

  a) Spherical bottom
  b) Cylindrical body
  c) Conical top

All the three parts are welded together to form the complete vessel.

- The vessel is attached with mechanical gear box system which enables it to rotate by 360 .
- The height of the vessel is 7-12m having base diameter of 1-3m.

2.Oxygen lance

- In BOF steelmaking, oxygen of high purity (at least 99.9% oxygen) is blown at supersonic speed onto the surface of the bath using a vertical lance, inserted through the mouth of the vessel.

- Water cooled lance is typically used in L-D furnace having three concentric tubes for circulating water and the center one to blow oxygen.

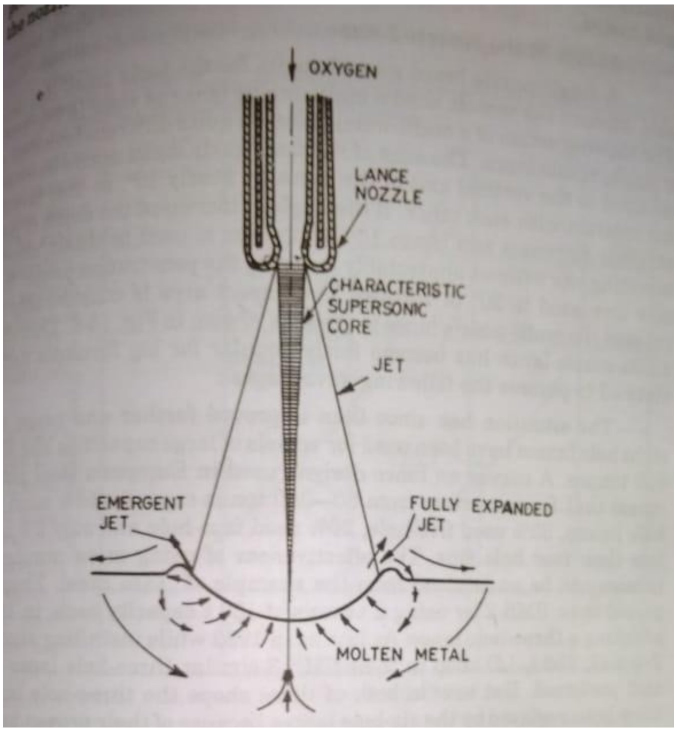


Fig: Oxygen lance

- The tip of the lance is made of copper.
- The lance is usually 8-10m long and its diameter is 20-25cm.

- Oxygen is blown at a pressure of 8-10atm.
- The tip of lance generally contains multiple nozzles. The opening of nozzles are not cylindrical type, they are convergent-divergent laval shape which helps in formation of oxygen jet during steel making.
- Water is used for cooling of the lance.

2. Vessel Lining

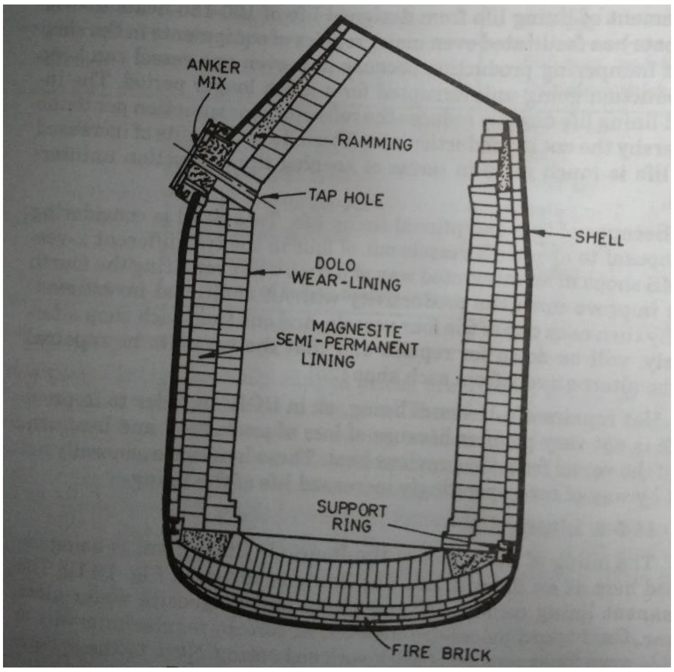


Fig: Refractory lining inside L-D furnace

- The refractory lining within the converter shell consists of a safety layer and a working layer.
- The bricks in inner layer of L-D furnace are magnesite whereas outer is of dolomite bricks.
- The refractory lining that wears out after each campaign that can normally last anywhere between 3000 and 10,000 heats is relined. This entire relining procedure normally takes 4–5 days.

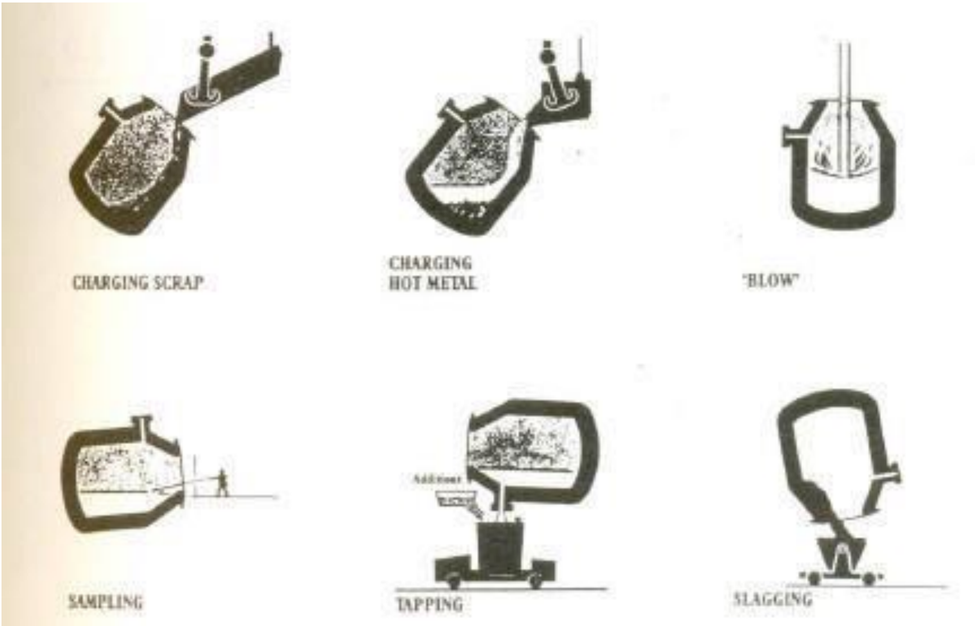
3. Hood

- During refining in L-D furnace a lot of toxic gases like CO and fumes are generated. So, a hood is given at the top of the furnace to restrict the gas and vapours to escape out to the atmosphere.

- The hood is connected to gas cleaning system which extract out the gases and collect it.

Sequence of processes in L-D furnace

- After previous heat is tapped the vessel is kept in inclined position for visual inspection of refractory lining. If there is any kind of damage is seen, it is repaired.



- After visual inspection scrap is charged first into the furnace in tilted condition.
- Furnace is rocked back to vertical position after charging of scrap so that the scrap get settled down properly at bottom of furnace.
- Then again the furnace is tilted for charging of hot metal.
- As the pouring of hot metal gets completed the furnace is moved back to vertical position then oxygen lance is lowered and blowing started.
- Blowing results in initiation of various exothermic reaction and then lime and other fluxes are charged from the top.
- Blowing continues for 15-25mins then it is stopped and lance is raised, furnace is tilted for sampling.
- If the compositional analysis of sample matches the desired composition the steel is tapped through the tap hole by tilting the furnace. The furnace is completely inverted for de-slagging operation.
- Tap to tap time of L-D furnace is 30-50mins.

Lecture-9

Refining reactions in L-D furnace

- Steelmaking is conversion of pig iron containing various impurities like carbon, silicon, manganese, phosphorus and sulphur into steel by decreasing their content to a controlled amount.

- With the exception of sulphur removal of all other impurities is favored under oxidizing conditions.

- In the case of oxidation of carbon the product, being a gas, passes off into the atmosphere but rest of the oxide products shall remain in contact with the iron melt in the form of a slag phase.

$$
\begin{aligned}
[Fe] &+ [O] = (FeO) \\
[C] &+ [O] = \{CO\} \\
[Si] &+ 2[O] = (SiO_2) \\
[Mn] &+ [O] = (MnO) \\
2[P] &+ 5[O] = (P_2O_5) \\
[S] &+ (CaO) = (CaS) + [O]
\end{aligned}
$$

- SiO_2, MnO and P_2O_5 formed by oxidation of Si, Mn and P, respectively will join the slag phase.

- The formation of these oxides can be facilitated by decreasing their activities which is possible by providing oxides of opposite chemical character serving as flux.

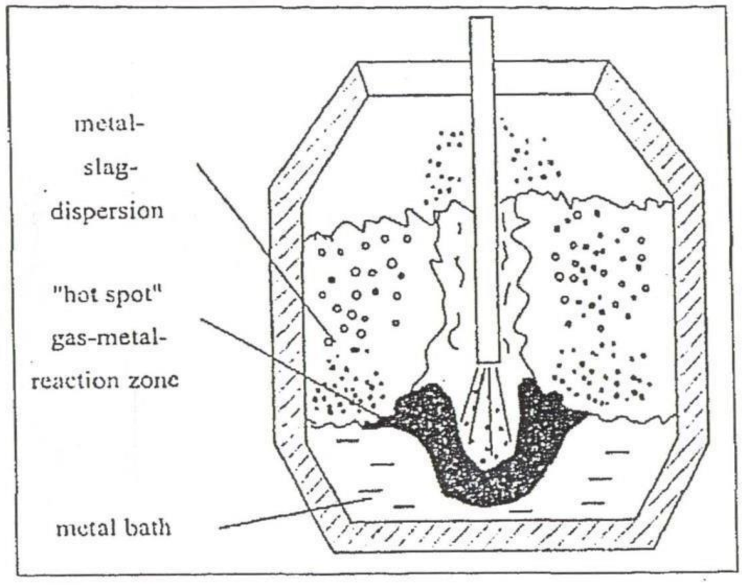
- As SiO_2 and P_2O_5 are acid oxides a basic flux is required for formation and easy removal of the slag.

- A strong basic slag is formed by addition of CaO and / or MgO to absorb P_2O_5 and SiO_2.

- The removal of carbon will take place in the form of gaseous products (CO).

Characteristics of L-D furnace

- During refining, controlled oxidation of the impurities in hot metal (with the exception of sulphur) takes place once oxygen is blown at supersonic speeds onto the liquid bath.
- As the oxygen jet strikes the metal bath surface it results in stirring of the bath. This stirring along with exothermic reaction results in dissolution of scrap and flux.
- The interaction of the oxygen jet(s) with the bath also produces crater(s) on the surface, which results in large number of tiny metal droplets get splashed.
- These droplets reside for a short time in the slag above the bath. Therefore, the existence of a metal-slag-gas emulsion within the vessel, virtually during the entire blowing/refining period.



ne LD - converter process showing different reaction zones

- Formation of emulsion results in faster oxidation and removal of impurities in the BOF process. The droplets ultimately return to the metal bath.
- A minimum amount of slag, with the desired characteristics, is necessary for ensuring that the emulsion is stable, i.e. the slag should not be too viscous, or too 'watery'. Only in this way can the kinetics of the removal of the impurities be enhanced .

Lecture-10

Primary Steelmaking Processes – Mn Hump, Quality of Steel, and Composition of Slag in the LD Process

1. Mn Hump in the LD Process

Definition

The **Mn hump** is the temporary increase in the manganese content of molten steel during the middle stage of oxygen blowing in the **LD (Basic Oxygen Furnace) process**.

Why Does the Mn Hump Occur?

- At the beginning of oxygen blowing, manganese is oxidized to manganese oxide (MnO):

  Mn+12O2→MnO

- As carbon oxidation becomes vigorous, carbon monoxide (CO) gas is formed.
- Due to the reducing atmosphere created by CO, some **MnO in the slag is reduced back to metallic manganese**, causing the manganese content in the molten steel to rise temporarily.
- Towards the end of blowing, manganese is again oxidized, and its content decreases.

Importance of the Mn Hump

- Indicates the progress of refining.
- Helps control oxygen blowing.
- Assists in achieving the required manganese content in steel.

Quality of Steel in L-D process

- L-D process is primarily used to produce mild steel (0.15-0.35%C), however it can also produce low or high carbon steel and alloy steel.
- Steel produced through L-D furnace contains very low C, N and P.
- P can be lowered from 0.15-0.17% to 0.015-0.02%.
  Dissolved nitrogen content is as low as 0.002

Composition of L-D slag

- Composition of L-D slag is:

CaO- 47-52%
Mgo – 2-5%
P2O5 – 1-3%

SiO_2 – 10-16%
MnO- 3-5%
FeO – 15-20%

- If high carbon steel is made then Fe content in slag is less.
- If high phosphorus is there in the charge then double slag practice is followed.

Advantage of LD process

- It is a faster process of steel making.
- Almost 90% of P can be removed by this process.
    - Faster reaction kinetics due to formation of emulsion which is not there in other process of steel making.
- It is an autogenous process and doesn’t required any other fuel.
- Easy to tap metal and slag.
- Economical process.

Disadvantage of LD process

- Almost 99.9% pure oxygen is required.
- Large amount of scrap cannot be charged.
- Proper slag should be produced for emulsion.
- Metal loss in slag and by vaporisation.

Lecture-11

Primary steelmaking process- steelMaking by L-D Converter: Raw material of LD process

The **Linz-Donawitz (LD) Converter**, also known as the **Basic Oxygen Furnace (BOF)**, is the most widely used primary steelmaking process. In this process, high-purity oxygen is blown into molten pig iron to remove impurities and convert it into steel.

Raw Materials Used in the LD Process

1. Hot Metal (Molten Pig Iron)

- It is the **main raw material** of the LD process.
- Produced in the **blast furnace**.
- Makes up about **70–90%** of the total charge.
- Temperature: **1250–1450°C**.
- Typical composition:
    - Carbon (C): **3.5–4.5%**
    - Silicon (Si): **0.5–1.5%**
    - Manganese (Mn): **0.3–1.0%**
    - Phosphorus (P): **0.05–0.20%**
    - Sulphur (S): **0.02–0.08%**
- It provides the heat required for the steelmaking reactions.

2. Steel Scrap

- Added to cool the molten iron because oxidation reactions generate a large amount of heat.
- Usually constitutes **10–30%** of the charge.
- Recycles waste steel, reducing production costs and conserving natural resources.
- Must be free from excessive rust, oil, and other contaminants.

3. Fluxes

Fluxes combine with impurities to form slag.

a) Lime (CaO)

- Most important basic flux.
- Removes phosphorus and sulphur.
- Produces a basic slag.

b) Dolomite (CaO·MgO)

- Protects the refractory lining.
- Supplies magnesium oxide (MgO) to the slag.

4. Oxygen

- High-purity oxygen (**99–99.5% purity**) is blown through a water-cooled lance.
- Oxidizes carbon, silicon, manganese, and phosphorus.
- Helps refine the molten iron into steel.
- Oxygen pressure is typically **8–15 bar**.

5. Coolants (When Required)

- Iron ore or additional scrap may be added to control the bath temperature.
- These materials absorb excess heat generated during refining.

6. Alloying Elements (After Refining)

After the blowing process, alloying elements are added to obtain the desired steel grade. Common alloying elements include:

- Manganese (Mn)
- Silicon (Si)
- Chromium (Cr)
- Nickel (Ni)
- Molybdenum (Mo)
- Vanadium (V)

Lecture-12

Quality of steel and composition of slag in LD process

1. Quality of Steel in the LD Process

The LD (Basic Oxygen Furnace) process produces **high-quality steel** because impurities are removed rapidly by blowing high-purity oxygen into molten pig iron.

Characteristics of LD Steel

- **Low carbon content** (can be controlled according to the steel grade).
- **Low phosphorus (P) and sulphur (S)**, resulting in better toughness and ductility.
- **Low nitrogen and hydrogen** content, reducing brittleness and improving weldability.
- **Uniform chemical composition** due to efficient mixing of the molten bath.
- **High cleanliness**, with fewer non-metallic inclusions.
- **Good mechanical properties**, such as high strength, hardness, ductility, and toughness.
- Suitable for manufacturing **structural steel, automobile sheets, pipelines, rails, machinery parts, and construction materials**.

Factors Affecting Steel Quality

- Purity of hot metal and scrap.
- Oxygen blowing rate and time.
- Basicity and fluidity of slag.
- Bath temperature.
- Proper deoxidation and alloy addition after blowing.

2. Composition of Slag in the LD Process

The slag formed during the LD process is **basic in nature** and helps remove impurities from the molten steel.

Typical Composition of LD Slag

Component	Approximate Percentage (%)
Calcium Oxide (CaO)	40–55
Iron Oxide (FeO)	10–20
Silicon Dioxide (SiO_2)	10–18
Magnesium Oxide (MgO)	5–10
Manganese Oxide (MnO)	3–8
Phosphorus Pentoxide (P_2O_5)	1–3
Aluminium Oxide (Al_2O_3) and others	1–5

Functions of Slag

- Removes **phosphorus** by forming stable phosphate compounds.
- Absorbs **sulphur** from the molten steel.
- Protects molten steel from atmospheric oxidation.
- Absorbs oxide inclusions and other impurities.
- Protects the refractory lining of the converter.
- Helps maintain the required bath temperature and promotes refining reactions.

<u>Lecture-13</u>

Advantages and limitations of LD process, importance of lance height

1. Advantages of the LD Process

- **High production rate** – One heat is completed in about **30–45 minutes**.
- **High-quality steel** – Produces steel with low phosphorus, sulphur, and nitrogen.
- **Low production cost** – Requires less fuel because heat is generated by oxidation reactions.

- **High productivity** – Large quantities of steel can be produced in a short time.
- **Efficient impurity removal** – Carbon, silicon, manganese, and phosphorus are removed effectively.
- **Simple operation** – Oxygen blowing is easy to control and automate.
- **Low labour requirement** – Highly mechanized process.
- **Lower environmental pollution** – Compared with older steelmaking processes such as the Bessemer and Open-Hearth processes.
- **High thermal efficiency** – Heat generated during oxidation is utilized effectively.

2. Limitations of the LD Process

- **High initial investment** – Requires expensive converters, oxygen plants, and gas-cleaning systems.
- **Requires hot metal** – Cannot operate using only steel scrap.
- **Limited sulphur removal** – Hot metal should be desulphurized before charging.
- **Requires high-purity oxygen** – Oxygen production increases operating cost.
- **Sensitive process control** – Temperature, oxygen flow, and blowing time must be carefully controlled.
- **Frequent refractory wear** – The converter lining requires periodic maintenance and replacement.
- **Not economical for very small-scale steel production.**

3. Importance of Lance Height in the LD Process

The **oxygen lance** is a water-cooled pipe used to blow high-purity oxygen into the molten bath. The **distance between the lance tip and the molten metal surface is called the lance height**.

Importance of Lance Height

- Controls the **oxygen jet impact** on the molten metal.
- Affects the **rate of oxidation** of carbon and other impurities.
- Ensures **proper mixing** of metal and slag.
- Influences the **formation of slag** and refining efficiency.
- Reduces **slopping** (overflow of slag and metal) when properly adjusted.
- Protects the converter lining from excessive wear.
- Helps maintain the desired **bath temperature**.
- Improves steel quality by ensuring uniform refining.

Effect of Lance Height

- **Low Lance Height**
  - Strong oxygen jet penetration.
  - Faster decarburization.
  - Greater bath agitation.
  - Increased risk of splashing, slopping, and refractory wear.
- **High Lance Height**
  - Softer oxygen impact.
  - Slower refining reactions.
  - Better slag formation.
  - Lower risk of splashing but less efficient impurity removal if too high.

Lecture-14

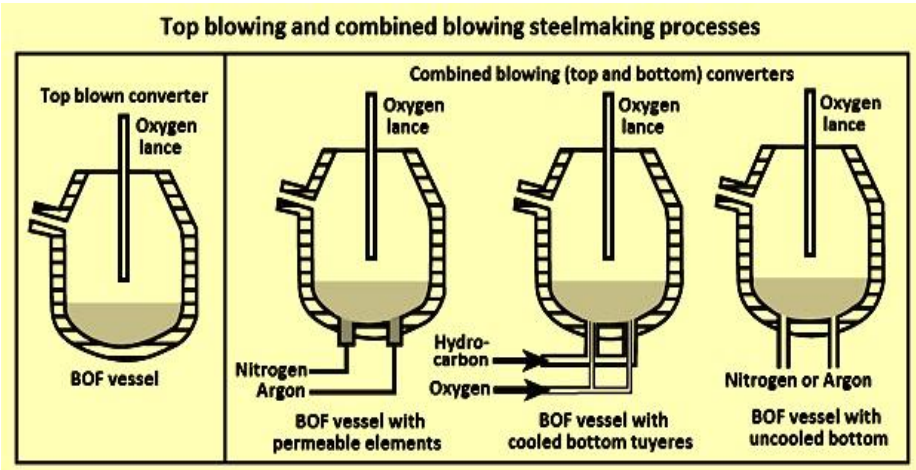
Developments in LD process: multi nozzle lance, combined blowing process.

Combined Blowing Process

- Inhomogeneities in chemical composition and temperature are created in the liquid steel during the oxygen (O2) blow in the top blown converters because of the lack of mixing in the liquid steel bath.

- The necessity to improve the steelmaking process in the top blown converter has led to the development of the combined blowing process.

- The combined blowing process also known as the top and bottom blowing or mixed blowing process is characterized by both a top blowing lance and a method of achieving stirring from the bottom. Fig 1 shows top blowing and combined blowing steelmaking processes.



- In the combined blowing converter, the agitating and the mixing of the bath are forced by the top blown O2 jets and the bottom inert gas streams, which can achieve a high mixing efficiency for the bath.
- In rare cases, O2 is also injected from the bottom with concentric double tube tuyeres together with shielding gases to control the temperature at the tuyere outlet and the wear of the bottom.

The most important benefits of combined blowing converter over top blowing in a BOF converter are

(i) Shorter of tap to tap time,

(ii) Improved steel bath homogenization / agitation and temperature distribution

(iii) Increased accuracy in achieving specific composition

(iv) Less splashing and slopping

(v) Lower iron oxide in slag

(vi) Improved quality of steel, since inert gas blowing at the end of the procedure diminishes the concentration of gases in the metal.

The disadvantages of the combined blowing are:

(i) The converter equipment for the combined-blown process is more complicated, which increases the cost of the shop

.

ii) High cost of Ar gas which is in many cases tried to replace at least partly with N_2.

<u>Multi-Nozzle Converter</u>

- Single nozzle lance is adequate for small furnace but for large furnace multi nozzle lance is used as with multi nozzle lance the impact area is increased.
- Multi nozzle lance has the following advantages:
  - ➢ Increased total throughput oxygen
  - ➢ Improved impact area leads to: effective dephosphorisation, less sloping

Lecture-15

Other steel making process: Working principle , process, advantages and limitations of: OLP process, OMB process.

OLP Steel making

- OLP stands for Oxygen Lime Process. It is also known as LDAC process.
- This process is designed to refine Thomas grade iron or high phosphorous iron(>1.5%).

Composition of Thomas grade iron:

C – 3.2-3.5

P – 1.5-2.0

Mn – 0.7-1.0

Si - 0.4-0.6 S<0.05

- In this process powdered lime is charged simultaneously along with oxygen. Which result in both decarburisation and dephosporisation.
- The vessel volume is 20% more than LD furnace in order to accommodate the higher slag volume.

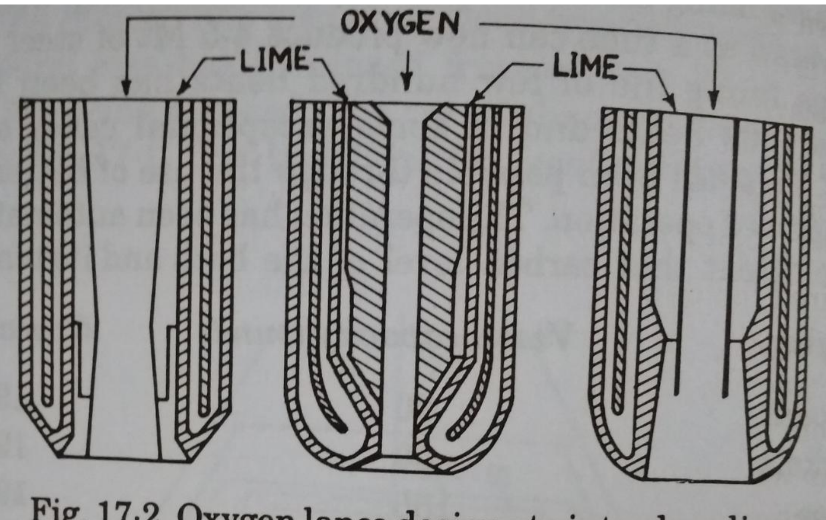


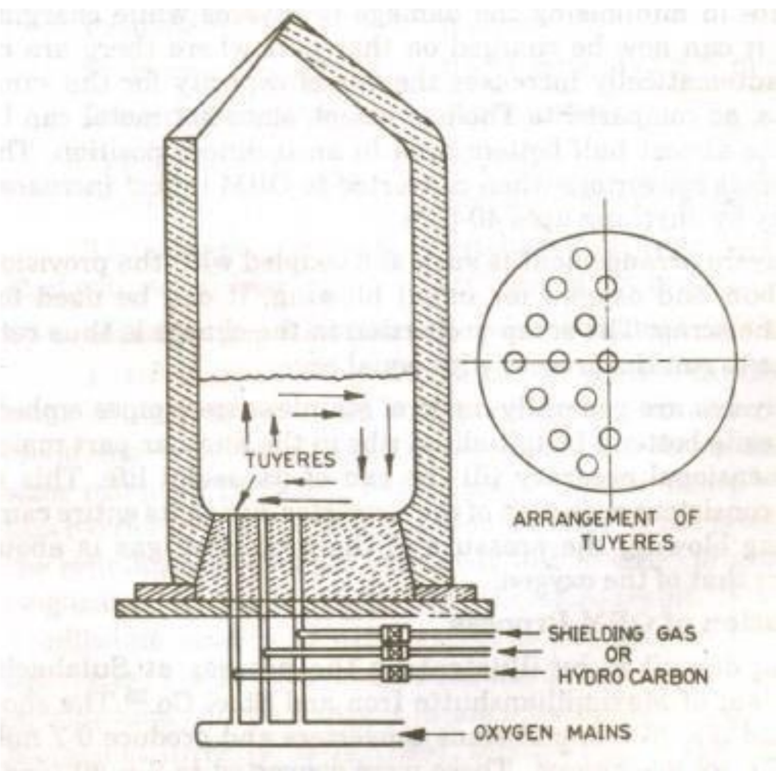
Fig. 17·2. Oxygen lance designs to introduce lime powder along with oxygen.

- Less amount of scrap is charged as compared to LD process because dissolution of lime requires heat.
- In this process blowing is done in two stages. First blowing is done for 15mins then the slag is drained out. At this stage C is reduced to 1.5-1.7% while P – 0.2%.
- Fresh lime is added in second stage of blowing and it is continued for about 5-8min and sampling is done.
- Finally P content is brought down to < 0.2% and tapping is done. It has a tap to tap time of 55-60min.

OBM Process :

 OBM processes is also known as Oxygen Bottom blowing method.

- In this process of steel making, oxygen is introduced from bottom through tuyere holes along with a shielding gas(propane).
- On entry propane gas cracks in an endothermic reaction and takes some of the heat generated due to entry of oxygen.
- In order to promote turbulence in the bath the tuyeres are arranged one half of the converter.



- After charging scrap and hot metal, blowing is started, then lime is charged from the top instantly.
- The blowing is divided in three parts, first the blowing is continued for around 16-17mins and slag is raked off.
- Fresh slag is prepared by adding lime and again blowing is done for a 1min which gives the final composition of C-0.1% and P- 0.025%.
- The final blowing is done only by nitrogen to remove out dissolved Hydrogen.

- Bottom blowing increases sharply the intensity of bath stirring and increases the area of gas-metal boundaries (10-20 times the values typical of top blowing). This facilitate substantially the formation and evolution of carbon monoxide, which leads to a higher rate of decarburization in bottom blowing.

Lecture-16

Deoxidation of Steel

- Contrary to iron making steelmaking is practiced in oxidizing conditions.
  - In most of the primary steelmaking processes either air or oxygen is blown.
  - Under these conditions oxygen easily gets dissolved in the steel melt (0.05-0.10%).
  - During solidification of steel castings excess oxygen is evolved because of very low solid solubility (0.003%) and is one of the causes of defective casting.
  - This excess oxygen has to be eliminated for production of sound casting. The process of removal of residual oxygen from the refined steel is called deoxidation.

In general deoxidation may be carried out partly in the furnace and major part in the ladle.

Choice of Deoxidisers :

  - The residual content of the deoxidiser in steel after deoxodation should not adversely affect the mechanical properties of steel.
- The rate of deoxidation i.e. formation of oxide products must be fast.
  - Al and Si are very effective in deoxidation of steel and hence they are used extensively.
  - Al, Si and Mn are reasonably cheap and hence used as common deoxidizers.
  - Sometimes Zr, Ti, V, Nb etc. are used in deoxidation of steel but they are costlier than common deoxidisers.
  - Depending upon the extent of de-oxidation steels are divided in three category:
    1. Rimming steel
    2. Semi-killed steel
    3. Killed steel

1. Rimming steel

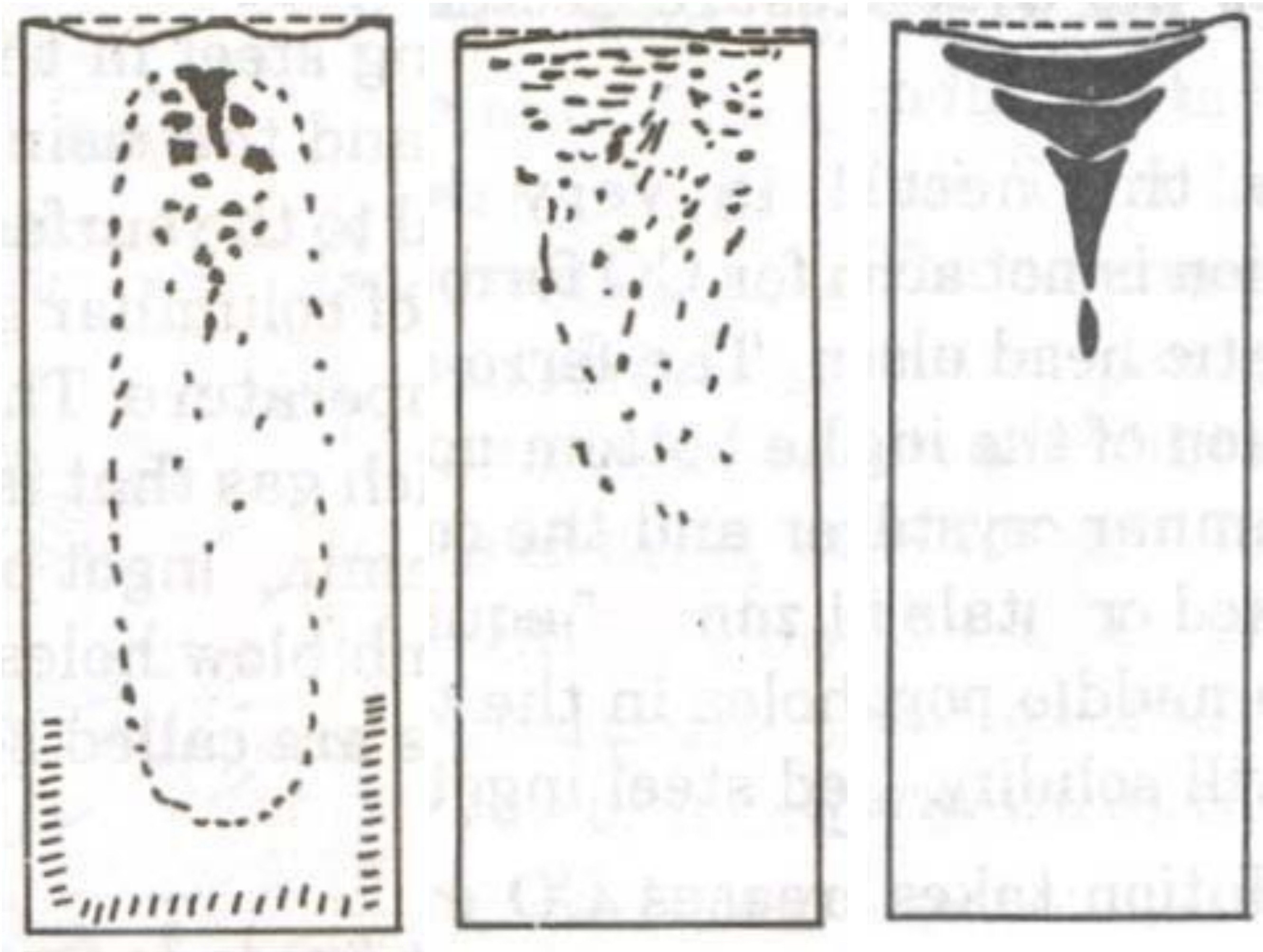
- Partially deoxidized or non- deoxidized low carbon steels evolving sufficient CO during solidification.
- In Rimming steel a lot of gas evolved during solidification. The steel, contains enough dissolved oxygen and which is possible only in low carbon steel (<0.15%).
- In general, no deoxidation is carried out inside the furnace. Only a small amount of deoxidation is carried out in the ladle using Fe-Mn and Al.
- These steel contain a lot of porosity due to the formation of carbon monoxide bubbles. But piping shrinkage is not there as in killed steels.

2. Semi-killed steel

- These are partially deoxidised steel such that only small amount of gas is evolved during solidification.
- The carbon content has been in the range of 0.15- 0.30%.
- Partial deoxidation is carried out in the furnace itself using Fe-Mn and Al.
- The gas is evolved towards the end of the solidification. The blow holes are therefore, present in the middle and top of the ingot.

3. Killed steel

- No gas evolution take place in killed steel during solidification.
- The heat is worked in such a way that by the time carbon level drops close to specification level the refining should be over.
- Aluminium together with ferroalloys of manganese and silicon is used for deoxidation.
- Deoxidation product should be given sufficient time to rise to the surface otherwise it will form non-metallic inclusions in steel.



- Rimming steel Semi-killed steel Killed steel

Solidification of Killed steel is accompanied by shrinkage.

Lecture-17

Stainless Steel Manufacturing Introduction to stainless steels: Defination and role of chromium (passivation)

Introduction

Stainless steel is a corrosion-resistant alloy steel that contains a minimum of **10.5% chromium (Cr)** by weight. It may also contain alloying elements such as **nickel (Ni), molybdenum (Mo), manganese (Mn), silicon (Si), nitrogen (N),** and **carbon (C)** to improve its properties.

Stainless steel is widely used because of its excellent corrosion resistance, high strength, good appearance, heat resistance, and ease of fabrication.

Definition of Stainless Steel

Stainless steel is an alloy steel containing **at least 10.5% chromium**, with or without other alloying elements, which forms a thin, protective oxide film on its surface, making it highly resistant to corrosion and rust.

Role of Chromium in Stainless Steel (Passivation)

Chromium is the **most important alloying element** in stainless steel. It provides corrosion resistance through a process called **passivation**.

What is Passivation?

Passivation is the formation of a **thin, invisible, hard, and self-healing layer of chromium oxide (Cr_2O_3)** on the surface of stainless steel when chromium reacts with oxygen in the air.

Reaction

4Cr+3O2→2Cr2O34Cr + 3O_

This chromium oxide film:

- Prevents further oxidation and corrosion.
- Protects the steel from rusting.
- Repairs itself automatically if the surface is scratched, provided oxygen is available.

Functions of Chromium

- Provides excellent **corrosion resistance**.
- Forms a **stable chromium oxide (Cr_2O_3) passive film**.
- Improves resistance to oxidation at high temperatures.
- Increases hardness and wear resistance.
- Improves strength and durability.

- Enhances resistance to chemicals and moisture.
- Gives stainless steel a bright and attractive appearance.

Advantages of Passivation

- Prevents rust formation.
- Extends the service life of stainless steel.
- Reduces maintenance costs.
- Improves performance in corrosive environments.
- Makes stainless steel suitable for food, medical, marine, and chemical industries.

Applications of Stainless Steel

- Kitchen utensils and cookware
- Food processing equipment
- Chemical and pharmaceutical plants
- Medical and surgical instruments
- Construction and architecture
- Automobile and railway components
- Marine equipment and pipelines

Lecture-18

Classification: Austenitic, Ferritic, Martensitic, duplex , Precipitation hardening, peoperties and application

Stainless steels are classified based on their **microstructure** and **alloy composition**.

1. Austenitic Stainless Steel

Composition

- Chromium (Cr): **16–26%**
- Nickel (Ni): **6–22%**
- Carbon: **Less than 0.08%**

Properties

- Excellent corrosion resistance.

  Non-magnetic in the annealed condition.
- High ductility and toughness.
- Good weldability and formability.
- Cannot be hardened by heat treatment (only by cold working).

Applications

- Kitchen utensils and cookware.
- Food processing equipment.
- Chemical processing plants.
- Medical and surgical instruments.
- Storage tanks and pipelines.

Examples: SS 304, SS 316

2. Ferritic Stainless Steel

Composition

- Chromium (Cr): **10.5–30%**
- Nickel (Ni): Very low or absent.
- Low carbon content.

Properties

- Good corrosion resistance.
- Magnetic.
- Good oxidation resistance.
- Cannot be hardened by heat treatment.
- Lower ductility than austenitic stainless steel.

Applications

- Automobile exhaust systems.
- Washing machine drums.
- Decorative panels.
- Heat exchangers.
- Kitchen appliances.

Example: SS 430

3. Martensitic Stainless Steel

Composition

- Chromium (Cr): **11–18%**
- Carbon: **0.1–1.2%**

Properties

- High hardness and strength.
- Magnetic.
- Can be hardened and tempered by heat treatment.
- Moderate corrosion resistance.
- Good wear resistance.

Applications

- Cutting tools.
- Knives and scissors.
- Surgical instruments.
- Turbine blades.
- Pump shafts.

Examples: SS 410, SS 420

4. Duplex Stainless Steel

Composition

- Chromium (Cr): **18–28%**
- Nickel (Ni): **4.5–8%**
- Molybdenum (Mo): **Up to 5%**

Properties

- Mixed microstructure of **austenite and ferrite**.
- Very high strength.
- Excellent corrosion resistance.
- Good resistance to stress corrosion cracking.
- Good weldability.

Applications

- Oil and gas industries.
- Chemical plants.
- Marine structures.
- Offshore platforms.
- Desalination plants.

Example: Duplex 2205

5. Precipitation Hardening (PH) Stainless Steel

Composition

- Chromium (Cr): **15–17%**
- Nickel (Ni): **3–8%**
- Contains copper (Cu), aluminium (Al), niobium (Nb), or titanium (Ti).

Properties

- Very high strength and hardness.
- Excellent corrosion resistance.
- Can be strengthened by precipitation hardening (aging heat treatment).
- Good toughness.
- Good dimensional stability.

Applications

- Aerospace components.
- Aircraft fittings.
- Nuclear equipment.
- High-pressure valves.
- Shafts and gears.

Example: 17-4 PH Stainless Steel

Lecture-18

Stainless steel Making(primary process): Raw material for stainless steel making

Introduction

Stainless steel is produced by refining **molten iron or steel** and adding alloying elements, mainly **chromium**, to obtain the required corrosion resistance and mechanical properties. The quality of stainless steel depends greatly on the purity and composition of the raw materials used.

Raw Materials for Stainless Steel Making

1. **Steel Scrap**

- The main raw material used in stainless steel production.
- Includes stainless steel scrap and carbon steel scrap.
- Helps reduce production cost and conserves natural resources.
- Must be clean and free from oil, rust, and other impurities.

2. **Hot Metal (Molten Pig Iron)**

- Used in some stainless steelmaking processes.
- Produced in a blast furnace.
- Supplies iron and heat to the furnace.
- Contains impurities such as carbon, silicon, phosphorus, and sulphur, which are removed during refining.
-

3. **Ferrochrome (Fe-Cr)**

- The most important alloying material.
- Supplies **chromium (Cr)**, which provides corrosion resistance by forming a passive chromium oxide film.
- Available as:
  - High-carbon ferrochrome
  - Low-carbon ferrochrome

4. **Nickel (Ni)**

- Improves corrosion resistance.
- Stabilizes the austenitic structure.
- Increases toughness, ductility, and weldability.
- Used mainly in austenitic stainless steels (e.g., SS 304 and SS 316).

5. **Ferroalloys**

Used to provide alloying elements and improve steel properties. Examples:

- Ferrosilicon (Fe-Si)
- Ferromanganese (Fe-Mn)
- Ferromolybdenum (Fe-Mo)
- Ferroniobium (Fe-Nb)
- Ferrotitanium (Fe-Ti)

6. Fluxes

Fluxes remove impurities and form slag.

Common fluxes:

- **Lime (CaO)**
- **Dolomite (CaO·MgO)**

Functions:

- Remove phosphorus and sulphur.
- Protect the furnace lining.
- Produce basic slag.

7. Oxygen

- High-purity oxygen is blown into the molten metal.
- Oxidizes carbon, silicon, manganese, and phosphorus.
- Generates heat required for refining.

8. Reducing Agents

Used during refining to recover chromium from slag.

Examples:

- Ferrosilicon (Fe-Si)
- Aluminium (Al)

9. Alloying Elements (As Required)

Different alloying elements are added depending on the required stainless steel grade.

Alloying Element	Function
Chromium (Cr)	Corrosion resistance (passivation)
Nickel (Ni)	Toughness and corrosion resistance
Molybdenum (Mo)	Improves resistance to pitting and crevice corrosion
Manganese (Mn)	Improves strength and de-oxidation
Silicon (Si)	De-oxidizer and improves oxidation resistance
Nitrogen (N)	Increases strength and corrosion resistance
Titanium (Ti)	Prevents carbide precipitation and improves weldability
Niobium (Nb)	Stabilizes carbon and improves corrosion resistance.

Lecture-19

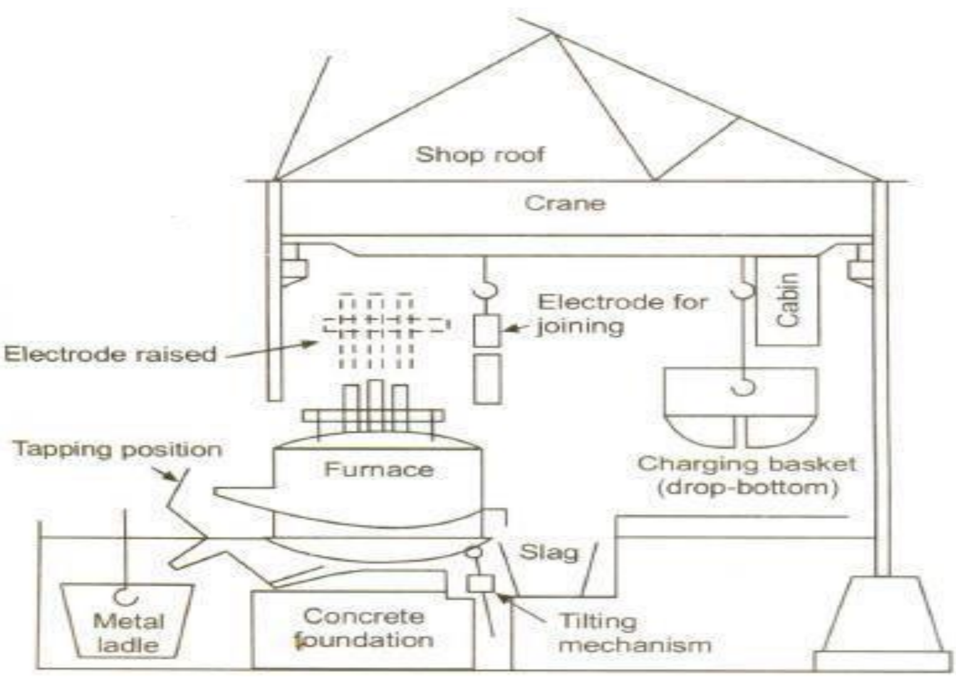
Electric Arc furnace Process

General Principle: The temperature generated by an electric arc using carbon electrodes exceed 4000°c and therefore, steel making temp can be readily maintained in an electric arc furnace. The arc f/c is of two types.

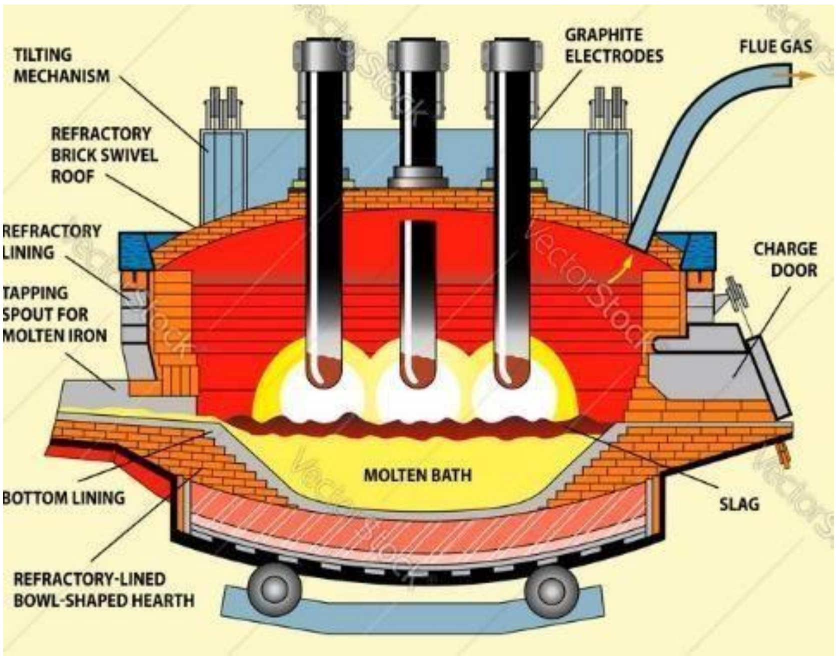
(1) Indirect arc f/c: - Here, the arc is struck two carbon electrodes and heat produced along this arc is then transferred to the charge by direct radiation and reflection from furnace lining. It is of small capacity and does not develop steel making temp rapidly.

(2) Direct arc f/c:- In this furnace arc is formed between electrodes and metallic charge. The resistance offered by the charge to the passage of current generated heat.

(3) The furnace proper looks more like a saucepan covered from top with an inverted saucer as shown in the figure. The electrodes are inserted through the cover from top.



Shop roof
Crane
Electrode for joining
Cabin
Electrode raised
Tapping position
Furnace
Charging basket (drop-bottom)
Slag
Metal ladle
Concrete foundation
Tilting mechanism



(Electric arc furnace)

The furnace unit consists of following parts:

- Furnace body i.e. the shell, the hearth, the walls, the spout, the doors, etc.
- Gears for furnace body movements.
- Roof and roof-lift arrangements.
- Electrodes, their holders and supports.
- Electrical equipment's i.e. the transformer, the cables, the electrode control mechanism, etc.

Types of process:-

- **Acid Process:** If the raw materials are very low in P and S acid lined furnace can be used for refining, using an acid slag. It is generally restricted to foundries.

- **Basic Process:** It is capable of refining any type of charge by maintaining basic slag in a basic lined furnace. Unlike any other steelmaking process electric furnace has practically no oxidising atmosphere of its own. Oxidising as well as reducing conditions for refining can be maintained by making slags of suitable compositions. Oxidising refining is carried out under a slag containing good amount of iron oxide. Reducing conditions can be maintained by having the slag highly basic but practically free of iron oxide. The following describes the ways in which these slags are used for refining in an arc furnace:

1. **Oxidising single slag practice:** It is used for making carbon or low alloy steels. The charge is melted and refined under a basic oxidising slag. The alloy additions may be made in the furnace or in the ladle.

2. **Oxidising double slag practice:** It is a modification over the single slag practice. The early slag is removed and a similar new slag is made again to obtain effective desulsphurisation and dephosphorisation during refining.

3. **Reducing single slag practice:** It is used for high alloy steelmaking to effect maximum recovery of alloying elements from the scrap. Hardly any refining take place. Carbon and phosphorus contents in the scrap
4. It must be well below the specification levels since these will not be removed during refining. Sulphur however could be removed in this practice since the conditions are reducing.

5. **Oxidising slag converted to reducing**. It is meant to remove carbon but recover most of the alloying contents like Cr, Mn, etc. in the scrap during high alloy steelmaking. Phosphorus content of the charge needs to be below the specification level, since it will otherwise revert back to the metal during the reducing period.

6. **Double slag practice**: It means refining under oxidising as well as reducing slags made separately. The first slag is oxidising and it eliminates all impurities like P, Si, C, Mn, etc. This slag is removed and a reducing slag is made by fresh additions of lime, coke and spar to desulphurise the metal and to carry out alloying very effectively. The practice is a must if effective desulphurisation and the large alloying additions are to be made. It is costly but the yield of the alloying additions is very high and the quality of the product is much better.

Arc furnace Heat (Steps)

The essential steps of the process are,

(1) Preparation of the furnace

(2) Charging

(3) Melt-down

(4) Refining

(5) Finishing and tapping of single slag heat

(6) Slag off and making reducing slag

(7) Refining and tapping of Double slag heat

These above steps should be organised in a systematic manner without any delay to obtain maximum efficiency.

(1) Preparation of the furnace. After the previous heat is tapped, the furnace lining is inspected and minor repair work in the damaged areas are performed.

(2) Charging: -

- In the top charging system the basket is loaded with a little light scrap at the bottom and heavy scrap at top to save the lining in herth area.
- Burnt lime and spar (CaF_2) are added to help form early slag.
- If refining is to be carried out during melting lumpy iron ore and mill scale are also included in the charge.
- Broken electrode and coke etc are added if required to have required 'C' in the bath at the melt-out

(3) Melt-Down –

- After first charging in over, the roof of the f/c is replaced to its position, the electrodes are lowered manually, the arc is struck.
- Then the electrodes are put on automatic control for continuous arc.
- As the metal melts and drip down, the electrode travels automatically further down to maintain a stable arc.
- After melting the bath is super-heated to the desired temperature.

(4) Refining:

- Refining is done by keeping the furnace in oxidation state. Oxidation of carbon in the bath causes boiling action results in stirring of bath and make refining reaction faster.
- If the bath contains phosphorus above the specified level it is removed by making the bath oxidising and basic.
- Once the bath reaches desired composition and temperature it is deoxidised and prepared for tapping.

(5) Finishing and tapping of single slag heat:

- The heat is tapped by opening the tap hole. The furnace is tilted by a jerk to prevent from flowing along with steel.

(6) Slag off and making reducing Slag: -

- In double slag practice, the final slag is removed at the end of oxidising period refining.
- Then reducing slag is formed by mixing coke on the slag after .
- After completion of reducing period alloying addition are done if required.

(7) Refining and tapping of Double slag heat

- After alloying addition, the bath composition is adjusted, tapping is carried out from the furnace.

Advantages:

- All type of steel can be made EAF furnace.
- Simultaneously oxidising and reducing atmosphere can be made.
- DRI, Pellet ,HBI can be charged as a charged material.
- Wide range capacity
- Recovery of alloying element
- high yield furnace about 91%

Lecture-20

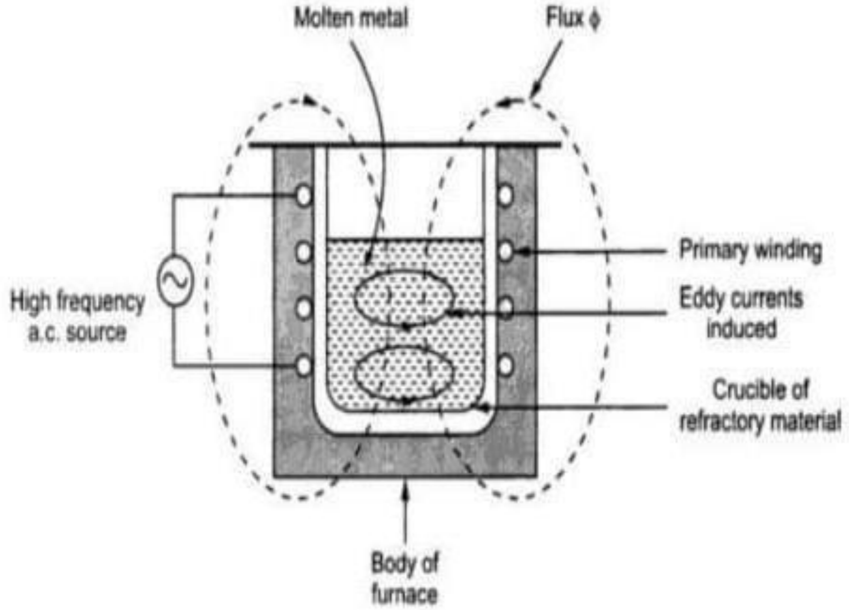
Introduction

Furnace Process

- Induction furnace is a type of electric furnace which uses electromagnetic induction to create heat.
- Induction furnace comprises a relatively thin refractory crucible encircled by copper coil.
- When the coil is energized, it leads to flow of current in the electrically charged material in the furnace. Due to resistance the material get heated and eventually melts.
- The induction furnace can range in size, from a small furnace used for very precise alloys only about a kilogram in weight to a much larger .

furnaces made to mass produce clean metal for many different applications.

- Foundries use this type of furnace and to melt iron and steel, copper, aluminium, and precious metals.
- Charge materials must be clean free of oxidation products and of a known composition.



ADVANTAGES OF INDUCTION FURNACE: Induction furnaces offer certain advantages over other furnace systems. They include:

1. Higher Yield- The absence of combustion sources reduces oxidation losses that can be significant in production economics

2. Faster Start-up. Full power from the power supply is available, instantaneously, thus reducing the time to reach working temperature. Cold charge-to-tap times of one to two hours are common.

3. Flexibility- No molten metal is necessary to start induction melting equipment. This facilitates repeated cold starting and frequent alloy changes.

4. Energy Conservation- Overall energy efficiency in induction melting ranges from 55 to 75 percent, and is significantly better than combustion processes

5. Better Working Environment- Induction furnaces are much quieter than gas furnaces, arc furnaces, or cupolas. No combustion gas is present and waste heat is minimized.

DISADVANTAGES OF INDUCTION FURNACE :

2. Refining in Induction Furnace is not as intensive or effective as in Electric Arc Furnace (EAF).
3. Life of Refractory lining is low as compared to EAF.
4. Removal of S & P is limited, so selection of charges with less impurity is required.

Lecture-21

Secondary Steelmaking Processes

Principle and Operation of LHF (Ladle Heating Furnace/Ladle Furnace), Inclusion Control and Clean Steel, and RH-OB Degassing Process

Secondary Steelmaking

Definition

Secondary steelmaking (also called **secondary metallurgy** or **ladle metallurgy**) is the treatment of molten steel **after it leaves the primary steelmaking furnace (LD/BOF or EAF)** and **before continuous casting**.

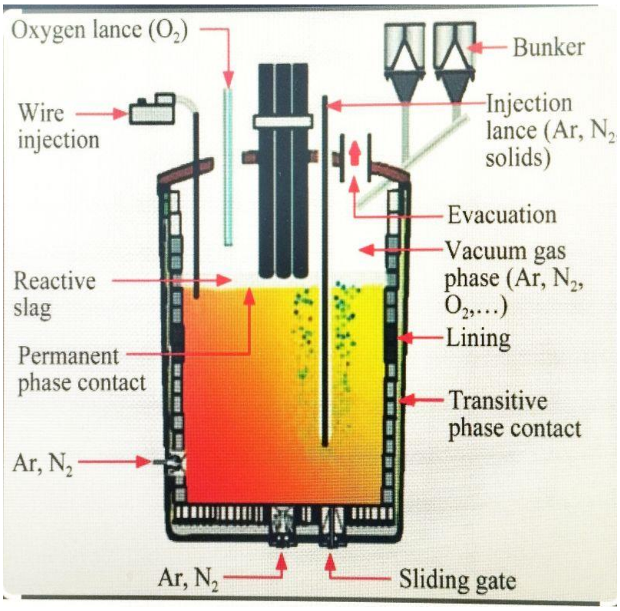
The main purpose is to improve the **quality, cleanliness, composition, and temperature** of steel.

Objectives of Secondary Steelmaking

- Remove dissolved gases (H_2, N_2, O_2)
- Remove non-metallic inclusions
- Adjust chemical composition
- Add alloying elements

- Control steel temperature
- Improve steel cleanliness
- Produce high-quality steel

1. LHF (Ladle Heating Furnace / Ladle Furnace)



1. Definition

The **Ladle Heating Furnace (LHF)**, also called the **Ladle Furnace (LF)**, is a secondary steelmaking unit where molten steel is heated and refined inside a ladle using **electric arc heating**.

It is used to maintain the required temperature and improve steel quality before casting.

Principle of LHF

The LHF works on the principle of **electric arc heating**.

- Electric current passes through graphite electrodes.
- An electric arc is produced between the electrodes and molten steel.
- The heat generated raises the steel temperature.
- Argon gas is blown from the bottom to stir the molten steel.
- Fluxes and alloying elements are added for refining.

Thus, steel is heated, stirred, and refined simultaneously.

Construction of LHF

Main parts:

- Steel ladle
- Refractory lining
- Graphite electrodes (usually three)
- Transformer
- Electrode lifting system
- Argon gas purging system

- Ladle cover
- Alloy and flux addition system

Operation of LHF

Step 1 – Transfer of Steel

Molten steel from BOF or EAF is poured into a ladle.

Step 2 – Heating

The ladle is placed under three graphite electrodes.

Electric current passes through the electrodes, producing an electric arc that heats the molten steel.

Step 3 – Argon Stirring

Argon gas is blown through porous plugs at the bottom of the ladle. Purpose:

- Mixes the molten steel uniformly.
- Helps alloying elements dissolve.
- Brings inclusions to the slag layer.
- Maintains uniform temperature.

Step 4 – Alloy Addition

Required alloying elements such as:

- Ferro-manganese
- Ferro-silicon
- Ferro-chromium

are added to achieve the desired steel composition.

Step 5 – Slag Refining

Basic slag is formed by adding lime and other fluxes. The slag

absorbs impurities and inclusions.

Step 6 – Tapping to Continuous Casting

After achieving the required composition and temperature, the ladle is sent to the continuous casting machine

Advantages of LHF

- Accurate temperature control.
- Uniform steel composition.
- Better inclusion removal.
- Better alloy recovery.
- Produces clean steel.
- Reduces dissolved oxygen.

Applications

- Stainless steel
- Alloy steel
- High-strength steel
- Bearing steel
- Spring steel

Flow Chart of LHF

Steel from BOF/EAF

↓

Transfer to Ladle

Electric Arc Heating

↓

Argon Stirring

↓

Alloy Addition

↓

Slag Refining

↓

Temperature Adjustment

↓

Continuous Casting

2. Inclusion Control and Clean Steel

What are Inclusions?

Inclusions are small non-metallic particles present inside molten steel. They reduce steel quality if they remain in the metal.

Types of Inclusions Oxide

Inclusions Examples:

- SiO_2
- Al_2O_3
- FeO
- MnO

Sulphide Inclusions

Example:

- MnS

- Nitride Inclusions

Examples:

- AlN
- TiN

Complex Inclusions

Combination of oxides, sulphides and nitrides.

Sources of Inclusions

- Oxidation during steelmaking.
- Slag entrainment.
- Refractory erosion.
- Improper deoxidation.
- Reoxidation by air.

Why are Inclusions Harmful?

Inclusions:

- Reduce strength.
- Reduce toughness.
- Cause cracks.
- Reduce fatigue life.
- Reduce surface quality.
- Cause casting defects.

Clean Steel

Definition

Clean steel is steel that contains very low levels of non-metallic inclusions and dissolved gases.

It has high strength, good toughness, and excellent surface quality.

Methods of Inclusion Control

1. Proper Deoxidation

Aluminium or silicon is added to remove dissolved oxygen. Example:

2Al+3O→Al2O32Al+3O \rightarrow Al_2O_32Al+3O→Al2O3

2. Argon Stirring

Argon gas carries inclusions upward into the slag layer.

3. Slag Refining

Basic slag absorbs oxide inclusions.

4. Vacuum Degassing

Removes dissolved gases such as hydrogen and nitrogen.

5. Calcium Treatment

Calcium converts harmful alumina inclusions into soft liquid inclusions.

6. Clean Tundish Practice

Prevent slag and refractory particles from entering the steel during casting.

Advantages of Clean Steel

- Higher strength.
- Better toughness.
- Better weldability.
- Longer service life.
- Better fatigue resistance.
- Improved surface finish

Lecture -22

RH-OB Degassing Process

Definition

The **RH-OB (Ruhrstahl-Heraeus with Oxygen Blowing)** process is an advanced secondary steelmaking process used for **vacuum degassing, decarburization, and alloy adjustment**.

It is mainly used for producing **ultra-low carbon steels** and **high-quality alloy steels**.

Principle

The RH-OB process works on two principles:

Vacuum Degassing

Under vacuum, dissolved gases such as hydrogen, nitrogen, and oxygen escape easily from molten steel.

Oxygen Blowing

Oxygen is blown into the steel under vacuum to oxidize carbon. This

reduces the carbon content to extremely low levels.

Construction

Main parts:

- Vacuum chamber
- Two snorkels (up-leg and down-leg)
- Vacuum pumps
- Oxygen lance
- Argon gas injection system
- Steel ladle

Operation of RH-OB Process

Step 1 – Transfer

Molten steel is brought from the BOF or EAF in a ladle.

Step 2 – Vacuum Chamber

The vacuum chamber is lowered onto the ladle.

Step 3 – Argon Injection

Argon gas is injected through the up-leg snorkel.

The gas bubbles lift molten steel into the vacuum chamber.

Step 4 – Vacuum Degassing

Inside the vacuum chamber:

- Hydrogen is removed.
- Nitrogen is removed.
- Oxygen is reduced.

Step 5 – Oxygen Blowing

Oxygen is blown into the molten steel. Carbon

reacts with oxygen:

C+12O2→COC+\frac{1}{2}O_2\rightarrow COC+21O2→CO
The carbon monoxide gas is removed by the vacuum system.

Step 6 – Alloy Adjustment

Required alloying elements are added.

Step 7 – Return Flow

Refined steel flows back into the ladle through the down-leg snorkel. This circulation continues until the desired composition is achieved.

Step 8 – Continuous Casting

The refined steel is sent to the continuous casting machine.

Advantages of RH-OB Process

- Produces ultra-low carbon steel.
- Removes hydrogen and nitrogen effectively.
- Improves steel cleanliness.
- Better alloy recovery.
- Uniform steel composition.
- Excellent steel quality.
- High productivity.

Applications

- Automobile sheet steel.
- Electrical steel.
- Pipeline steel.
- Stainless steel.
- High-strength low-alloy steel.

Flow Chart of RH-OB Process

Molten Steel from BOF/EAF
↓
Transfer to Ladle
↓
Vacuum Chamber Lowered
↓
Argon Injection
↓
Steel Circulation
↓
Vacuum Degassing
↓
Oxygen Blowing
↓
Carbon Removal
↓
Alloy Addition
↓
Steel Returns to Ladle
↓
Continuous Casting

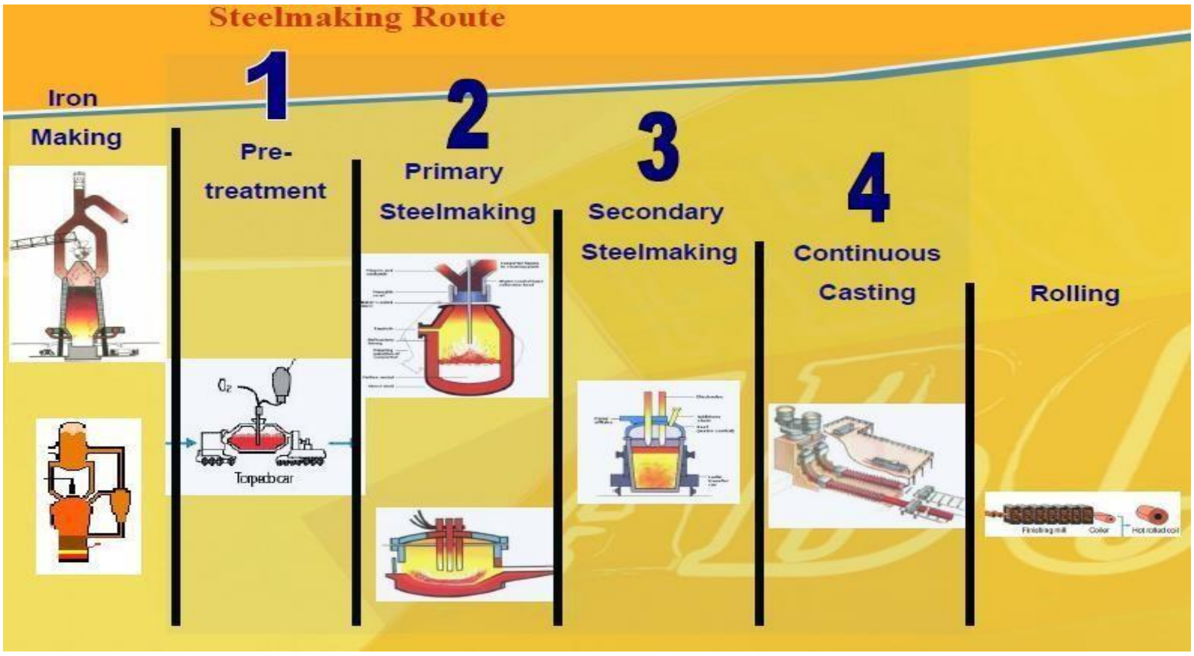
Comparison of LHF and RH-OB

Feature	LHF (Ladle Furnace)	RH-OB Process
Heating Source	Electric arc	Vacuum + oxygen blowing
Main Purpose	Heating and alloy adjustment	Vacuum degassing and decarburization
Gas Removal	Limited	Excellent
Carbon Removal	Small	Very high
Temperature Control	Excellent	Good
Steel Quality	High	Very high
Main Products	Alloy steels	Ultra-low carbon and clean steels

Feature LHF (Ladle Furnace) RH-OB Process

Lecture-23

Secondary Steel Making Processes



- Primary steelmaking is aimed at fast scrap melting and rapid refining.
- It is capable of refining to a broad steel specifications, but is not designed to meet the stringent demands on steel quality, and consistency of composition and temperature that is required for various grades of steel.
- In order to achieve such requirements, liquid steel from primary steelmaking units has to be further refined in the ladle after tapping. This is known as *Secondary Steelmaking*.
- Secondary refining removes impurities and adjusts elements. Secondary refining usually takes place in the ladle (a transportation vessel for molten steel). It is very important for the production of high-grade steel. Examples include LF,VAD, VOD, AOD, VD etc.

Objectives of secondary steelmaking

- De-oxidation -Removal of Oxygen
- Desulphurization -To sulphur concentrations as low as 0.002%
- Alloying -Addition of alloying elements
- Micro cleanliness -Removal of non-metallic inclusions
- Superheat Control - + / -5 degree C

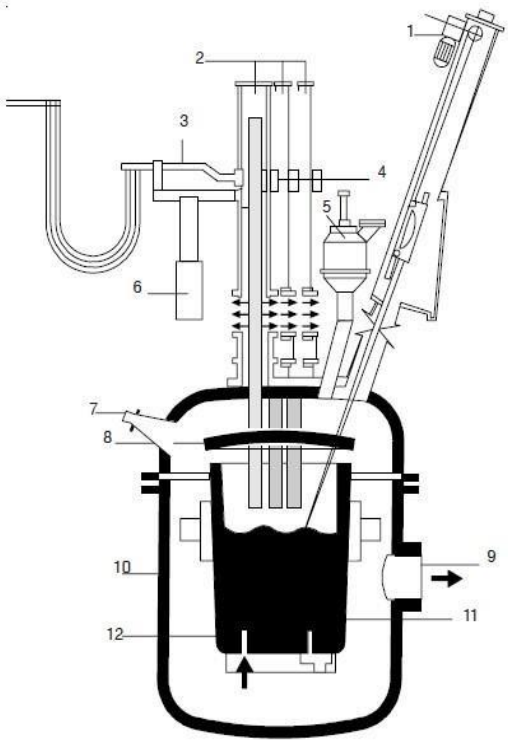
Advantages:

- Lower impurity contents
- Better cleanliness. (i.e. lower inclusion contents)
- Stringent quality control. (i.e. less variation from heat-to-heat)
- Micro-alloying to impart superior properties.
- Better surface quality and homogeneity in the cast product.

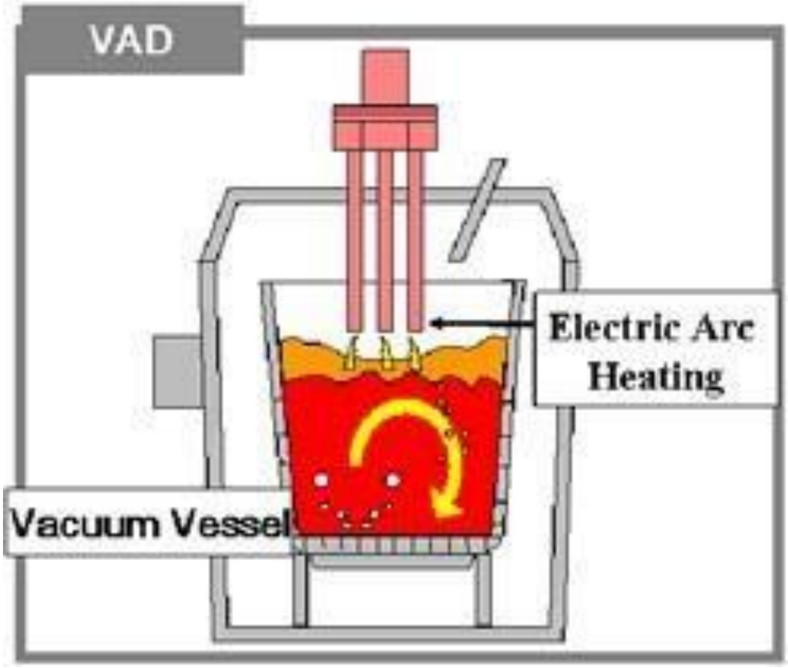
Vacuum Arc Degassing (VAD) Process

- During steelmaking i.e. refining of pig iron where impurities like carbon, silicon, manganese and phosphorus are eliminated to the

  required level. Oxygen, nitrogen and hydrogen get dissolved as harmful impurities.
- As solubility decreases with decrease of temperature excess gases dissolved in steel are liberated during solidification.
- The evolution of the gas gives rise to the formation pin holes, blow holes, pipes etc.
- The unsoundness caused by these cavities affect the mechanical properties of steel.



1. Vacuum temperature and sampling lance
2. Telescopic tubes for vacuum-tight electrode sealing
3. Water-cooled high-current system
4. Electrode clamping mechanism
5. Vacuum lock for alloying agents
6. Guide mast for electrode control
7. Sight glass with rotor
8. Heat shield
9. Vacuum connection
10. Vacuum treatment vessel
11. Steel casting ladle
12. Inert gas bubbling brick (porous plug)

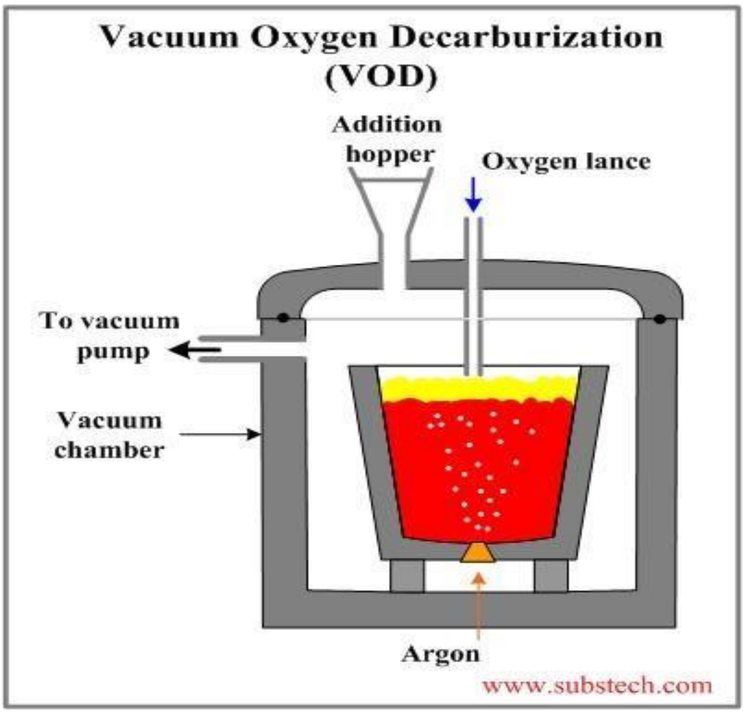


- Vacuum arc degassing (VAD) process is a ladle degassing process with electrodes added for the purpose of reheating the liquid steel.
- The ladle sits in a vacuum tank and is stirred by inert gas from the bottom with provision for heating through electrodes and alloying additions.
- Heating is done by the arc with graphite electrodes, as in a ladle furnace. Heating, degassing, slag treatment and alloy adjustment are carried out without interrupting the vacuum.

Vacuum oxygen decarburization (VOD)

- Exposing steel to vacuum conditions has a profound effect on all metallurgical reactions involving gases. First, it lowers the level of gases dissolved in liquid steel. Hydrogen, for example, is readily removed in a vacuum to less than two parts per million.
- Another important process is vacuum decarburization and deoxidation. Extensive decarburization is achievable with a Vacuum Oxygen Decarburization (VOD) unit.

- vacuum oxygen decarburization (VOD), which has an oxygen lance in the centre of the tank lid to enhance carbon removal under vacuum.
- The VOD is often used to lower the carbon content of high-alloy steels without also overoxidizing such oxidizable alloying elements as chromium.
- The carbon can be lowered to around 0.02% at around 15-18% chromium at a temp. 1600 2 hr □c. & time taken by VOD process is about to 2 hr 30 min.



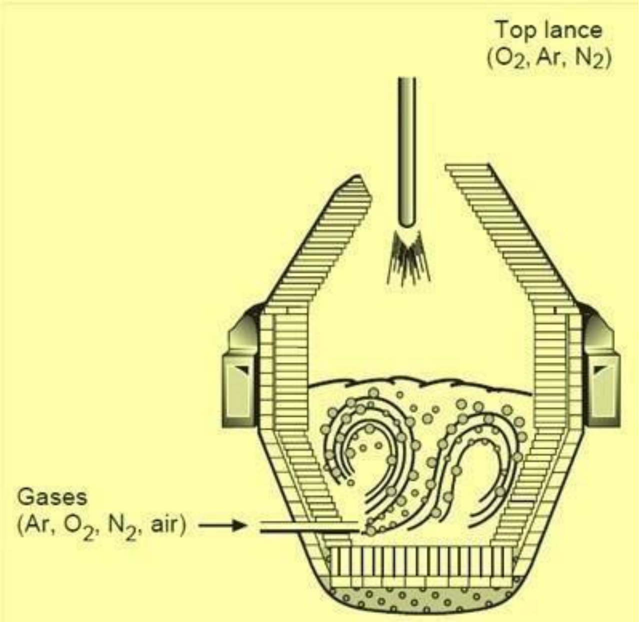
ADVANTAGES:

- Extensive decarburization with low alloying element losses.
- Chemical heating of liquid steel.
- Improved conditions for desulfurization by proper additions.
- Improved conditions for Inclusion flotation.

Argon oxygen decarburization (AOD)

- It is a process primarily used in stainless steelmaking and other high grade alloys with oxidizable elements such as chromium and aluminium.
- After initial melting the metal is then transferred to an AOD vessel where it is subjected to three steps of refining:

    1. Decarburization
    2. Reduction
    3. Desulphurization



- Initially, when the carbon content of the melt is high, O2 blowing through the top lance is predominant, though the gas mixture introduced though the side tuyere also contains a high percentage of oxygen.
- However, as decarburisation proceeds, oxygen blowing from the top is reduced in stages and argon blowing increased. Some stainless steel grades contain nitrogen as a part of the specifications, in which case, nitrogen is employed in place of argon in the final stages.

Decarburization:

- The decarburization step is controlled by ratios of oxygen to argon or nitrogen to remove the carbon from the metal bath.
- The gases are usually blown through a top lance and tuyeres in the sides/bottom.
- In the stages of blowing carbon is removed by the combination of oxygen and carbon forming CO gas.
- To drive the reaction to the forming of CO, the partial pressure of CO is lowered using argon or nitrogen.
- The burning of carbon increases the bath temperature. Reduction:
- After a desired carbon and temperature level have been reached the process moves to reduction.
- Reduction recovers the oxidized elements such as chromium from the slag.
- To achieve this, alloy additions are made with elements that have a higher affinity for oxygen than chromium, using either a silicon alloy or aluminium.

Desulphurization:

- Desulphurization is achieved by having a high lime concentration in the slag and a low oxygen activity in the metal bath.

$$S(bath) + CaO(slag) \rightarrow CaS(slag) + O(bath)$$

So, additions of lime leads to dilute sulphur in the metal bath. Also, aluminium or silicon may be added to remove oxygen.

ADVANTAGES:

- Higher metallic yields with lower material costs.
- Pinpoint accuracy in chemistry control down to 0.01% carbon and lower, rapid desulfurization to less than 0.001%.
- Improved conditions for Inclusion flotation.

Lecture-24

Inclusion Control and Clean Steel Production Definition of

Inclusion

Inclusions are unwanted **non-metallic solid particles** present in molten steel or finished steel. These particles are formed during steelmaking or enter the steel from external sources. They reduce the quality and performance of steel.

Examples of Inclusions

- Aluminium oxide (Al_2O_3)
- Silicon dioxide (SiO_2)
- Manganese sulphide (MnS)
- Iron oxide (FeO)
- Calcium aluminate ($CaO–Al_2O_3$)

Types of Inclusions

1. Oxide Inclusions

Formed due to oxidation during steelmaking. Examples:

- Al_2O_3
- SiO_2
- FeO
- MnO

2. Sulphide Inclusions

Formed by the reaction of sulphur with metals. Example:

- MnS
- NiS

3. Nitride Inclusions

Formed when nitrogen reacts with alloying elements.

Examples:

- AlN
- TiN

4.Complex Inclusions

Combination of oxides, sulphides, and nitrides.

Sources of Inclusions

1. Oxidation of molten steel.
2. Slag particles entering the steel.
3. Erosion of refractory lining.
4. Improper deoxidation.
5. Exposure of molten steel to air (reoxidation).

Harmful Effects of Inclusions

- Reduce tensile strength.
- Reduce toughness.
- Cause cracks.

- Reduce fatigue life.
- Cause poor surface finish.
- Create casting defects.
- Lower machinability.

What is Clean Steel?

Clean steel is steel containing **very low amounts of inclusions and dissolved gases (H_2, N_2, O_2)**. It has better mechanical properties and a longer service life.

Methods of Inclusion Control

1. Proper Deoxidation

Deoxidizers such as **Aluminium, Silicon, and Manganese** are added to remove dissolved oxygen.

Chemical Reaction

2Al+3O→Al2O32Al + 3O \rightarrow Al_2O_32Al+3O→Al2O3

These oxides float into the slag.

2. Argon Stirring

Argon gas is injected through porous plugs at the bottom of the ladle.

Functions

- Mixes molten steel.
- Carries inclusions to the slag layer.
- Maintains uniform temperature.
- Improves alloy distribution.

3. Slag Refining

A basic slag (rich in CaO) absorbs oxide inclusions and sulphur.

4. Vacuum Degassing

Removes dissolved gases such as hydrogen, nitrogen, and oxygen.

5. Calcium Treatment

Calcium converts solid alumina inclusions into soft liquid calcium aluminates, making them easier to remove.

6. Clean Tundish Practice

- Prevents slag from entering the mould.
- Uses tundish dams and weirs.
- Controls steel flow.

Inclusion Removal Diagram

```
                    Slag Layer
--------------------------------------------------------------------
     ▲         ▲         ▲         ▲
     |         |         |         |
  Inclusions Float Up Molten Steel
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
              ↑       ↑       ↑
- - - - - - - Argon Gas - - - - - - - - - - - - - - - - - - - - - -
```

Advantages of Clean Steel

- Higher strength.
- Better toughness.
- Better fatigue resistance.

- Improved weldability.
- Better surface finish.
- Longer service life.
- Fewer casting defects.

2. Process Control and Automation in Secondary Steelmaking

Definition

Process control is the continuous monitoring and adjustment of steelmaking operations to produce steel of the required quality.

Automation means using computers, sensors, PLCs (Programmable Logic Controllers), and automatic control systems to perform these operations with minimum human intervention.

Objectives of Process Control

- Maintain correct steel temperature.
- Control chemical composition.
- Control oxygen content.
- Add alloys accurately.
- Reduce production time.
- Improve steel quality.
- Reduce production cost.

Important Parameters Controlled

1. Temperature

Steel temperature is measured using **immersion thermocouples** or temperature sensors.

Correct temperature is essential for:

- Alloy dissolution
- Continuous casting
- Good steel quality

2. Chemical Composition

Elements monitored:

- Carbon
- Manganese
- Silicon
- Phosphorus
- Sulphur
- Chromium
- Nickel

Samples are analyzed using spectrometers.

3. Oxygen Content

Oxygen sensors measure dissolved oxygen. If

oxygen is high, deoxidizers are added.

4. Argon Flow Rate

Argon flow is automatically controlled to ensure proper stirring.

5. Vacuum Pressure

In RH or VD processes, vacuum pressure is continuously monitored.

6. Alloy Addition

Automatic weighing and feeding systems add the correct quantity of alloys.

Automation Equipment Used

- Temperature sensors
- Oxygen probes
- Spectrometers
- PLC (Programmable Logic Controller)
- Computer control systems
- Flow meters
- Load cells
- Automatic alloy feeders
- Vacuum pressure gauges

Advantages of Automation

- Accurate temperature control.
- Accurate alloy addition.
- Better steel quality.
- Faster production.
- Lower labour requirement.
- Reduced human errors.
- Better process safety.
- Higher productivity.
- Lower manufacturing cost.

Disadvantages

- High installation cost.
- Requires skilled operators.
- Expensive maintenance.
- Dependence on electronic systems.

Comparison: Manual vs Automated Steelmaking

Manual Control	Automated Control
Operator dependent	Computer controlled
Lower accuracy	High accuracy
More human errors	Fewer human errors
Slower process	Faster process
Higher labour requirement	Lower labour requirement
Lower productivity	Higher productivity
Difficult quality control	Easy quality control

Applications

- Ladle Furnace (LF/LHF)
- RH Degassing
- VD (Vacuum Degassing)
- Continuous Casting
- Stainless Steel Production
- High-quality Alloy Steel Production

Lecture-24

Stainless Steel

Definition

Stainless steel is an alloy steel containing **at least 10.5% chromium (Cr)**. Chromium forms a thin protective oxide layer called the **passive film**, which protects the steel from rust and corrosion.

Main Alloying Elements

- Chromium (Cr)
- Nickel (Ni)
- Carbon (C)
- Molybdenum (Mo)
- Manganese (Mn)
- Nitrogen (N)

What are Stainless Steel Grades?

A **grade** is a classification of stainless steel based on its **chemical composition, microstructure, mechanical properties, and applications**.

Examples:

- SS 304
- SS 316
- SS 410
- SS 430
- Duplex 2205

Types (Grades) of Stainless Steel

There are five main grades of stainless steel.

1. Austenitic Stainless Steel
2. Ferritic Stainless Steel
3. Martensitic Stainless Steel
4. Duplex Stainless Steel
5. Precipitation Hardening Stainless Steel

1. Austenitic Stainless Steel

Composition

- Chromium: **16–26%**
- Nickel: **6–22%**
- Carbon: Less than **0.08%**

Common Grades

- SS 304
- SS 304L
- SS 316
- SS 316L
- SS 310

Properties

- Excellent corrosion resistance
- Non-magnetic
- High ductility
- Good weldability

High toughness

Applications

- Kitchen utensils
- Food processing equipment
- Chemical plants
- Dairy equipment
- Pharmaceutical industries
- Storage tanks

2. Ferritic Stainless Steel

Composition

- Chromium: **10.5–18%**
- Very low carbon
- Little or no nickel

Common Grades

- SS 409
- SS 430
- SS 446

Properties

- Magnetic
- Good corrosion resistance
- Good oxidation resistance
- Low cost
- Poor weldability

Applications

- Automobile exhaust systems
- Washing machines
- Decorative panels
- Home appliances

3. Martensitic Stainless Steel

Composition

- Chromium: **11–18%**
- Carbon: **0.1–1.2%**

Common Grades

- SS 410
- SS 420
- SS 440C

Properties

- Very hard
- High strength
- Heat treatable
- Moderate corrosion resistance

Applications

- Surgical instruments
- Knives
- Turbine blades
- Pump shafts
- Valves

4. Duplex Stainless Steel

Composition

- Chromium: **22–25%**
- Nickel: **5–7%**
- Molybdenum: **2–4%**
- Nitrogen added

Common Grades

- Duplex 2205
- Super Duplex 2507

Properties

- Excellent corrosion resistance
- Very high strength
- Good weldability
- Resistant to stress corrosion cracking

Applications

- Offshore platforms
- Oil and gas industries
- Chemical plants
- Marine equipment
- Pressure vessel

5. Precipitation Hardening (PH) Stainless Steel

Composition

Contains

- Chromium
- Nickel
- Copper
- Aluminium

- Niobium

Common Grades

- 17-4 PH
- 15-5 PH

Properties

- Very high strength
- Excellent toughness
- Heat treatable
- Good corrosion resistance

Applications

- Aircraft parts
- Aerospace industry
- Nuclear industry
- Defence equipment
- High-pressure components

Comparison of Stainless Steel Grades

Grade	Chromium (%)	Nickel (%)	Magnetic	Heat Treatable	Corrosion Resistance	Common Applications
Austenitic	16–26	6–22	No	No	Excellent	Kitchenware, chemical plants
Ferritic	10.5–18	Very low	Yes	No	Good	Exhaust systems, appliances
Martensitic	11–18	Low	Yes	Yes	Moderate	Knives, surgical tools
Duplex	22–25	5–7	Slightly	No	Excellent	Offshore, marine
Stainless Steel	15–17	3–7	Yes	Yes	Very Good	Aerospace, defence

Industrial Selection Criteria for Stainless Steel

Selecting the correct stainless steel grade depends on the service conditions and application.

1. Corrosion Resistance

The grade should resist corrosion in its working environment.

- Mild environment → SS 304
- Marine environment → SS 316 or Duplex
- Chemical industry → SS 316 or Duplex

2. Mechanical Strength

If high strength is required:

- Duplex Stainless Steel
- PH Stainless Steel

are preferred.

3. Operating Temperature

For high-temperature applications, grades such as:

- SS 310
- SS 309

are selected because they have good oxidation resistance.

4. Weldability

For welded structures:

- Austenitic grades (304, 316)

are preferred due to their excellent weldability.

5. Machinability

If extensive machining is required, grades with improved machinability are selected, such as:

- SS 303

6. Heat Treatment Requirement

If high hardness is required after heat treatment:

- Martensitic grades (410, 420, 440C)
- PH Stainless Steel (17-4 PH)

are suitable.

7. Cost

Cost also influences selection.

- Ferritic Stainless Steel → Low cost
- Austenitic Stainless Steel → Moderate cost
- Duplex Stainless Steel → High cost
- PH Stainless Steel → Very high cost

8. Magnetic Property

- Non-magnetic applications → Austenitic
- Magnetic applications → Ferritic or Martensitic

9. Fabrication Requirement

For easy forming and bending:

- Austenitic Stainless Steel

  is the best choice.

Lecture-25

Common Casting Defects in Steel

1. Blow Holes

Blow holes are large gas cavities formed inside the casting due to trapped gases such as hydrogen or carbon monoxide.

Causes:

- Excess dissolved gases in molten steel
- Poor deoxidation
- Wet moulds

Prevention:

- Proper deoxidation
- Vacuum degassing
- Dry moulds

2. Pin Holes

Pin holes are very small gas pores found near the surface of the casting.

Causes:

- Hydrogen gas
- Moisture in mould or refractory
  High pouring temperature

Prevention:

- Dry moulds
- Proper degassing
- Controlled pouring temperature
-

3. Shrinkage Cavity

A shrinkage cavity is an internal void formed because molten steel contracts during solidification and insufficient molten metal is available to fill the space.

Causes:

- Improper feeding
- Poor riser design

Prevention:

- Proper riser design
- Directional solidification
-

4. Hot Cracks (Hot Tears)

Hot cracks develop while the steel is still hot during the final stage of solidification due to thermal stresses.

Causes:

- Uneven cooling
- Restrained contraction
- Poor mould design

Prevention:

- Uniform cooling
- Proper mould design
- Controlled solidification

5. Cold Cracks

Cold cracks occur after complete solidification due to residual stresses or improper cooling.

Causes:

- Rapid cooling
- Improper heat treatment

Prevention:

- Controlled cooling
- Stress-relief heat treatment
-

6. Non-metallic Inclusions

These are unwanted particles such as oxides, sulphides, and slag trapped inside the steel.

Causes:

- Slag entrapment
- Poor deoxidation
- Refractory erosion

Prevention:

- Argon stirring
- Slag control
- Vacuum treatment

7. Centreline Segregation

Centreline segregation is the accumulation of carbon and alloying elements at the centre of a continuously cast slab or billet.

Causes:

- Uneven solidification
- Improper cooling

Prevention:

- Electromagnetic stirring (EMS)
- Controlled cooling
- Proper casting speed

8. Slag Entrapment

Slag particles become trapped inside the molten steel during casting.

Causes:

- Poor slag removal
- Turbulent pouring

Prevention:

- Proper slag skimming
- Clean pouring practices

Lecture-26

Pit Side

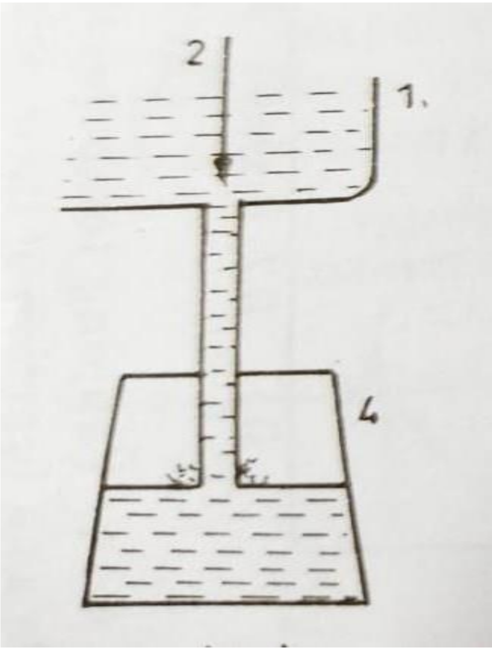
Practice Teeming Methods:

Teeming refers to direct pouring of liquid steel in an ingot mould. Three methods are used for teeming of liquid steel into mould:

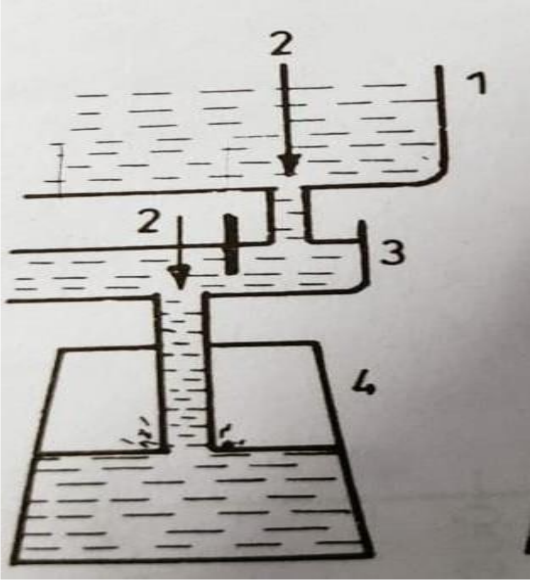
1. Direct pouring
2. Tundish teeming
3. Bottom teeming

1. Direct pouring:

- The metal is teemed directly in the mould from the ladle.
- The rate of pouring can be controlled by the size and design of nozzle.
- As, the metal stream directly hits the bottom of mould, the wear of bottom is quit severe.



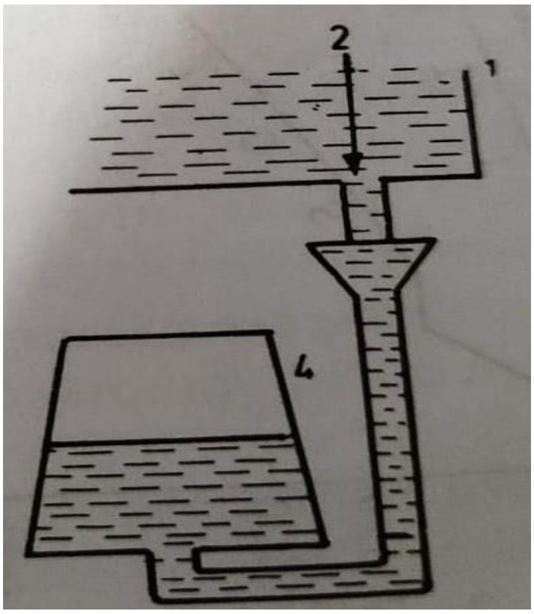
Direct pouring



2. Tundish Teeming

- To minimize ingot defect uniform metal flow is required.
- A tundish (reservoir) is therefore inserted in between ladle and mould which ensures uniform flow of metal into mould.
- The tundish is filled to a certain depth which is maintained throughout the teeming period to eliminate the flow variation.
- A tundish have one or more nozzles to distribute metal into several mould at a time. Which reduces overall teeming period of a ladle.

3. Bottom teeming



1- Teeming Ladle 2- Stopper rod 4- Mould

- In this teeming process, steel is teemed into a vertical runner which is connected at the bottom to a horizontal through runner, the end of which is elbow shape, opens up in the bottom of the mould.

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

- However bottom teeming uses more refractory and preparation for casting. Also steel that solidified in the runner has to be scrapped.

- This type of teeming process is used only if superior quality of ingot is necessary.

Lecture-27

Ingot defects :

i) Pipe formation:

Cause:

- Steel contracts about 2.5-3% on solidification. The volumetric shrinkage during solidification appears in the form of cavity known as pipe.
- In killed steels pipe formation occurs toward the end of solidification. The portion of ingot containing pipe has to be discarded which affects yield.

Remedy:

- Use of hot top feeder on the mould. The volume of the hot top is 1015% higher than ingot volume.
- Pouring extra metal into mould after partial solidification.

ii) Blow holes

Cause:

- Evolution of gas during solidification of steel. Entrapment of gas produces blow holes in the ingot.
- Blow holes located inside the ingot can be welded during rolling. Rimming steels show blow holes due to rimming reaction between carbon and oxygen.

Remedy: Control of gas evolution during solidification so that blow hole forms only within the ingot skin of adequate thickness.

iii) Segregation:

- It is the difference in composition of steel within the ingot than some average composition.
- Segregation is due to
  a) Difference in solubility of solute elements in liquid and solid steel.
  b) Rate of solidification: faster rate of solidification avoids the elements to segregate.
  c) Larger size ingots: are susceptible to segregation than smaller size ones. Larger size ingots require more time for solidification.
- Remedy: soaking of ingots at high temperature can minimize segregation.

iv) Non-metallic inclusions:

- Non-metallic inclusions are inorganic oxides, sulphides and nitrides formed by reaction between metal like Fe, Ti, Zr, Mn, Si & Al with non-metallic elements like oxygen, nitrogen, sulphur etc.
- These are two types:
  a) Indigenous: those arising during steel making.
  b) Exogenous: those arising from mechanical erosion of contacting refractory lining.

Remedy:

- Proper care during de-oxidation.
- Use of strong refractory in the mould.
- Vacuum treatment.

v) Ingot cracks

- Surface cracks are formed due to friction between mould and ingot surface. The improper design of mould taper and corner radius cause surface cracks.

- Different types of cracks are: Transverse cracks: They are parallel to the base of ingot and are formed due to longitudinal tension in the ingot skin.

- Longitudinal cracks are formed due to lateral tension in the skin. They are parallel to vertical axis of ingot.

- Remedy: proper design of mould, thick mould wall, proper cleaning of mould before pouring.

Lecture28

Continuous Casting of Steel

Introduction

- For more than 150 years till the 1960s, ingot casting of liquid steel into ingots for further shaping by stepwise rolling or forging, was the only method available for casting liquid steel into a solid shape.

- Continuous casting on a commercial scale came into picture from in 1960.

- Since then, continuous casting has come a long way, and today, a staggering 75% of the total crude steel production in the world is continuously cast into one shape or another (slabs, blooms, billets, other shapes).

- The main advantage of continuous casting is that the product is ready for direct rolling, sometimes even without further reheating.

Lecture-29

Principle

- It may be defined as teeming of a liquid steel in a short mould with a false bottom through which partially solidified ingot is continuously withdrawn at the same rate at which metal is poured in the mould.

Or

- Continuous casting of steel is a process in which liquid steel is continuously solidified into a strand of metal.

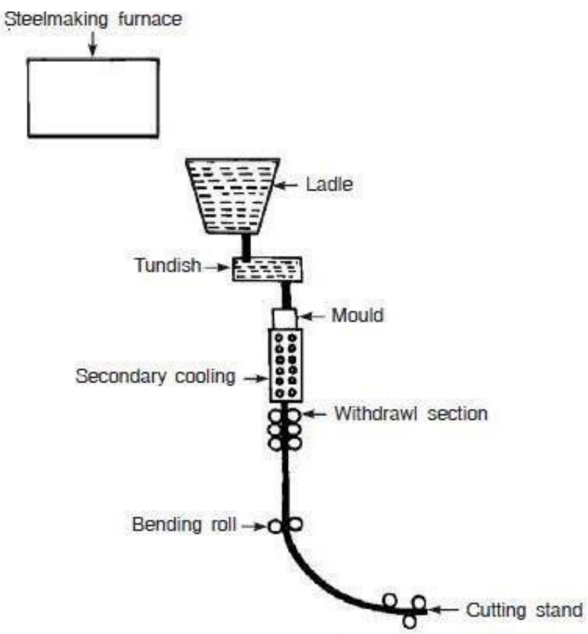


Figure 3.6 Essential features of continuous casting.

Casting process/ Component	Primary Task	Secondary Task
Ladle	Transport and hold the liquid steel	Facilitate inclusion removal
Ladle Turret	Position full ladles over the tundish and remove empty ones	Free the cranes for higher productivity
Tundish	Act as a buffer between ladle and mold	Facilitate inclusion removal
Mold	Cool down the liquid steel to form a solidified shell	
Strand System	Further cool the strand to fully solidified and straighten the strand	

- Depending on the dimensions of the strand, these semi-finished products are called slabs (flat products, i.e. plate, sheet, coils), blooms (long products, i.e. bars, beams) and billets (long products, i.e. bars, channels, wires).

The basic equipment and operations involved in continuous casting are:

- A source of liquid steel, generally after secondary treatment to ensure temperature homogeneity in the entire ladle.
- A ladle for transferring and holding the liquid metal.
- A tundish for distributing the metal into the continuous casting moulds made of copper.
- The mould(s) to freeze an outer skin.
- Water sprays to complete the solidification.
- A drive system to control the rate of withdrawal of the cast products from the mould.

Continuous Casting Process

- Liquid steel is supplied to the continuous caster from the secondary steelmaking shop. The ladle is usually delivered by crane and positioned into a ladle turret, which subsequently rotates the ladle into the casting position. A slide gate in the bottom of the ladle is opened to allow the liquid steel to flow via a protective shroud into a tundish, a vessel that acts as a reservoir between the ladle and the mould.

- As the tundish fills, stopper rods are raised in order to allow the casting of steel into a set of water-cooled copper moulds below the tundish.

- Solidification begins at the mould walls and the steel is withdrawn from the mould by a dummy bar.

- Throughout the entire casting process, the mould oscillates vertically in order to separate the solidified steel from the copper mould.

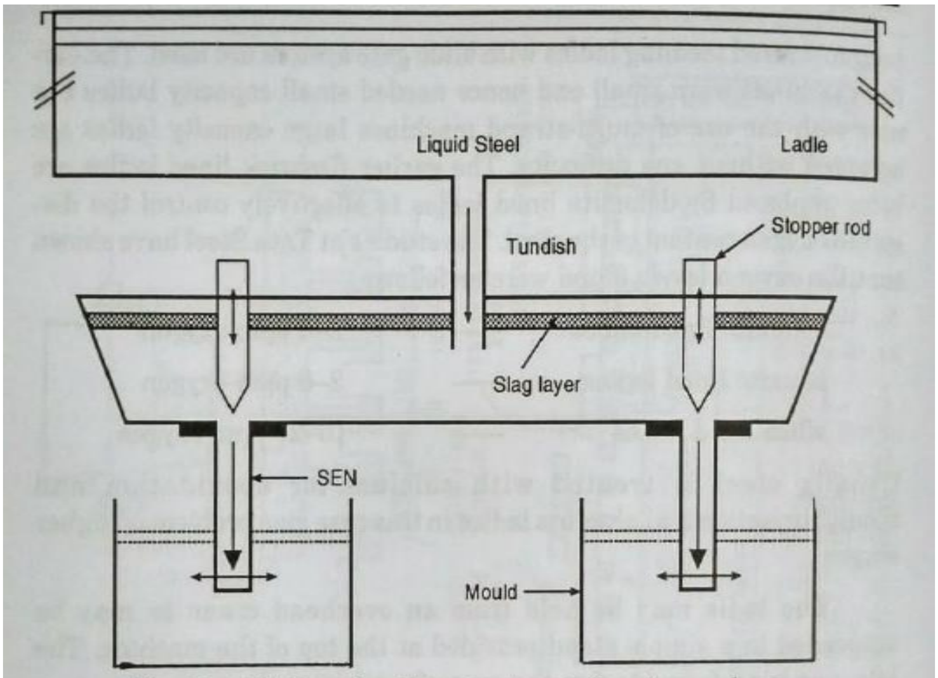
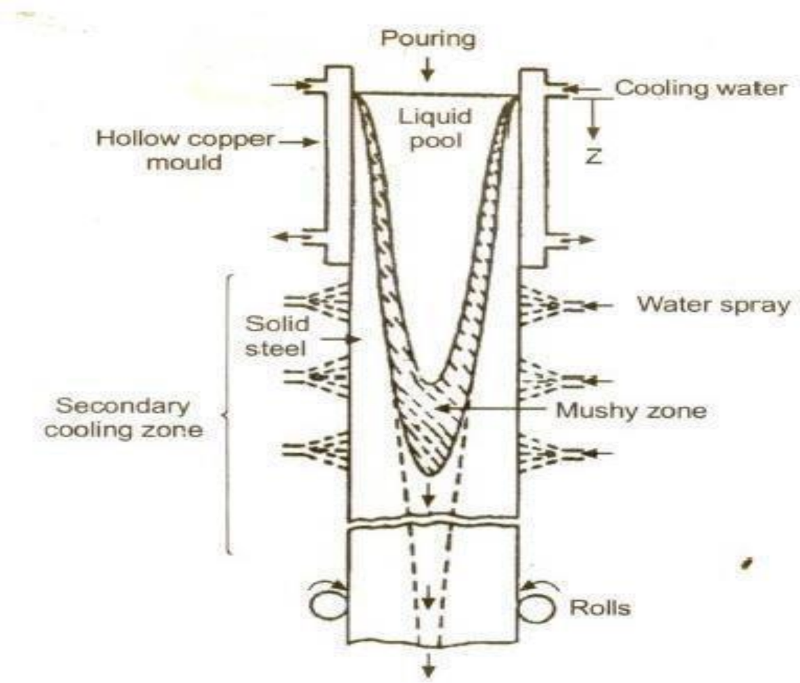


Fig. 28·5. Modern Tundish showing its location and use.

- The strand is withdrawn from the mould by a set of rolls which guide the steel through an arc until the strand is horizontal. The rolls have to be positioned close enough together to avoid bulging or breaking of the thin shell.

- As the steel leaves the mould, it has only a thin solidified shell which needs further cooling to complete the solidification process. This is achieved in the so-called secondary cooling zone, in which a system of water sprays situated between the rolls are used to deliver a fine water mist onto the steel surface. At this point, the steel, solidified shell and liquid centre, is called the strand.

- After the strand has been straightened and has fully solidified, it is torch-cut to pre- determined product lengths. These are either discharged to a storage area or to the hot rolling mill.



- Heat transfer in continuous casting takes place in mould and in secondary cooling by a combination of conduction, convection and radiation. Figure shows heat transfer in the mould and secondary cooling.

Lecture-30

The advantages of continuous casting (over ingot casting) are:

- It is directly possible to cast blooms, slabs and billets, thus eliminating blooming, slabbing mills completely, and billet mills to a large extent.
- Better quality of the cast product.
- Higher crude-to-finished steel yield (about 10 to 20% more than ingot casting).
- Higher extent of automation and process control.

Types Of Continuous Casting Machine

1. The Vertical Type
2. The Vertical-mould and horizontal-discharge type and
3. The Curved mould (S-type)

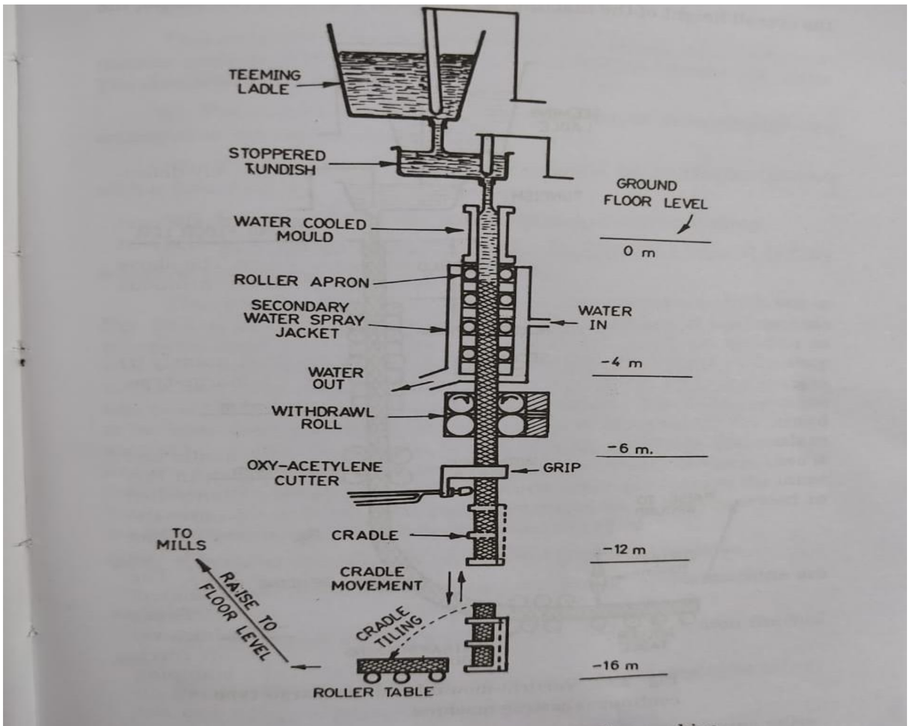
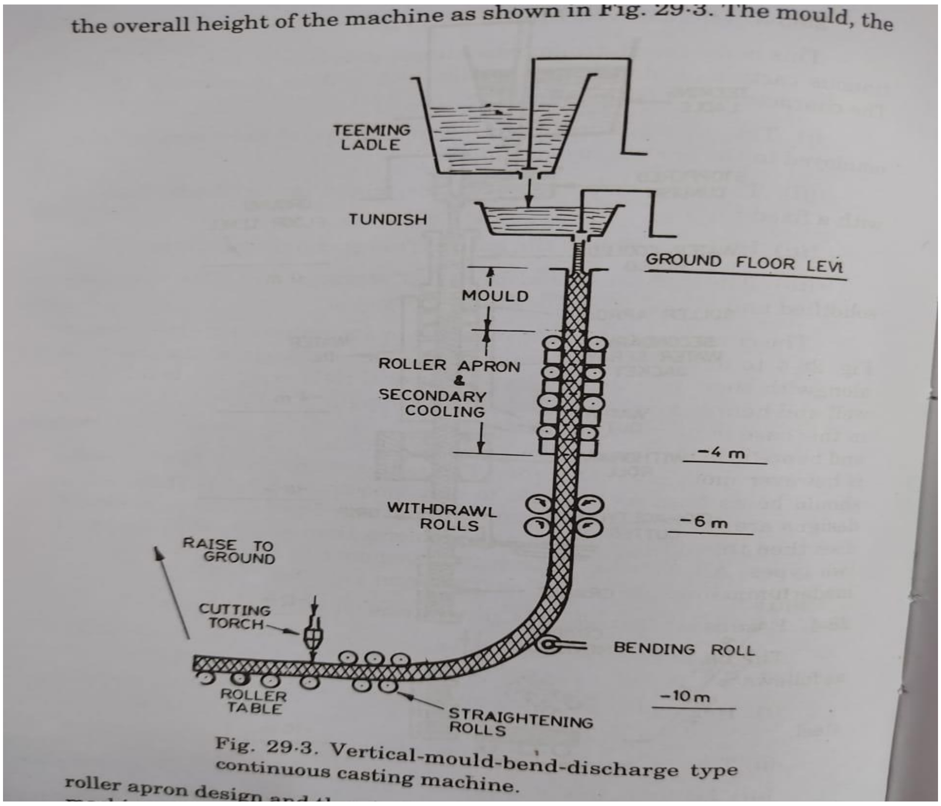
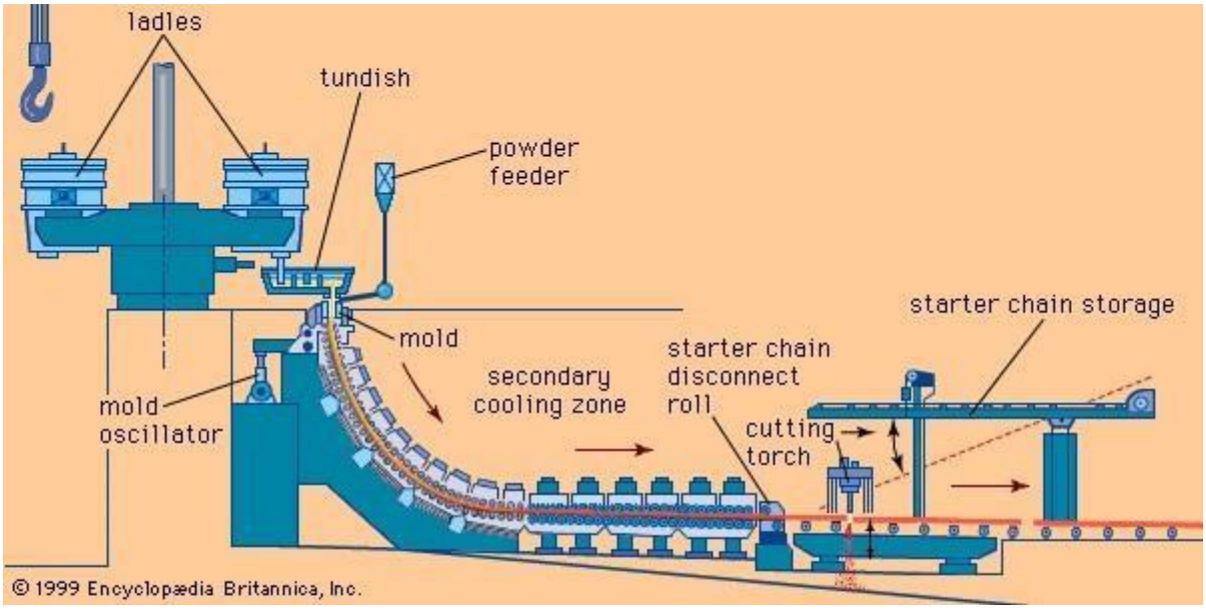


Fig. 28·2. Vertical type continuous casting machine.



(Vertical mould bend discharge type continuous casting machine)



Lecture -31

Products of Continuous Casting

Continuous casting is a process in which molten steel is continuously solidified into semi-finished products of different shapes and sizes. These products are further processed by rolling, forging, or machining to manufacture finished steel products.

1. Slabs

Slabs are wide and rectangular steel sections produced by continuous casting. They generally have a thickness of **150–300 mm** and a width of **600–2500 mm**.

Applications:

- Steel plates
- Steel sheets
- Coils
- Shipbuilding
- Automobile body panels
- Pressure vessels

Simple Diagram

```
 ______________________________________
|                                      |
|                                      |
|                                      |
|______________________________________|
              Slab
```

2. Blooms

Blooms are square or rectangular sections with a cross-sectional area generally **greater than 230 × 230 mm**.

Applications:

- Structural sections
- Railway rails
- I-beams
- H-beams
- Heavy engineering components

Simple Diagram

```
 ______________
|              |
|              |
|              |
|______________|
     Bloom
```

3. Billets

Billets are smaller square or round sections with a cross-sectional area generally **less than 230 × 230 mm**.

Applications:

- Bars
- Rods
- Wire rods
- Reinforcement bars (TMT bars)
- Fasteners

Simple Diagram

```
 ____________
|            |
|            |
|____________|
   Billet
```

4. Round Billets (Rounds)

Round billets are circular sections produced directly by continuous casting.

Applications:

- Seamless pipes
- Tubes
- Shafts
- Bearings
- Forged components

Simple Diagram

```
   _________
 /           \
|             |
 \___________/
Round Billet
```

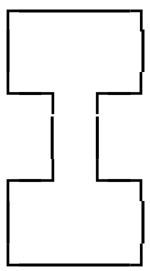
5. Beam Blanks

Beam blanks are specially shaped cast products used for manufacturing structural beams.

Applications:

- H-beams
- I-beams
- Structural columns
- Bridge construction

Simple Diagram



Beam Blank

6. Near-Net Shape Cast Products

These products are cast close to their final dimensions, reducing the need for rolling or machining.

Examples:

- Thin slabs
- Strip cast products
- Beam blanks

Applications:

- Automobile industry
- Appliance manufacturing

- Engineering products

Lecture-32

Green Steel Technology

Green steel technology is the production of steel with very low carbon dioxide (CO_2) emissions by using clean energy, sustainable raw materials, and advanced manufacturing processes. It aims to reduce the environmental impact of the steel industry while maintaining steel quality and productivity.

Brief Idea on Green Steel

Traditional steelmaking mainly uses blast furnaces and coke, which produce large amounts of CO_2. Green steel replaces fossil fuels with cleaner alternatives such as hydrogen, renewable electricity, and recycled steel scrap. It also uses energy-efficient technologies and carbon reduction methods to make steel production more sustainable.

Lecture-33

Advantages of Green Steel

1. Reduces carbon dioxide (CO_2) emissions.
2. Helps control global warming and climate change.
3. Improves air quality by reducing pollution.
4. Conserves natural resources through increased recycling of steel scrap.
5. Reduces dependence on fossil fuels like coal and coke.
6. Improves energy efficiency and lowers long-term operating costs.
7. Helps industries meet environmental regulations and sustainability goals.

8. Enhances the company's environmental reputation and competitiveness.

Suitable Practices in the Steel Industry

1. Use hydrogen instead of coke as the reducing agent in ironmaking.

2. Increase the use of steel scrap in Electric Arc Furnaces (EAF).

3. Use renewable energy sources such as solar and wind power.

4. Improve energy efficiency with modern equipment and waste heat recovery systems.

5. Install Carbon Capture, Utilization and Storage (CCUS) systems to reduce CO_2 emissions.

6. Use high-quality raw materials to reduce energy consumption.

7. Optimize production processes using automation and digital monitoring.

8. Increase recycling and reuse of steel and industrial by-products.

9. Adopt cleaner transportation and logistics for raw materials and finished products.

10. Follow environmental management systems and continuous emission monitoring.

Lecture -34

Basic Idea about Emissions and Effluent Treatment Emissions

1. Emissions are gases, dust, smoke, and particulate matter released into the atmosphere from industrial processes.
2. Major pollutants include carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOCs).
3. Emissions cause air pollution, global warming, acid rain, and health hazards.
4. Industries control emissions using electrostatic precipitators (ESP), bag filters, scrubbers, cyclones, and low-NOx burners.
5. Continuous Emission Monitoring Systems (CEMS) are used to monitor emission levels and ensure compliance with environmental standards.

Effluent Treatment

1. Effluent treatment is the process of treating industrial wastewater before discharge or reuse.
2. Wastewater from steel plants contains suspended solids, oil and grease, heavy metals, acids, alkalis, and other harmful chemicals.
3. Effluent Treatment Plants (ETPs) remove contaminants through screening, sedimentation, oil separation, neutralization, coagulation, filtration, biological treatment, and disinfection.
4. Treated water is safely discharged or recycled for industrial purposes.
5. Proper effluent treatment protects water resources, reduces pollution, and meets environmental regulations.

Importance

1. Reduces air and water pollution.
2. Protects human health and the environment.
3. Conserves natural resources through water recycling.
4. Ensures compliance with environmental laws and standards.
5. Supports sustainable and eco-friendly industrial development.

Lecture -35

Waste Heat Recovery

1. Waste heat recovery is the process of capturing and reusing heat generated during industrial processes that would otherwise be lost to the environment.

2. In steel plants, waste heat is produced from blast furnaces, coke ovens, basic oxygen furnaces, reheating furnaces, and hot exhaust gases.
3. Recovered heat is used to produce steam, generate electricity, preheat combustion air, or heat process water.
4. Common waste heat recovery systems include waste heat boilers, recuperators, regenerators, heat exchangers, and steam turbines.
5. Waste heat recovery reduces fuel consumption and operating costs.
6. It improves the overall energy efficiency of the steel plant.
7. It decreases greenhouse gas emissions and environmental pollution.
8. It conserves natural resources by reducing the demand for additional fuel.
9. It increases plant productivity and supports sustainable steel production.
10. Waste heat recovery is an important energy conservation measure in modern steel industries.

By-Product Utilization

1. By-product utilization is the process of converting industrial waste materials into useful products instead of disposing of them.
2. It reduces waste generation and promotes efficient use of resources.
3. Blast furnace slag is used in cement manufacturing, road construction, and concrete production.
4. Steelmaking slag is used for road base material, railway ballast, and soil improvement.
5. Coke oven gas is used as a fuel for heating furnaces and generating electricity.
6. Blast furnace gas and basic oxygen furnace gas are recovered and used as fuel within the steel plant.
7. Mill scale is recycled in the sinter plant or used in ironmaking.
8. Dust and sludge containing iron are recycled to recover valuable metals.
9. By-product utilization reduces disposal costs and environmental pollution.
10. Effective utilization of by-products supports circular economy practices and sustainable development in the steel industry.

Lecture-36

Ingot Defect	Causes	Remedies
Blow Holes	Dissolved gases such as hydrogen, oxygen, and nitrogen in molten steel; inadequate deoxidation	Proper deoxidation using aluminium or silicon; vacuum degassing; control gas absorption
Pipe (Shrinkage Cavity)	Volume contraction during solidification; insufficient feeding of molten metal	Use hot tops or feeders; proper ingot design; controlled solidification
Segregation	Uneven distribution of alloying elements and impurities during solidification	Controlled cooling; electromagnetic stirring; homogenization heat treatment
Non-metallic Inclusions	Presence of slag, oxides, sulfides, and refractory particles	Clean steelmaking practices; proper slag control; filtration; secondary refining
Cracks (Hot and Cold Cracks)	Thermal stresses, rapid cooling, improper handling, and poor mould design	Uniform cooling; proper mould design; controlled casting conditions
Surface Scabs	Entrapped slag or oxide films sticking to the ingot surface	Clean molten steel; proper slag removal; smooth pouring practice
Cold Shut	Low pouring temperature or interrupted metal flow	Maintain proper pouring temperature and continuous pouring
Misrun	Insufficient fluidity of molten steel due to low temperature or slow pouring	Increase pouring temperature; improve gating system and pouring rate
Shrinkage Porosity	Inadequate feeding during solidification	Use risers, feeders, and directional solidification techniques

Ingot Defect	Causes	Remedies
Surface Cracks	Uneven cooling, thermal stress, or poor mould lubrication	Control cooling rate; ensure proper mould lubrication; maintain correct pouring temperature

Advantages of Green Steel Practices in Reducing Ingot Defects

1. Cleaner steel with fewer non-metallic inclusions.
2. Reduced gas content through secondary refining and vacuum degassing.
3. Better temperature control during casting.
4. Lower defect rate due to process automation.
5. Improved steel quality and higher product yield.
6. Reduced material waste and energy consumption.
7. Environment-friendly production with lower carbon emissions.