LECTURE NOTES

On

Fuel, furnace and refractories

ORISSA SCHOOL OF MINING ENGINEERING
Government of Odisha
ଓଡ଼ିଶା ଖଣି ଯାନ୍ତ୍ରିକ ବିଦ୍ୟାଳୟ, କେନ୍ଦୁଝର

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Metallurgical Engineering Department

Orissa school Of Mining Engineering ,Keonjhar

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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 responsibilities

COURSE CONTENT

UNIT-1	Introduction to Fuels (5 Hours) Definition and classification of fuels (solid, liquid, and gaseous fuels) , Sources of fuel and their uses in industries, Calorific value: gross and net calorific value ,Proximate and ultimate analysis of fuels ,Physical and chemical properties of fuels (moisture content, ash, sulfur, carbon content)
UNIT-1I	Types of Fuels (Solid Fuels Liquid Fuels Gaseous Fuels) (15 Hours) Origin of Coal, Coal: types, composition, and classification , coking properties and swelling index of coal, Carbonization of coal , Differentiate between H.T.C and L.T.C , Test carried out for coke(Shatter and Micum index) ,Origin and constitution of petroleum .Discuss on flash point, fire point, cloud point, pour point, aniline point, octane number and cetane number . Production and utilization of Methane, water gas, producer gas, carbureted water gas, coke oven gas, blast furnace gas, natural gas, mixed gas.

UNIT-III	Furnaces and Their Types (5 Hours) Overview of Furnace, Types of Metallurgical furnaces (a) heat treatment furnace (b) melting furnace (c) smelting furnace (d) refining furnaces . Heat losses in furnace .Types of waste heat recovery system such as regenerators and recuperators.
UNIT-IV	Refractories – Basics and Classification (10 Hours) Introduction to Refractory materials, Classification of Refractories, properties of Refractories. Special refractories like high alumina, mullite, SIC, Zirconia . Criteria for selection and types of refractories selected for blast furnace, L.D furnace, arc furnace, coke oven.
UNIT-V	Recent advancements in Fuels, Furnaces & Refractory (10 Hours) Carbon Capture & Utilization (CCU) in Fuel Technologies: CO_2 Sequestration in Industrial Applications, Clean Coal Technologies, Advanced Refractory Materials: Nano-Refractories, Graphite-Based & Carbon-Composite Refractories, Ultra-High-Temperature Ceramics (UHTCs), Alternative Fuels for Industrial Heating: Waste-Derived Fuels, Hydrogen, Syngas, Carbon- Neutral and Carbon-Negative Technologies, Eco-Friendly Furnace Technologies: Hybrid & Solar-Assisted Furnaces

Lecture-01

FUEL

A fuel is any material that can be made to react with other substances so that it release energy.

The heat energy release by reaction of fuel is converted to mechanical energy or any other energy

Definition

Material that is burned to produce heat or power

CLASSIFICATION OF TYPES OF FUEL

Generally 3 types of fuel –

Solid – wood , cow dung cake and agricultural waste Liquid –

kerosene ,diesel, petrol

Gaseous – biogas , CNG and LPG

Fuels are classified mainly in 4 general classes such as

a) Fossil fuel
b) By product fuel
c) Chemical fuel
d) Nuclear fuel

(a) FOSSIL FUEL *:-*

Fossil fuel are those which have been divided from fossil remains of plant and animal and are found in the crest of the earth.

e.g.- Coal, Petroleum, Natural gas etc.

(b) BY PRODUCT FUEL :-

By product fuels are the co-product some regular manufacturing process. These are secondary nature of fuels.

$$Fe2O3 + CO \longrightarrow Fe + CO2$$

Ex- Coke oven gas and Blast furnace gas.

(c) CHEMICAL FUEL :-

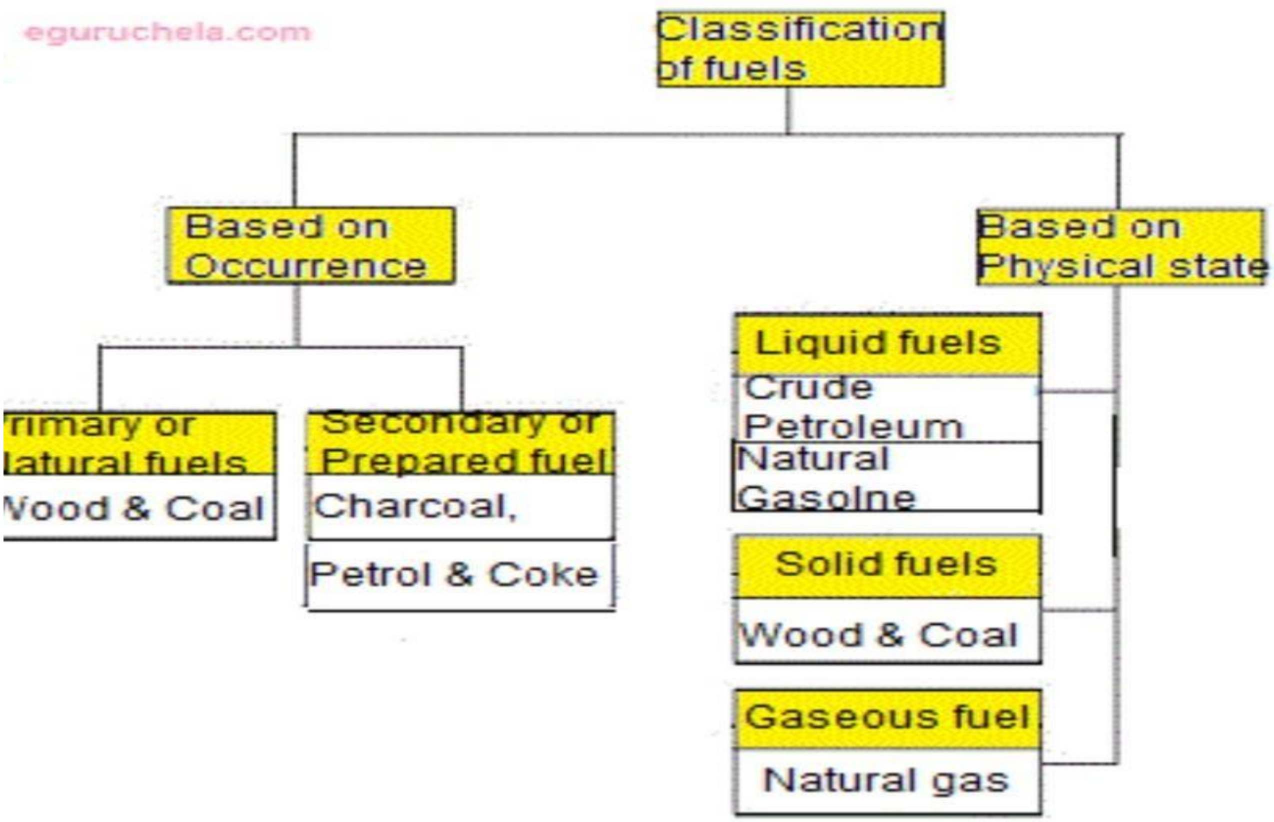
Chemical fuel are an exotic nature normally not used in conventional process.

Ex- Hydrozine (A rocket fuel)
Ammonium Nitrate, Flourine
etc.

- A fuel is a substance which gives heat energy on combustion
- A fuel contain carbon and hydrogen as main combustion

Lecture -02

TYPES OF FUEL



Lecture-03

Sources of Fuel and Their Uses in Industries

1. Coal

- Used in steel plants for coke making and blast furnaces
- Used in thermal power plants for electricity generation
- Used in cement industries and brick kilns
- Used in boilers for steam production

2. Petroleum (Crude Oil)

- Used as fuel in furnaces and boilers

• Raw material for petrochemical industries
• Used for manufacturing lubricants, plastics and chemicals
• Used in transportation and heavy machinery

3. Natural Gas
• Used in steel reheating furnaces
• Used in fertilizer industries
• Used in glass and ceramic industries
• Used for power generation and industrial heating

4. Coke
• Used as a reducing agent in blast furnaces
• Used as fuel in iron and steel industries
• Used in foundries for melting metals

5. Biomass
• Used in paper and sugar industries
• Used for steam generation in boilers
• Used for renewable energy production

Calorific value

It is defined as the quantity of heat liberated by the combustion of unit quantity of fuel

Lecture-04

1. LPG (Liquefied Petroleum Gas)
• Used for heating and metal cutting
• Used in food processing industries
• Used in laboratories and small-scale industries

2. Diesel
• Used in generators for backup power
• Used in construction and mining equipment
• Used in heavy vehicles and industrial machinery

3. Furnace Oil
• Used in industrial furnaces
• Used in boilers for steam generation
• Used in textile, chemical and cement industries

4. Electricity

• Used in electric arc furnaces
• Used in induction furnaces
• Used for operating industrial machines and equipment

5. Hydrogen

• Used in green steel production
• Used in petroleum refining
• Used in fuel cells for clean energy

Gross Calorific Value (GCV):

- Gross Calorific Value is the total amount of heat released when one unit mass or volume of fuel is completely burned and the water formed during combustion is condensed.
- It includes the latent heat of condensation of water vapour.
- Also called **Higher Calorific Value (HCV)**.

Net Calorific Value (NCV):

- Net Calorific Value is the amount of heat released when one unit mass or volume of fuel is completely burned, excluding the latent heat of water vapour because the water remains in the vapour state.
- It does not include the latent heat of condensation.
- Also called **Lower Calorific Value (LCV)**.

Lecture-05

Proximate analysis of coal

Proximate analysis means to obtain the weight percentage of moisture , volatile matter , fixed carbon and Ash in coal

- **Moisture:** Water lost by heating coal at 105–110°C for 1 hour; high moisture lowers burning efficiency.

- **Volatile Matter:** Gases (like methane and hydrogen) driven off when heated at 925°C for 7 minutes; high amounts mean easy ignition.
- **Ash Content:** Non-combustible mineral residue left after burning at 700–750°C; high ash reduces overall purity and heat value.
- **Fixed Carbon:** The solid combustible carbon left behind, calculated by subtracting moisture, volatile matter, and ash percentages from 100%

Ultimate analysis of coal

Ultimate analysis means finding out the weight percentage of carbon , hydrogen, nitrogen, oxygen and Sulphur of the pure coal free from moisture .

- **Carbon (C):** The main heat-producing element; higher carbon means higher quality and better heating value.
- **Hydrogen (H):** Burns to form water; aids in volatile matter formation and affects overall flame properties.
- **Nitrogen (N):** Present in small amounts; burns to form nitrogen oxides which contribute to air pollution.
- **Sulfur (S):** An undesirable impurity; causes corrosion and forms sulfur dioxide when burned.
- **Oxygen (O):** Reduces the net calorific value of coal; calculated by finding the remaining percentage after other elements are measured.

Lecture-06

Physical and Chemical Properties of Fuel

1. Moisture Content (Physical Property)

- Moisture is the amount of water present in the fuel.
- High moisture reduces the calorific value.
- It increases fuel consumption.
- More heat is required to evaporate the water during combustion.
- It lowers combustion efficiency.

2. Ash Content (Physical Property)

- Ash is the non-combustible residue left after complete burning of fuel.
- High ash content reduces heating value.
- It causes clinker formation and slagging in furnaces.
- It increases handling and disposal costs.
- It decreases combustion efficiency.

3. Sulfur Content (Chemical Property)

- Sulfur is an impurity present in many solid and liquid fuels.
- During combustion, it forms sulfur dioxide (SO_2) and sulfur trioxide (SO_3).
- These gases cause air pollution and acid rain.
- Sulfur leads to corrosion of boilers and equipment.
- Low sulfur content is preferred for cleaner combustion.

4. Carbon Content (Chemical Property)

- Carbon is the main combustible element in fuel.
- Higher carbon content gives higher calorific value.
- It increases heat generation during combustion.
- Complete combustion produces carbon dioxide (CO_2).
- Incomplete combustion produces carbon monoxide (CO), reducing efficiency and causing pollution.

Lecture-07

Origin theory of coal

Coal is a complex mixture of plants substance altered in varying degrees by physical and chemical process

IN SITU THEORY

Coal seam occupies the same situ where the original plant grew where their remain accumulated several million years ago to produce coal under the action of heat , pressure and bacteria

DRIFT THEORY

According to this theory the plants , trees etc were uprooted and drifted by rivers to lakes and estuaries to get deposited there to form coal during the course of time after they got buried .

If sea water is the carrying agent or if the deposit it covered by marine inorganic sediments the coal formed are rich in hydrogen and pressure properties.

Lecture-08

Types of Fuel

- **Solid Fuels:** Wood, coal, coke, charcoal, peat, lignite.
- **Liquid Fuels:** Petrol, diesel, kerosene, furnace oil, crude oil.
- **Gaseous Fuels:** Natural gas, LPG, CNG, producer gas, water gas, biogas, blast furnace gas.

Composition of Fuel

- Carbon (C) – Main heat-producing element.
- Hydrogen (H) – Increases calorific value.
- Oxygen (O) – Reduces heating value as it is already combined with hydrogen.
- Sulfur (S) – Causes corrosion and air pollution.
- Nitrogen (N) – Does not contribute to combustion and lowers flame temperature.
- Moisture – Reduces calorific value and combustion efficiency.
- Ash – Non-combustible residue that reduces fuel efficiency.

Lecture-09

Caking of coal

When powdered coal is carbonized it forms an expanded lumpy mass . Such coals are called caking coal and the phenomenon known as caking of coal.

Coking of coal

- When the residue is very hard and strong it is called coke and the process is called coking of coal .
- The coal is called coking coke .
- When coal is don't form strong , hard and coherent residue coke .
- When coal is carbonized , the caking coal will first expand and then contract Slightly leaving a larger , weak and porous residue.
- All the coking coal are called coking coals .

Non- coking coals

Those coals which do not fuse , form lumpy mas and a compact residue are non – coking coals.

Swelling Index of Coal

- Swelling index is a measure of the tendency of coal to expand or swell when heated in the absence of air.
- It indicates the caking and coking properties of coal.
- It is also known as the **Free Swelling Index (FSI)** or **Crucible Swelling Number (CSN)**.
- It is determined by heating a small coal sample in a standard crucible under specified conditions and comparing the coke button formed with standard profiles.
- The swelling index generally ranges from **0 to 9**.
- **Low swelling index (0–2):** Non-coking coal with poor caking property.
- **Medium swelling index (3–5):** Weakly coking coal.
- **High swelling index (6–9):** Strongly coking coal suitable for metallurgical coke production.
- It is an important property in selecting coal for coke ovens and blast furnace operations.

Lecture-10

Carbonization of coal

Heating of coal is absence of air at high temperatures to produce a residence coke , tar and gas is called it's carbonization .

Coalification

The process of conversion of Lignite to anthracite is called coalification or metamorphism of coal .

Low Temperature Carbonization (LTC)	High Temperature Carbonization (HTC)
• Carbonization is carried out at **500–700°C**.	• Carbonization is carried out at **900–1200°C**.
• Produces **soft coke (semi-coke)**.	• Produces **hard metallurgical coke**.
• Coke has **higher volatile matter**	• Coke has **very low volatile matter**.
• Coke is **less strong and porous.**	• Coke is **strong, hard and porous**.
• Gas produced has **higher calorific value**.	• Gas produced has **lower calorific value**.
• Tar yield is **high.**	• Tar yield is **low**.
• Semi-coke is mainly used as **domestic and industrial fuel**.	• Coke is mainly used in **blast furnaces and metallurgical industries**.
• Carbonization process is **slower**.	• Carbonization process is **faster**.

Lecture-11

Coal – Types

- Peat
- Lignite (Brown Coal)
- Bituminous Coal
- Anthracite Coal

Composition of Coal

- Carbon (C)
- Hydrogen (H)
- Oxygen (O)
- Nitrogen (N)
- Sulfur (S)
- Moisture
- Ash
- Volatile Matter

Classification of Coal

- **Based on Rank (Degree of Coalification):** Peat, Lignite, Bituminous, Anthracite.
- **Based on Coking Property:** Coking Coal, Semi-coking Coal, Non-coking Coal.
- **Based on Carbon Content:** Low Carbon Coal, Medium Carbon Coal, High Carbon Coal.
- **Based on Geological Age:** Young Coal (Peat, Lignite) and Mature Coal (Bituminous, Anthracite).

Lecture-12

DIFFERENT TEST CARRIED OUT FOR COKE

Shatter index of coke

It measures the resistance of coke to breakage by impact that is of its strength 50 lb of 2 inches size coke is placed in a rectangular box of dimensions 28 x 18 x 15 placed 6 ft above a steel base plate ½ inches thick . The hinged base of the box is released suddenly when the content drop on to the base plates

Box is dropped several times and coke is then screened through a series of sieves of sieves made of square stamped sheet. The percentage of coke retained on 2" ,1.5" and 0.5 " sieves are recorded and called shatter index desirable values of shatter index for blast furnace coke are 80% on 2 screen, 90% on 1.5" screen and 97% on 0.5 screen

Micum index of coke

This is a measure of both hardness and strength of the coke . 50kgof coke of 50mm size is rotated in the micum drum for 4 minutes at the rate of 25 rotation per minute (rpm) . Micum drum is a cylindrical steel drum fitted lengthwise with four angles item 90° apart inside the drum after rotating the coke it is taken out and screened through 60 mm 40mm 20mm 10mm round hole screen.

The percentage of coke retained on a 40 mm screen is called M 10 index (micum 10 index).

M40 gives the hesitance of the coke to breakage by impact that is a measure of the strength of the coke.

M10 gives the resistance of the coke to breakage by abrasion (that is subbing) and it is a measure of hardness of the coke.

High M40 and low M10 values are desirable for metallurgy coke .

Origin theory of petroleum

Petroleum is a naturally occurring brown to black oil mainly found under the crust of the earth.

Carbide theory According to this theory hydrocarbon present in petroleum are formed by the action of water and inorganic carbides .

Inorganic carbides is turn ore formed by the reaction of metal and carbon Under high temperatures and pressure condition inside the earth

$Ca + 2C \xrightarrow{\text{HIGH TEMPERATURES}} CaC_2$ (Calcium carbide)

Engler theory

Petroleum is formed by the decay and decomposition of marine animals under high pressure and temperature.

Engler theory is supported by there facts

Presence of brine or sea water together with petroleum

Presence of nitrogen and Sulphur compound

Presence of fossil (the remain of animals and plants)

Modern theory

Petroleum is formed by decay and decomposition of marine animals as well as the of vegetables organism of the pre historical forest

It is animal as well as plant origin
Presence of brine and coal in the petroleum.

Lecture-13

PROPERTIES OF PETROLEUM PRODUCTS

Specific gravity

- It determines the maximum power per unit of weight/volume.
- Hydrocarbon of low specific gravity possess the maximum thermal Power per unit volume. Hydrocarbon of high specific gravity possess the maximum thermal energy per unit weight.
- The lighter the crude oil , the larger is the content of the lighter constituent like gasoline and kerosene
- Higher specific gravity means higher carbons to hydrogen ratio . Heavier oils have lower gross calorific value on weight basis but higher gross calorific value on volume basis
- Aromatics have higher specific gravity than paraffin
- Increase in specific gravity means decrees in paraffin content

Molecular weight

- Molecular weight of a substance is the summation of mass of all the atoms in the molecule
- If molecular weight is high than the fuel may not help in smooth combustion
- Molecular weight can be defined as the measure of the sum of the atomic weight values of the atoms in a molecule

Vapour pressure :

Presence of vapor petroleum product is important

- With decrease atmospheric pressure at high altitude the vapor comes out of the liquid fuel causing vapor locking and difficulty in stockings ignition engines
- If the vapor pressure of fuel us too low , stating of engine and lubricating oil dilution becomes difficult
- If the vapor pressure is high , vapor occurs in fuel tanks and pipelines causing pumping difficulty
- If the vapor pressure is high that means flash point is low resulting in danger of fire and explosion beside , breathing loss is high .
- lubricants having high vapor pressure will be lost quickly if it is applied on they are film boundary lubrication .
- vapor pressure is measured by ried bomb calorimeter

High viscosity fuel oil can't be properly atomized resulting in loss of fuel by complete combustion

- Highly viscous oil has to be preheated to reduce the viscosity to minimize the pressure drop in pumping to different refineries from oil tank
- High viscosity lubricating oil reduce its fluidity
- It affects the flow through pipelines, nozzles and orifice
- Viscosity can be measured in red wood storage and handling

Flash point

It is the minimum temperature at which oil gives out sufficient vapor to form an inflatable mixture with air and catches fire momentarily that is flashes when flame is applied

Flash point gives idea about

Nature of boiling point diagram of the system

Explosion hazard during Storage and handling

Volatility of the liquid fuel

Flash point can be determined by pensky – martens apparatus

Fire point

It is the lowest temperature at which vapor giesoff by oil ignites and continue to burn for at least 5 second

In most cases , fire point is 5- 40°c higher than flash point and is determined in the same apparatus as in flash point determination i.e pensky master apparatus

It gives idea of fire hazards during the storage and use of oil

This haziness is due to the separation of crystal of wax or increase of viscosity .

Cloud point

When and oil is cooled at a specified rate , the temperature at which it becomes cloudy / hazy is called the cloud point of oil.

The temperature is below which the wax crystal will appear that is cloud point

Petroleum products that are transparent in a 40 mm thick layer and cloud point below 49°c.

Pour point

- The temperature at which the oil just causes to flow is called the pour point
- It determines the temp below which an oil can not be used as a lubricants as well as the waxy nature of oil
- Naphtha and aromatic have lower power than paraffin
- Cloud point and PowerPoint indicate the suitability of lubricants in cold conditions

- Lubricants used in a machine working at low temp. Should posses low power point
- Presence of waxes in the lubricating oil raise the power point
- The difference of PowerPoint and cloud point is 4-6°f usually.

Freezing point

It is the temperature at which fuel oil freezer completely and can not flow at all

This is important in case of aviation gasoline at high altitude where low temp is observed the fuel supply from fuel tank to engine may be imposed due to choking of pipelines if the freezing point is not sufficiently less

Paraffin possess higher freezing point than napthene

and aromatics

Aviation gasoline should have freezing point below 60°c to avoid trouble due to crystal formation is feeling.

Lecture-14

Production of methane (CH_4)

- Methane is associated with coal in mines as it absorbs the methane formed during coalification process
- At the time of coal mining the gas is gradually and it must be removed
- The composition of methane gas from coal mines is variable but it in essentially a high concentration methane gas

CH_4 – 93-99 %

C_2H_6-0-3 %

CO_3-0-4%

N_2- 2-6%

WATER GAS

It is a medium calorific value gas comprising mainly C0 and H_2

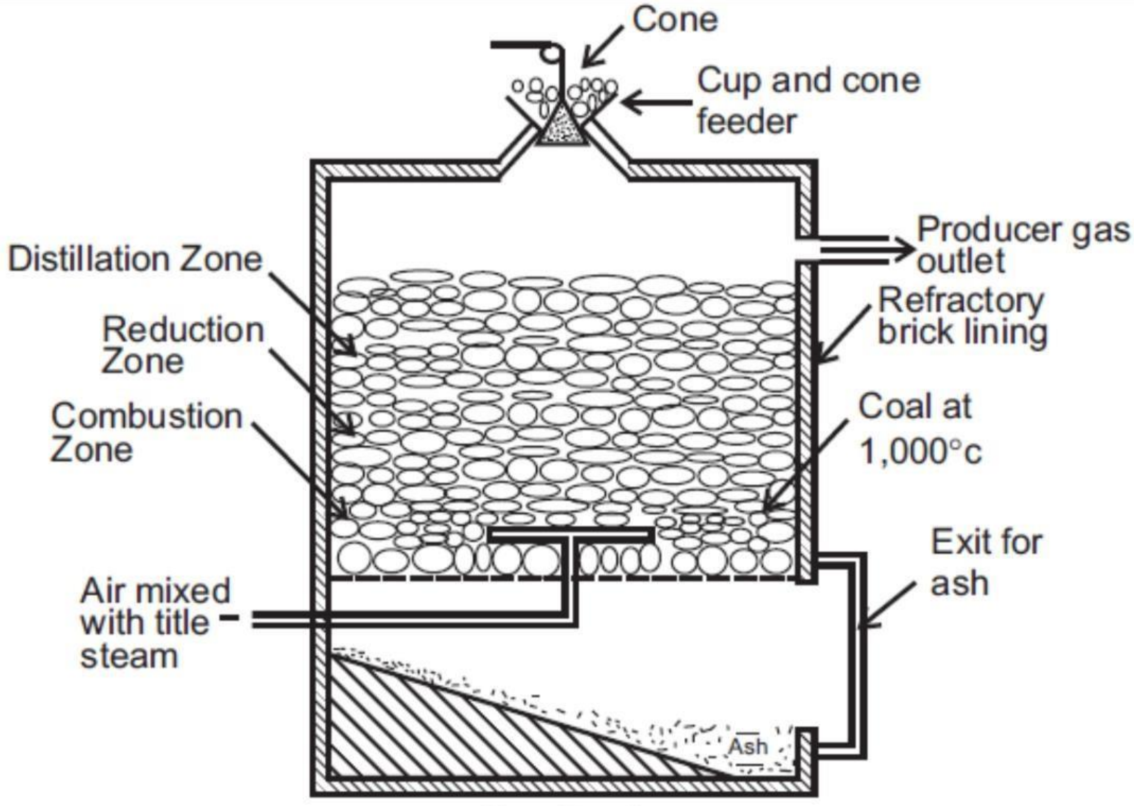
It is prepared by action of superheated steam on a bed of hot coal at about 1000 c
.
$C+2\ H_2O. \dashrightarrow CO_2+2\ \underline{H_2}$

- A water gas generator is a cylindrical vessel made of steel
- It is about 4-5 m in height and 2-3 in diameter at the top it is provided with a feeder.
- Water gas outlet is provided near the top
- Two separate inlet to blow steam and air
- At the bottom it is provided an arrangement for taking out ash Formed
- During the steam blow , water gas is produced
- On the other hand , nitrogen, carbon dioxide, carbon monoxide are formed during the air blow
- Composition of water gas is H=48-51%. CO=40-42% CH_4=0.1-0.5%. CO_2=3-5% N_2=3-6%
- Calorific value = 2500-2800 kcal/Nm^3

Water gas is also called blue water gas / blue gas as it burns with a bluish flame due to the presence of high quantity of carbon monoxide

Uses of water gas

- It is used as a fuel in furnace
- Normally it is enriched by adding hydrocarbon gas and the mixture is called carbureted water gas which has high calorific value
- It is also used as a source of hydrogen for ammonic synthesis in fertilizer plant
- If a mixture of H_2, CO, CO_2 , N_2 is added with air and steam , the gas produced is called semi water gas



Gas Producer

Coke oven gas:-

It is produced during high temperature carbonization of cooking coal.

Yield of coke oven gas is 290-300 Nm^3

Co=7-8%, H2= 58-60%, CH4= 23-25%, Co2= 2-4%, O2= 0.5-0.8%, N2= 2-3%.

Uses of coke oven gas:-

It has more extended use than BF gas because of:-

- Relativity low distribution cost due to its specific gravity, high CV and cleanliness
- It's ability to develop extremely high temperature by combustion.
- High heat released rate thereby eliminating excessively large combustion chamber furnace.
- Coke oven gas is use mostly in mixture with BF gas in the iron and steel works.
- Coke oven heating
- Blast furnace stove heating
- Boiler of captive thermal plant.
- Forge furnaces and foundry oven.

Characteristics of Coke oven gas:-

- It burns with a luminous to semi luminous flame depending upon the degree of mixing of gas and air
- It's rate of flame propagation is higher than that of natural gas, producer gas and BF gas
- It has low specific gravity
- It has high theoretical flame temperature
- It's explosive range is twice of natural gas.

Lecture-15

Producer gas

- It comprises CO and N_2 and is produced by blowing air or a mixture of air and steam through hot bed of solid fuels (coal/ coke)
- Dry air is blown through a bed of coke of sufficient depth and at a sufficiently high temperatures
- Gas obtained consists of CO and N_2 in ratio of 1:2 with little CO_2 and H_2
- Addition of steam with carbon ($C+H_2O = CO+H_2$) with takes place with absorption of heat
- Composition of producer gas

CO_2 = 4-6% CO=20-30% H_2=11-20% CH_4=0-3% N_2=46-55%

Use of producer gas

Used for firing in glass melting and open hearth furnace

It is used in internal combustion engine

Carbureted water gas

- Calorific value of water gas is too low for being an effective gaseous fuels in town gas distribution
- It is enriched to make carbureted water gas by mixing with hydrocarbon oil vapor
- Calorific value is 10000-13000 kcal/Nm^3
- Carbureted water gas is a mixture of water gas and oil gas
- When hydrocarbon oil is sprayed in passed through water gas, the oil cracks and produces methane, ethane, propane, with high calorific value
- Composition of carbureted water gas
  CO =30.5%. CO_2 = 5-6%. CH_4 = 14%. O_2 = 0.4%. H_2 = 37.0%
- Calorific value 4300 Kcal/Nm^3

Carbureted water gas is used as an ingredient of town gas and as substitute of coal gas to meet peak loads of gas supply

Lecture-16

Heat Losses in Furnace

- **Heat loss through furnace walls, roof and floor:** Heat escapes to the surroundings by conduction, convection and radiation due to high furnace temperature.
- **Heat loss through hot flue gases:** A large amount of heat is carried away by exhaust gases leaving the chimney if they are discharged at high temperature.
- **Heat loss due to incomplete combustion:** Inadequate air supply or poor mixing of fuel and air results in incomplete combustion, producing CO instead of CO_2 and reducing heat generation.
- **Heat loss due to excess air:** Excess combustion air absorbs heat and leaves the furnace with flue gases, reducing thermal efficiency.
- **Heat loss due to moisture in fuel:** Moisture present in the fuel absorbs heat for evaporation, lowering the useful heat available.
- **Heat loss due to moisture in combustion air:** Humidity in the air also requires heat for evaporation and heating, causing energy loss.
- **Heat loss through furnace openings:** Heat escapes from charging doors, tapping holes, observation ports and other openings by radiation and convection.
- **Heat loss through air leakage:** Cold air entering through cracks and gaps cools the furnace and increases the volume of flue gases.
- **Heat carried away by hot ash and slag:** Ash and slag leaving the furnace at high temperatures contain a considerable amount of heat.
- **Heat loss due to unburnt fuel:** Some combustible material may remain unburnt in ash or slag, resulting in fuel wastage.
- **Heat absorbed by furnace refractories:** During heating, a portion of the heat is stored in refractory bricks and furnace structures instead of heating the charge.
- **Heat loss during start-up and shutdown:** Extra fuel is required to heat the furnace from cold conditions, and heat is lost during cooling after shutdown.
- **Heat carried away by the heated charge supports and fixtures:** Furnace trays, hearths, rollers and other fixtures absorb heat along with the charge.
- **Heat loss due to scale formation:** Oxidation of the metal surface consumes heat and forms scale, reducing process efficiency.
- **Heat loss due to poor insulation:** Damaged or inadequate insulation increases heat transfer to the surroundings and decreases furnace efficiency.

Lecture-17

Overview of Furnace

- A furnace is a device used to generate high temperatures for heating, melting, refining, smelting and heat treating metals.
- It converts the energy of fuel (solid, liquid or gaseous) or electricity into heat.
- Metallurgical furnaces are essential equipment in iron and steel plants, foundries and non-ferrous metal industries.
- They are designed to provide controlled heating, high thermal efficiency and uniform temperature distribution.
- The furnace chamber is lined with refractory materials to withstand high temperatures and reduce heat loss.
- A typical furnace consists of a furnace shell, refractory lining, burners or heating elements, charging door, chimney or exhaust system, temperature control system and charging/discharging arrangements.
- The main objectives of a furnace are:
  - To achieve the required temperature.
  - To transfer heat efficiently to the charge.
  - To minimize fuel consumption and heat losses.
  - To ensure safe and economical operation.
  - To produce good quality metal or heat-treated products.

Types of Metallurgical Furnaces

(A) Heat Treatment Furnaces

Heat treatment furnaces are used to heat metals to specific temperatures and cool them under controlled conditions to improve their mechanical properties such as hardness, strength, toughness and ductility.

1. Annealing Furnace

- Used for annealing steel and non-ferrous alloys.
- Heated to the required temperature and cooled slowly inside the furnace.
- Relieves internal stresses and improves ductility and machinability.

2. Normalizing Furnace

- Used to normalize steel.
- Steel is heated above the critical temperature and cooled in air.
- Produces a fine-grained structure with improved strength and toughness.
-

3. Hardening Furnace

- Used for hardening carbon and alloy steels.
- Steel is heated above the critical temperature and rapidly quenched in water, oil or polymer solution.
- Increases hardness and wear resistance.

4. Tempering Furnace

- Used after hardening.
- Steel is reheated below the critical temperature and cooled.
- Reduces brittleness while maintaining adequate hardness.

5. Carburizing Furnace

- Used for case hardening of low-carbon steel.
- Carbon is diffused into the surface at high temperature.
- Produces a hard wear-resistant surface with a tough core.

6. Nitriding Furnace

- Uses ammonia gas to diffuse nitrogen into the steel surface.
- Produces a hard surface without quenching.
- Improves wear resistance and fatigue strength.

7. Vacuum Heat Treatment Furnace

- Heat treatment is carried out under vacuum.
- Prevents oxidation and decarburization.
- Used for high-quality alloy steels and tool steels.

Applications of Heat Treatment Furnaces

- Automobile components
- Machine tools
- Gears and shafts
- Bearings
- Springs
- Aerospace components

(B) Melting Furnaces

Melting furnaces are used to melt metals before casting or further refining. They operate at temperatures above the melting point of the metal.

1. Cupola Furnace

- Vertical shaft furnace used mainly for melting cast iron.
- Uses coke as fuel.
- Continuous operation with high melting capacity.
- Widely used in foundries.

2. Crucible Furnace

- Metal is melted inside a refractory crucible.
- Heated by coke, oil, gas or electricity.
- Suitable for small-scale melting of aluminium, brass and bronze.

3. Induction Furnace

- Works on electromagnetic induction.
- No direct contact between fuel and metal.
- Produces clean metal with precise temperature control.
- Commonly used for steel and alloy melting.

4. Electric Arc Furnace (EAF)

- Heat is generated by an electric arc between graphite electrodes and the metal charge.
- Used for melting steel scrap and producing alloy steels.
- High efficiency and excellent temperature control.

5. Reverberatory Furnace

- Heat from the flame is reflected from the roof onto the charge.
- Fuel does not directly contact the metal.
- Used mainly for aluminium and copper alloys.

6. Rotary Furnace

- Cylindrical furnace that rotates during melting.
- Ensures uniform heating and mixing.
- Used for aluminium recycling and non-ferrous metals.

7. Blast Furnace

- Used for producing pig iron from iron ore.
- Operates continuously using coke, iron ore and limestone.
- It is a reduction furnace rather than a simple melting furnace.

Applications of Melting Furnaces

- Steel plants
- Foundries
- Aluminium industries
- Copper industries
- Brass and bronze manufacturing
- Metal recycling plants

Lecture-18

(C) Smelting Furnaces

Smelting furnaces are used to extract metals from their ores by heating them with a reducing agent such as coke or carbon monoxide. During smelting, the metal oxide is reduced to metal and impurities combine with flux to form slag.

1. Blast Furnace

- Used for smelting iron ore to produce pig iron.
- Raw materials are iron ore, coke and limestone.
- Coke acts as both fuel and reducing agent.
- Limestone combines with impurities to form slag.
- Operates continuously and has high productivity.

2. Submerged Arc Furnace (SAF)

- Uses electric arcs submerged beneath the charge.
- Heat is generated inside the raw materials.
- Used for producing ferroalloys such as ferromanganese, ferrosilicon and ferrochrome.
- Also used for calcium carbide production.

3. Electric Smelting Furnace

- Operates using electrical energy.
- Used for smelting non-ferrous metals such as copper, nickel and zinc.
- Produces high-purity metal with better process control.

4. Flash Smelting Furnace

- Finely ground sulphide concentrates are injected with oxygen-rich air.
- Heat generated by oxidation of sulphides sustains the process.

- Widely used for copper and nickel extraction.
- High efficiency with low fuel consumption.

Applications of Smelting Furnaces

- Iron and steel industries
- Ferroalloy production
- Copper smelters
- Nickel industries
- Lead and zinc extraction
- Non-ferrous metal industries

(D) Refining Furnaces

Refining furnaces are used to remove impurities from molten metal and improve its chemical composition and quality. They produce clean metal with the desired composition and mechanical properties.

1. Basic Oxygen Furnace (BOF/LD Converter)

- Converts molten pig iron into steel by blowing high-purity oxygen.
- Removes carbon, silicon, manganese and phosphorus.
- Produces large quantities of high-quality steel in a short time.

2. Electric Arc Furnace (EAF)

- Used for refining and melting steel scrap and direct reduced iron.
- Allows accurate control of temperature and composition.
- Produces carbon steel, alloy steel and stainless steel.

3. Argon Oxygen Decarburization (AOD) Furnace

- Mainly used for stainless steel refining.
- Oxygen and argon are blown into molten steel.
- Removes carbon while minimizing chromium oxidation.
- Produces high-quality stainless steel.

4. Vacuum Oxygen Decarburization (VOD) Furnace

- Refining is carried out under vacuum.
- Removes carbon, hydrogen, nitrogen and dissolved gases.
- Produces ultra-low carbon stainless steel and special alloy steels.
-

5. Ladle Refining Furnace (LRF/LF)

- Secondary steelmaking furnace used after primary steelmaking.
- Performs alloy addition, temperature adjustment, deoxidation and desulphurization.
- Improves steel cleanliness and composition before continuous casting.

Applications of Refining Furnaces

- Carbon steel production
- Stainless steel manufacturing
- Alloy steel production
- Tool steel manufacturing
- High-quality engineering steels
- Continuous casting plants

Lecture-19

Regenerator Furnace

- A regenerator furnace is a furnace that uses **regenerators** to recover heat from hot exhaust gases and transfer it to the incoming combustion air and fuel.
- It consists of two or more chambers filled with refractory checker bricks.
- Hot flue gases pass through one chamber and heat the checker bricks.
- After a fixed time, the direction of gas flow is reversed.
- Cold air and fuel pass through the heated checker bricks, absorbing the stored heat before entering the furnace.
- This process increases combustion temperature and improves fuel efficiency.
- Thermal efficiency is generally **70–85%**.
- It is suitable for **very high-temperature operations**.
- Applications include **open hearth furnaces, glass melting furnaces and coke oven batteries**.

Advantages

- High thermal efficiency.
- Large fuel savings.
- High flame temperature.
- Suitable for continuous high-temperature operation.
- Reduces fuel consumption.
-

Disadvantages

- High initial cost.
- Large size.
- Complex construction and operation.
- Requires periodic reversal of gas flow.

Recuperator Furnace

- A recuperator furnace uses a **recuperator (heat exchanger)** to recover heat continuously from hot flue gases.
- The hot exhaust gases and incoming combustion air flow on opposite sides of metal or ceramic tubes or plates.
- Heat is transferred through the walls of the heat exchanger without mixing the gases.
- The preheated air enters the furnace, improving combustion efficiency.
- Heat recovery is continuous and does not require flow reversal.
- Thermal efficiency is generally **50–70%**.
- It is suitable for **medium and high-temperature furnaces**.
- Applications include **reheating furnaces, annealing furnaces, soaking pit furnaces and industrial heating furnaces**.

Advantages

- Continuous heat recovery.
- Simple construction.
- Lower maintenance.
- Compact design.
- Lower installation cost than regenerative systems.

Disadvantages

- Lower efficiency than regenerators.
- Heat exchanger tubes may fail at very high temperatures.
- Heat recovery is limited by the heat exchanger material.

Difference Between Regenerator and Recuperator

Regenerator	Recuperator
Stores heat in refractory checker bricks.	Transfers heat through a heat exchanger.
Gas flow is reversed periodically.	Gas flow is continuous.
Higher thermal efficiency (70–85%).	Lower thermal efficiency (50–70%).
Suitable for very high temperatures.	Suitable for medium and high temperatures.
Large and complex construction.	Compact and simple construction.
Higher installation cost.	Lower installation cost.
Used in open hearth and glass furnaces.	Used in reheating, annealing and industrial furnaces.

Lecture-20

Refractories :

Refractories are material which with stand high temperature and do not fuse even at a very high temperature that us fireclay, silica, chromite, magnetic etc.

Types of refractory material : (Depending upon chemical nature)

Acid Refractory : (silica is chief constituents)

- Acidic refractory which readily combines with bases.

Ex – Fireclay, silica, Quartz, semi-silica

Base refractory :

- It consist of basic oxide without free silica.

Ex – Bauxite, magnesite, dolomite (lime is not used as refractory due to it's dehydrating) alumina, zirwria.

Neutral refractory :

- Which does not combine with acid or bases.

Ex – chromite, graphite, carbon refractory, carbide.

Properties of refractories :

1. Refractories Or fusion point -

It is the temperature at which the refractory fuses.

- It should be much higher than the operating temperature of the refractory.

- Fusion point decreases when refractory is under load and this is called refractories under load (RUL).

2. Strength -

It is the resistance of the refractory to compressive loads, tension and shear stress.

In taller furnaces the refractory has to support a heavy load, hence strength under the combined effect of temperature and load is important.

3. Spalling –

It is the fracture of refractory due to it's uneven expansion on account of heat when they are subject to rapid heating and cooling.

- For reducing spalling , a refractory should be well fired and it's porosity should be core.

4. Thermal conductivity –

Ordinary furnace block should have low thermal conductivity but refractory used in coke oven, regenerator should have high heat conductivity.

- Thermal conductivity is increase when the porosity of refractory brichs decreases that is when the air entrapped in refractory decreases.

5. Electrical conductivity –

Electrical conductivity of refractory material must be low.

- Except graphite all over all other refractories are bad conductor of electricity.

6. Abrasion Resistance –

A refractory is subjected to wear, it comes in contact with a moving charge in case of blast furnace, descending charge material result in abrasion wearing away of the refractory lining material.

7. Erosion Resistance –

Erosion (damage due to mechanical action) occurs when metal or gad carrying dust and slag particles hit against the refractory lining resulting in chipping off of particles from the refractory.

Lecture-21

Special Refractories

1. Zirconia Refractory (ZrO_2)

Definition:

Zirconia refractory is a high-performance refractory made mainly from zirconium dioxide (ZrO_2). It is used where extremely high temperatures and excellent chemical resistance are required.

Composition:

- Zirconium dioxide (ZrO_2): 90–99%
- Stabilizers: CaO, MgO, Y_2O_3 (to improve thermal stability)
- Small amount of silica and other impurities

Properties:

- Very high melting point (about **2700°C**)
- Excellent resistance to molten metals and slags
- High mechanical strength at elevated temperatures
- Good thermal shock resistance (when stabilized)
- Low thermal conductivity
- Excellent corrosion and wear resistance

Advantages:

- Can withstand extremely high temperatures
- High chemical inertness
- Long service life
- Suitable for severe operating conditions

Disadvantages:

- Very expensive
- High density
- Difficult to manufacture and machine

Applications:

- Continuous casting nozzles
- Glass melting furnaces
- Steel ladles and tundishes
- High-temperature crucibles
- Aerospace and nuclear industries

2. High Alumina Refractory

Definition:

High alumina refractory is a refractory material containing **more than 45% Al_2O_3**. It is widely used because of its excellent refractoriness and mechanical strength.

Composition:

- Alumina (Al_2O_3): 45–99%
- Silica (SiO_2): Small amount
- Iron oxide (Fe_2O_3), TiO_2 and other impurities: Trace amounts

Properties:

- High refractoriness (up to **1800–1900°C**)
- High compressive strength
- Good abrasion resistance
- Excellent resistance to chemical attack
- Good thermal shock resistance
- Low porosity and high durability

Advantages:

- High mechanical strength
- Good corrosion resistance
- Long service life
- Suitable for high-temperature operations
- More economical than zirconia refractories

Disadvantages:

- Lower refractoriness than zirconia
- Can be attacked by highly basic slags
- Performance decreases under repeated severe thermal cycling

Applications:

- Blast furnaces
- Electric arc furnaces
- Cement rotary kilns
- Steel ladles
- Reheating furnaces
- Incinerators
- Boiler linings

3.Mullite :

- It's composition is $3Al_2O_3.2SiO_2$.

- It occur rarely nature.

- It is formed when kyanite, sillimanite is heated.

- It is formed in burnt fire – clay also.

- Mullite is very hard, specific gravity is 3.16.

- It's decomposition temperature is 1810°c.

- So all these properties make it one of the very good refractory.

- It's composition is generally so balanced by adding a little bauxite Al_2O_3

Some accelerator such as alkali, silicates, magnesium etc that it conform to the chemical composition of mullite.

- Then it is fired 1350°c-1380°c so that mullite, $2Al_2O_3.2SiO_2$ is formed.

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- 4.Silicon carbide (SIC) :

- SIC or carborundum is one if the refractories.

$$SiO_2 + 3C = SiC + 2CO$$

Raw materials for SIC refractories—

1. Carborundum (SIC) – It is crushed and ground to the required size.

2. Binding material such as lime, plaster of Paris l, aluminum sulphate, dolomite, tar, mineral oil.

Manufacture :

- Ground carborundum and binding material are mixed with a little water in a pan will and the mixture obtained is moulded into bricks by hand.

- The moulded bricks are burnt in electric furnaces up to 1400°c to 2000°c

Lecture-22

Criteria for Selection of Refractories for Blast Furnace

- High refractoriness to withstand temperatures above 1600°C
- High mechanical strength to bear the burden of raw materials
- Excellent resistance to abrasion caused by descending burden
- High resistance to chemical attack from acidic/basic slags and hot metal
- Good thermal shock resistance to withstand temperature fluctuations
- High resistance to carbon monoxide and reducing atmosphere
- Low porosity to minimize slag and metal penetration
- Good dimensional stability with low shrinkage or expansion
- High thermal conductivity in areas requiring efficient cooling (e.g., hearth)
- Long service life with low maintenance cost
- Ease of installation and repair
- Economical and readily available

Types of Refractories Selected for Blast Furnace

Blast Furnace Zone	Refractory Used	Reason
Throat	Fire clay bricks	Good abrasion resistance and moderate temperature resistance
Stack	Fire clay bricks, High alumina bricks	Resist abrasion from burden and moderate temperatures
Belly	High alumina bricks	Higher temperature and better slag resistance
Bosh	High alumina bricks, Silicon carbide (SiC) bricks	Excellent abrasion, thermal shock and slag resistance
Tuyere zone	Silicon carbide bricks, High	Withstand high temperature, hot blast

Blast Furnace Zone	Refractory Used	Reason
	alumina bricks	and erosion
Hearth	Carbon bricks, Graphite blocks	Excellent resistance to molten iron, high thermal conductivity and long service life
Bottom	Carbon bricks, Graphite blocks	Resist molten iron penetration and provide durability
Ceramic cup (modern furnaces)	High alumina or Alumina–Silicon Carbide–Carbon (Al_2O_3–SiC–C) bricks	Protect carbon lining and improve furnace campaign life

Common Refractories Used in Blast Furnaces

- Fire clay refractories
- High alumina refractories
- Carbon bricks
- Graphite blocks
- Silicon carbide (SiC) refractories
- Alumina–Silicon Carbide–Carbon (Al_2O_3–SiC–C) refractories
- Ceramic cup refractories

Lecture-23

Criteria for Selection of Refractories for LD (Basic Oxygen) Furnace

- High refractoriness to withstand temperatures of 1600–1700°C
- Excellent resistance to basic slag (rich in CaO)
- High resistance to chemical corrosion by slag and molten steel
- Good thermal shock resistance to withstand rapid heating and cooling
- High hot strength to resist deformation at elevated temperatures
- Good abrasion and erosion resistance due to high-velocity oxygen jet and metal movement
- Low porosity to reduce slag and metal penetration
- High spalling resistance
- Good dimensional stability during repeated heating cycles
- Long service life with low maintenance cost
- Easy repair and compatibility with slag splashing practice

- Economical and readily available

Types of Refractories Selected for LD Furnace

LD Furnace Zone	Refractory Used	Reason
Barrel (side wall)	Magnesia-Carbon (MgO-C) bricks	Excellent resistance to basic slag, thermal shock and erosion
Slag line	Magnesia-Carbon (high carbon) bricks	Maximum resistance to slag attack and wear
Trunnion area	Magnesia-Carbon bricks	High mechanical strength and thermal stability
Bottom	Magnesia-Carbon bricks or Dolomite bricks	Resist molten steel and slag attack
Cone and mouth	Burnt Magnesia bricks or Magnesia-Carbon bricks	Resist high temperature and abrasion during charging and tapping
Tap hole area	High-quality Magnesia-Carbon bricks	High erosion and impact resistance

Common Refractories Used in LD Furnace

- Magnesia-Carbon (MgO-C) bricks (most widely used)
- Burnt Magnesia bricks
- Fused Magnesia bricks
- Dolomite bricks
- Magnesia-Chrome bricks (used in older designs; now less common due to environmental concerns)
- Gunning and repair refractory materials for maintenance

Why Basic Refractories are Used in LD Furnace

- The LD process uses **basic slag** containing a high percentage of **CaO**, which would rapidly attack acidic refractories.
- Basic refractories such as **magnesia** and **dolomite** have excellent resistance to basic slags and provide longer furnace lining life.

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Lecture-24

1. Criteria for Selection of Refractories for Electric Arc Furnace (EAF)

- High refractoriness to withstand temperatures above 1700°C
- Excellent resistance to basic slag
- High resistance to thermal shock due to repeated heating and cooling
- High mechanical strength at elevated temperatures
- Good abrasion and erosion resistance
- High resistance to oxidation
- Low porosity to reduce slag and metal penetration
- Good spalling resistance
- Good electrical and thermal performance where required
- Long service life with low maintenance cost
- Easy repair and economical operation

Types of Refractories Selected for Electric Arc Furnace (EAF)

EAF Zone	Refractory Used	Reason
Roof	High alumina bricks or Silica bricks	Resist high temperature and thermal shock
Side wall	Magnesia-Carbon (MgO-C) bricks	Excellent resistance to basic slag and erosion
Slag line	Magnesia-Carbon bricks	High resistance to severe slag attack
Hearth	Magnesia-Carbon bricks or Dolomite bricks	Resist molten steel and slag
Bottom	Magnesia bricks or Dolomite bricks	High durability and corrosion resistance
Tap hole	High-quality Magnesia-Carbon bricks	Resist erosion during tapping

Common Refractories Used

- Magnesia-Carbon (MgO-C) bricks
- Magnesia bricks
- Dolomite bricks
- High alumina bricks
- Silica bricks (mainly for the roof in some furnace designs)

2. Criteria for Selection of Refractories for Coke Oven

- High refractoriness to withstand operating temperatures of about 1000–1400°C
- Excellent resistance to thermal shock

- High mechanical strength to support oven structure
- Low thermal expansion for dimensional stability
- Good resistance to coke abrasion
- Good resistance to chemical attack by coke oven gases
- Low porosity
- Long service life
- Good heat storage capacity in heating chambers
- Economical and easy to maintain

Types of Refractories Selected for Coke Oven

Coke Oven Zone	Refractory Used	Reason
Oven walls	Silica bricks	Excellent strength and dimensional stability at high temperatures
Heating chambers	Silica bricks	High refractoriness and good heat transfer
Checker chambers (regenerators)	Silica bricks or Fire clay bricks	Good heat storage and thermal efficiency
Foundation and lower parts	Fire clay bricks	Good strength and economical
Doors and repair areas	High alumina bricks or Fire clay bricks	Better wear and thermal shock resistance

Common Refractories Used

- Silica bricks (most widely used)
- Fire clay bricks
- High alumina bricks (for repair and high-wear areas)

- **Lecture-25**

Recent Advances in Fuel

- Development of **green hydrogen** as a clean fuel for steel and metallurgical industries
- Increased use of **biofuels** and biomass to reduce fossil fuel consumption
- Use of **pulverized coal injection (PCI)** to lower coke consumption in blast furnaces
- Adoption of **natural gas** and **syngas** for cleaner combustion
- Waste heat recovery systems to improve fuel efficiency
- AI-based combustion control for optimum fuel consumption
- Carbon Capture, Utilization and Storage (CCUS) to reduce CO_2 emissions

- Low-carbon and carbon-neutral fuels for sustainable steel production

Recent Advances in Furnaces

- Energy-efficient regenerative and recuperative burners
- Oxygen-enriched and oxy-fuel combustion technology
- Smart furnaces with IoT sensors and AI-based process control
- Electric Arc Furnaces (EAF) powered by renewable electricity
- Hydrogen-ready direct reduction and reheating furnaces
- Improved furnace insulation to reduce heat loss
- Automatic charging and tapping systems
- Waste heat recovery for steam and power generation
- Low-NOx burners to reduce air pollution
- Digital monitoring and predictive maintenance for improved reliability

Recent Advances in Refractories

- Development of **nano-structured refractories** with higher strength and durability
- High-performance **Magnesia-Carbon (MgO-C)** refractories with improved oxidation resistance
- Advanced **Alumina-Silicon Carbide-Carbon (Al_2O_3-SiC-C)** refractories for blast furnaces
- Zirconia-based refractories for ultra-high-temperature applications
- Carbon-bonded refractories with longer service life
- Monolithic refractories (castables, gunning and ramming mixes) replacing conventional bricks
- Self-flow and low-cement castables for faster installation and better performance
- Environment-friendly chrome-free refractory materials
- Refractory health monitoring using sensors and AI for predictive maintenance
- Recycling and reuse of spent refractories to reduce cost and environmental impact

Lecture-26

Carbon Capture and Utilization (CCU) in Fuel Technology

Definition

Carbon Capture and Utilization (CCU) is a technology in which carbon dioxide (CO_2) emitted from industrial processes is captured, purified, and converted into useful products instead of being released into the atmosphere.

Process

1. CO_2 is produced from industries such as steel plants, cement plants, refineries, and power plants.
2. CO_2 is captured using absorption, adsorption, membrane separation, or cryogenic methods.
3. The captured CO_2 is purified and compressed.
4. The CO_2 is utilized for producing valuable products or industrial processes.

Applications

- Production of synthetic fuels (methanol, methane, aviation fuel)
- Enhanced Oil Recovery (EOR)
- Carbonation of concrete and building materials
- Manufacture of chemicals such as urea and sodium bicarbonate
- Beverage carbonation
- Dry ice production
- Greenhouse cultivation to enhance plant growth
- Production of polymers and plastics

Advantages

- Reduces greenhouse gas emissions
- Improves fuel and energy efficiency
- Converts waste CO_2 into valuable products
- Supports circular carbon economy
- Reduces dependence on fossil resources
- Helps industries achieve net-zero carbon targets

Limitations

- High installation and operating cost
- Large energy requirement for CO_2 capture
- Limited commercial utilization pathways
- Requires advanced technology and infrastructure

CO_2 Sequestration in Industrial Applications

Definition

CO_2 sequestration is the long-term storage of captured carbon dioxide to prevent its release into the atmosphere and reduce global warming.

Methods of CO_2 Sequestration

1. Geological Sequestration

- CO_2 is injected into deep underground rock formations.
- Storage locations include depleted oil and gas reservoirs, deep saline aquifers, and unmineable coal seams.

2. Mineral Sequestration

- CO_2 reacts with minerals containing calcium or magnesium to form stable carbonates.
- Produces permanent and environmentally safe storage.

3. Ocean Sequestration

- CO_2 is stored in deep ocean waters.
- Limited due to potential environmental impacts.

4. Biological Sequestration

- Trees, forests, soils, and algae absorb atmospheric CO_2 through photosynthesis.
- Used in afforestation and reforestation programs.

Industrial Applications

- Steel industry
- Cement industry

- Thermal power plants
- Fertilizer plants
- Refineries
- Chemical industries
- Hydrogen production plants

Advantages

- Significant reduction in CO_2 emissions
- Helps mitigate climate change
- Supports sustainable industrial development
- Enables compliance with environmental regulations
- Can improve recovery of oil and gas through CO_2 injection

Limitations

- High capital and operating costs
- Long-term monitoring is required
- Potential risk of CO_2 leakage
- Suitable geological storage sites are limited
- Public acceptance and regulatory approvals may be challenging

Lecture-27

Clean Coal Technology (CCT)

Definition

Clean Coal Technology (CCT) refers to advanced technologies that improve the efficiency of coal utilization while reducing emissions of pollutants such as CO_2, SO_2, NO_x, particulate matter, and mercury.

Objectives

- Improve coal combustion efficiency
- Reduce greenhouse gas emissions
- Minimize air pollution
- Increase energy efficiency
- Promote sustainable use of coal resources

Major Clean Coal Technologies

1. Coal Washing (Coal Beneficiation)

- Removes ash, sulfur, and impurities before combustion.
- Improves coal quality and combustion efficiency.

2. Pulverized Coal Combustion (PCC)

- Coal is ground into fine powder before burning.
- Provides efficient and complete combustion.

3. Fluidized Bed Combustion (FBC)

- Coal burns in a bed of suspended particles.
- Reduces SO_2 and NO_x emissions and improves combustion efficiency.

4. Supercritical and Ultra-Supercritical Boilers

- Operate at very high pressure and temperature.
- Increase thermal efficiency and reduce fuel consumption.

5. Integrated Gasification Combined Cycle (IGCC)

- Coal is converted into synthesis gas ($CO + H_2$).
- Syngas is cleaned before combustion, reducing pollutants and improving efficiency.

6. Carbon Capture, Utilization and Storage (CCUS)

- Captures CO_2 from flue gases.
- CO_2 is either utilized for useful products (CCU) or stored underground (CCS).

7. Flue Gas Desulfurization (FGD)

- Removes sulfur dioxide (SO_2) from exhaust gases.
- Helps prevent acid rain.

8. Low-NO_x Burners

- Reduce nitrogen oxide (NO_x) formation during combustion.

9. Electrostatic Precipitators (ESP) and Bag Filters

- Remove fly ash and particulate matter from flue gases.

Advantages

- Higher fuel efficiency
- Reduced CO_2, SO_2, NO_x, and particulate emissions
- Better environmental performance
- Lower operating cost through efficient fuel use
- Improved power plant performance
- Compliance with environmental regulations

Limitations

- High installation cost
- Complex technology and maintenance
- Requires skilled operation
- Some technologies consume additional energy
- Coal remains a fossil fuel with residual CO_2 emissions

Applications

- Thermal power plants
- Steel and metallurgical industries
- Cement industries
- Chemical industries
- Industrial boilers
- Coal gasification and fuel production

Lecture-28

Advanced Refractory Materials

1. Nano Refractories

Definition

Nano refractories are advanced refractory materials containing nanoparticles (1–100 nm) that improve the physical, mechanical, and thermal properties of conventional refractories.

Composition

- Nano alumina (Al_2O_3)
- Nano silica (SiO_2)
- Nano zirconia (ZrO_2)
- Nano magnesia (MgO)
- Nano titanium dioxide (TiO_2)

Properties

- High refractoriness
- Higher mechanical strength
- Improved thermal shock resistance
- Low porosity and high density
- Better wear and corrosion resistance
- Longer service life

Advantages

- Higher durability
- Better resistance to slag and molten metal attack
- Improved energy efficiency
- Reduced maintenance and replacement costs
- Faster sintering and stronger bonding

Applications

- Blast furnaces
- Electric Arc Furnaces (EAF)
- LD (BOF) converters
- Cement rotary kilns
- Glass furnaces
- Petrochemical reactors

2. Graphite-Based Refractories

Definition

Graphite-based refractories are refractories containing natural or synthetic graphite as the major carbon component. They are widely used where high thermal conductivity and resistance to molten metals are required.

Composition

- Natural or synthetic graphite
- Carbon
- Alumina or magnesia (in some grades)
- Resin or pitch as a binder

Properties

- Excellent thermal conductivity
- High thermal shock resistance
- High refractoriness
- Low wettability to molten metal
- Good electrical conductivity
- Good resistance to thermal stress

Advantages

- Excellent resistance to molten metal attack
- Rapid heat transfer
- Good dimensional stability
- Long service life
- Easy machining

Limitations

- Oxidizes in air at high temperatures
- Requires antioxidant additives or protective atmosphere
- Higher cost than ordinary fire-clay refractories

Applications

- Continuous casting nozzles
- Crucibles
- Blast furnace hearths
- Electric Arc Furnaces

- Foundries
- Non-ferrous metal melting

3. Carbon Composite Refractories

Definition

Carbon composite refractories are composite materials made by combining carbon with ceramic oxides such as magnesia, alumina, or silicon carbide to improve overall performance.

Common Types

- Magnesia–Carbon (MgO–C)
- Alumina–Carbon (Al_2O_3–C)
- Alumina–Silicon Carbide–Carbon (Al_2O_3–SiC–C)
- Dolomite–Carbon (CaO–MgO–C)

Properties

- Excellent resistance to basic slags
- High thermal shock resistance
- High mechanical strength
- Low thermal expansion
- Low wettability by molten steel and slag
- Excellent erosion and corrosion resistance

Advantages

- Longer lining life
- Reduced slag penetration
- Better resistance to spalling
- Suitable for severe steelmaking conditions
- Lower maintenance cost

Limitations

- Carbon oxidation at high temperatures
- Requires antioxidants such as Al, Si, or Mg
- Higher manufacturing cost

Applications

- LD (BOF) converters

- Electric Arc Furnaces (EAF)
- Steel ladles
- Blast furnace hearths
- Tundishes
- Continuous casting systems

Comparison of Advanced Refractory Materials

Property	Nano Refractories	Graphite-Based Refractories	Carbon Composite Refractories
Main constituent	Nanoparticles	Graphite and carbon	Carbon + ceramic oxides
Strength	Very high	High	Very high
Thermal shock resistance	Excellent	Excellent	Excellent
Corrosion resistance	Excellent	Good	Excellent
Thermal conductivity	Moderate	Very high	High
Oxidation resistance	High	Lower	Moderate (improved with antioxidants)
Main applications	High-performance furnaces	Crucibles, nozzles, hearths	BOF, EAF, ladles, blast furnaces

Lecture-29

Ultra High Temperature Ceramics (UHTCs)

Definition

Ultra High Temperature Ceramics (UHTCs) are advanced ceramic materials that can withstand **temperatures above 2000°C**, with some remaining stable beyond **3000°C**. They possess excellent thermal stability, hardness, oxidation resistance, and wear resistance, making them suitable for extreme environments.

Composition

- Zirconium Diboride (ZrB_2)
- Hafnium Diboride (HfB_2)
- Zirconium Carbide (ZrC)
- Hafnium Carbide (HfC)
- Tantalum Carbide (TaC)

- Silicon Carbide (SiC) (added to improve oxidation resistance)

Properties

- Very high melting point (above 3000°C)
- Excellent refractoriness
- High hardness and strength
- Good thermal conductivity
- Excellent wear and erosion resistance
- High resistance to thermal shock
- Good oxidation resistance (especially with SiC addition)
- Good chemical stability at high temperatures

Advantages

- Can operate at extremely high temperatures
- Excellent mechanical strength at elevated temperatures
- Long service life
- High resistance to corrosion and molten metals
- Lightweight compared to many high-temperature alloys
- Suitable for harsh aerospace and metallurgical environments

Limitations

- Expensive to manufacture
- Brittle compared with metals
- Difficult to machine
- Oxidation protection is required for prolonged use above about **1600°C**

Applications

- Rocket nozzles
- Hypersonic aircraft leading edges
- Space vehicle nose cones
- Thermal protection systems
- High-temperature furnace components
- Crucibles for molten metals
- Nuclear reactors
- Plasma arc equipment
- Cutting tools and wear-resistant components

Examples of UHTCs

- Zirconium Diboride (ZrB_2)
- Hafnium Diboride (HfB_2)
- Zirconium Carbide (ZrC)
- Hafnium Carbide (HfC)
- Tantalum Carbide (TaC)
- Titanium Diboride (TiB_2)

Lecture-30

Alternative Fuels for Industrial Heating

Definition

Alternative fuels are fuels other than conventional coal, oil, and natural gas that are used for industrial heating to improve energy efficiency, reduce fuel costs, and lower greenhouse gas emissions.

Waste-Derived Fuels (WDF)

Definition

Waste-Derived Fuels (WDF) are fuels produced by processing municipal, industrial, agricultural, or commercial wastes into combustible materials that can be used for heat and power generation.

Types of Waste-Derived Fuels

- Refuse-Derived Fuel (RDF)
- Solid Recovered Fuel (SRF)
- Tire-Derived Fuel (TDF)
- Waste plastics fuel
- Biomass waste fuel
- Used oil and waste lubricants
- Sewage sludge fuel
- Agricultural residue fuel

Production Process

1. Collection of waste.
2. Segregation of recyclable and non-combustible materials.
3. Drying to reduce moisture.
4. Shredding and size reduction.
5. Pelletizing or briquetting (if required).

6. Use as fuel in boilers, kilns, and furnaces.

Advantages

- Reduces landfill waste
- Conserves natural fossil fuels
- Lowers fuel cost
- Reduces greenhouse gas emissions
- Provides energy from waste
- Promotes circular economy

Limitations

- Variable fuel quality
- Higher ash content
- Emission control systems are required
- Collection and processing costs
- Proper segregation is necessary

Industrial Applications

- Cement kilns
- Steel reheating furnaces
- Power plants
- Industrial boilers
- Brick kilns
- Paper industries
- Lime kilns

Lecture-31

Eco-Friendly Furnace Technology

Definition

Eco-friendly furnace technology refers to advanced furnace systems that reduce fuel consumption, greenhouse gas emissions, and environmental pollution while improving energy efficiency and productivity.

Features

- High energy efficiency
- Low CO_2, NO_x, and SO_2 emissions

- Waste heat recovery systems
- Advanced insulation to reduce heat loss
- Automatic combustion and temperature control
- Use of renewable and alternative fuels
- Integration with digital monitoring and AI-based control
- Reduced operating and maintenance costs

Advantages

- Lower fuel consumption
- Reduced environmental pollution
- Improved product quality
- Higher productivity
- Longer furnace life
- Compliance with environmental regulations
- Supports sustainable industrial development

Applications

- Steel industries
- Cement plants
- Glass industries
- Ceramic industries
- Heat treatment furnaces
- Non-ferrous metal industries

Hybrid Furnace

Definition

A hybrid furnace combines **two or more heat sources**, such as electricity and natural gas, hydrogen and gas, or solar energy and electricity, to achieve higher efficiency and lower emissions.

Working Principle

- The furnace automatically switches or combines different heat sources depending on operating conditions.
- Smart control systems optimize energy use to reduce fuel consumption.

Advantages

- Higher energy efficiency
- Lower fuel cost

- Reduced CO_2 emissions
- Greater operational flexibility
- Improved temperature control
- Increased reliability

Applications

- Steel reheating furnaces
- Heat treatment furnaces
- Forging industries
- Glass manufacturing
- Ceramic industries

Solar-Assisted Furnace

Definition

A solar-assisted furnace uses **solar thermal energy** along with conventional fuels or electricity to provide heat for industrial processes.

Working Principle

1. Mirrors or heliostats concentrate sunlight onto a receiver.
2. The receiver converts solar energy into heat.
3. The heat is supplied directly to the furnace or stored in a thermal storage system.
4. Conventional fuel or electricity provides additional heat when solar energy is insufficient.

Advantages

- Significant reduction in fossil fuel consumption
- Lower CO_2 emissions
- Reduced operating cost
- Uses renewable energy
- Improves overall furnace efficiency
- Supports carbon-neutral industrial operations

Limitations

- High initial investment
- Dependent on sunlight availability
- Requires large installation area
- Thermal energy storage may be required for continuous operation

Applications

- Metal heat treatment
- Steel reheating
- Ceramic and glass industries
- Solar research furnaces
- High-temperature material testing

*****THANK YOU *****