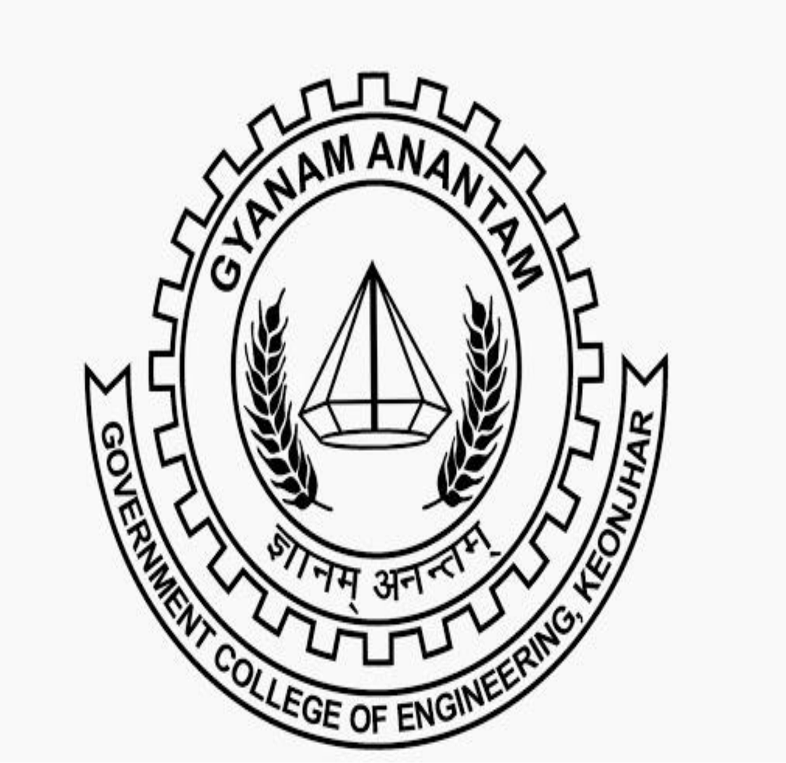
FUEL REFRACTORIES AND FURNACES

LECTURE NOTES



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DISCLAIMER

FUEL, REFRACTORIES & FURNACES (3-1-0)

Module-I **(10 hours)**

Definition of Fuel; Types of Fuel; Conventional and Non-conventional Fuel; Types of Energy Resources; Potential of Energy Resources and their exploitation

Module-II **(08 hours)**

Types of solid fuels. Origin and formation of coal. Classification of Coal.

Module-III **(08 hours)**

Types of furnaces and classification, Industrial application of furnaces, design and construction aspects of furnaces. Chimney design, process efficiency.

Module-IV **(14 hours)**

Refractories: refractory material and characterization, types of Refractories and their application in boilers and furnace construction. Properties and testing methods of Refractories. Manufacture of fire basic bricks, acidic and neutral Refractories, refractory mortars, cements and monoliths, special refractory and ceramics. Role of refectories in energy conservation in furnaces.

TEXT BOOK:

1. Elements of Fuels, Furnaces and Refractories by O.P. Gupta, Khanna Publ., 1997

2. Fuels and refractories by Book by J. D. Gilchrist

MODULE-I

Fuel:

Energy from the Sun is converted into chemical energy by photosynthesis. But, as we know, when we burn dried plants or wood, producing energy in the form of heat and light, we are releasing the Sun's energy originally stored in that plant or in that wood through photosynthesis. We know that, in most of the world today, wood is not the main source of fuel. We generally use natural gas or oil in our homes, and we use mainly oil and coal to heat the water to produce the steam to drive the turbines for our huge power generation systems.

The substances which give energy in the form of heat and light on their combustion with air in a manner which could be utilised efficiently and economically are known as fuel.

These fuels - coal, oil, and natural gas - are often referred to as fossil fuels.

The various types of fuels (like liquid, solid and gaseous fuels) that are available depend on various factors such as costs, availability, storage, handling, pollution and landed boilers, furnaces and other combustion equipment.

The knowledge of the fuel properties helps in selecting the right fuel for the right purpose and for the efficient use of the fuel. Laboratory tests are generally used for assessing the nature and quality of fuels.

Conventional and Non-conventional Source of Energy:

a) Conventional Energy Sources:

Conventional sources of energy are also called non-renewable sources. These sources of energy are in limited quantity except hydro-electric power.

These are further classified as commercial energy and non-commercial energy:

- **Commercial Energy Sources:**

These are coal, petroleum and electricity. These are called commercial energy because they have a price and consumer has to pay the price to purchase them.

- **Non-Commercial energy Sources:**

These sources include fuel wood, straw and dried dung. These are commonly used in rural India. According to an estimate, the total availability of fuel wood in India was only 50 million tonnes a year. It is less than 50% of the total requirements.

Agricultural wastes like straw are used as fuel for cooking purposes. The straw can be used as valuable organic manure for increasing fertility of soil and in turn productivity.

b) Non-Conventional Sources of Energy:

Besides conventional sources of energy there are non-conventional sources of energy. These are also called renewable sources of energy. Examples are Bio energy, solar energy, wind energy and tidal energy.

The various sources are given below:

1. Solar Energy:

Energy produced through the sunlight is called solar energy. Under this programme, solar photovoltaic cells are exposed to sunlight and in the form of electricity is produced. Photovoltaic cells are those which convert sun light energy into electricity. Solar energy is used for cooking, heating water and distillation of water etc.

2. Wind Energy:

This type of energy can be produced by harnessing wind power. It is used for operating water pumps for irrigation purposes.

3. Tidal Energy:

Energy produced by exploiting the tidal waves of the sea is called tidal energy. Due to the absence of cost effective technology, this source has not yet been tapped.

4. Bio Energy:

This type of energy is obtained from organic matter.

It is of two kinds:

- **Biogas:**

Biogas is obtained from cow dung gas plant by putting cow dung into the plant. Besides producing gas this plant converts cow dung into manure. It can be used for cooking, lighting and generation of electricity.

- **Biomass:**

It is also of a source of producing energy through plants and trees. The purpose of bio mass programme is to encourage afforestation for energy. So that fuel for the generation of energy based on gas technique and fodder for the cattle could be obtained.

5. Energy from Urban Waste:

Urban waste poses a big problem for its disposal and it can be used for generation of power.

Electrical Energy

Electrical energy is not a fuel but is a substitute for fuel and replaces it (or displaces it) in many industrial applications.

Electricity can be generated from several sources of energy.

- By conversion of chemical energy in coal, oil, peat or other conventional fuels into heat by burning, into mechanical energy by steam-raising, and then to electrical energy by using a turbine and dynamo.
- By conversion of the potential energy in water in elevated reservoirs to kinetic energy in raceways and then to mechanical and electrical energy using turbines and dynamos.
- By similar conversion of the kinetic energy in wind.
- By conversion of nuclear energy via heat and steam.
- By the use of electrolytic cells and fuel cells in which chemical energy can be converted directly to electrical energy.

TYPE OF FUELS

The fuels can be commonly classified on the basis of physical state of their occurrence, source, process of production and renewable/non-renewable quality as follows:

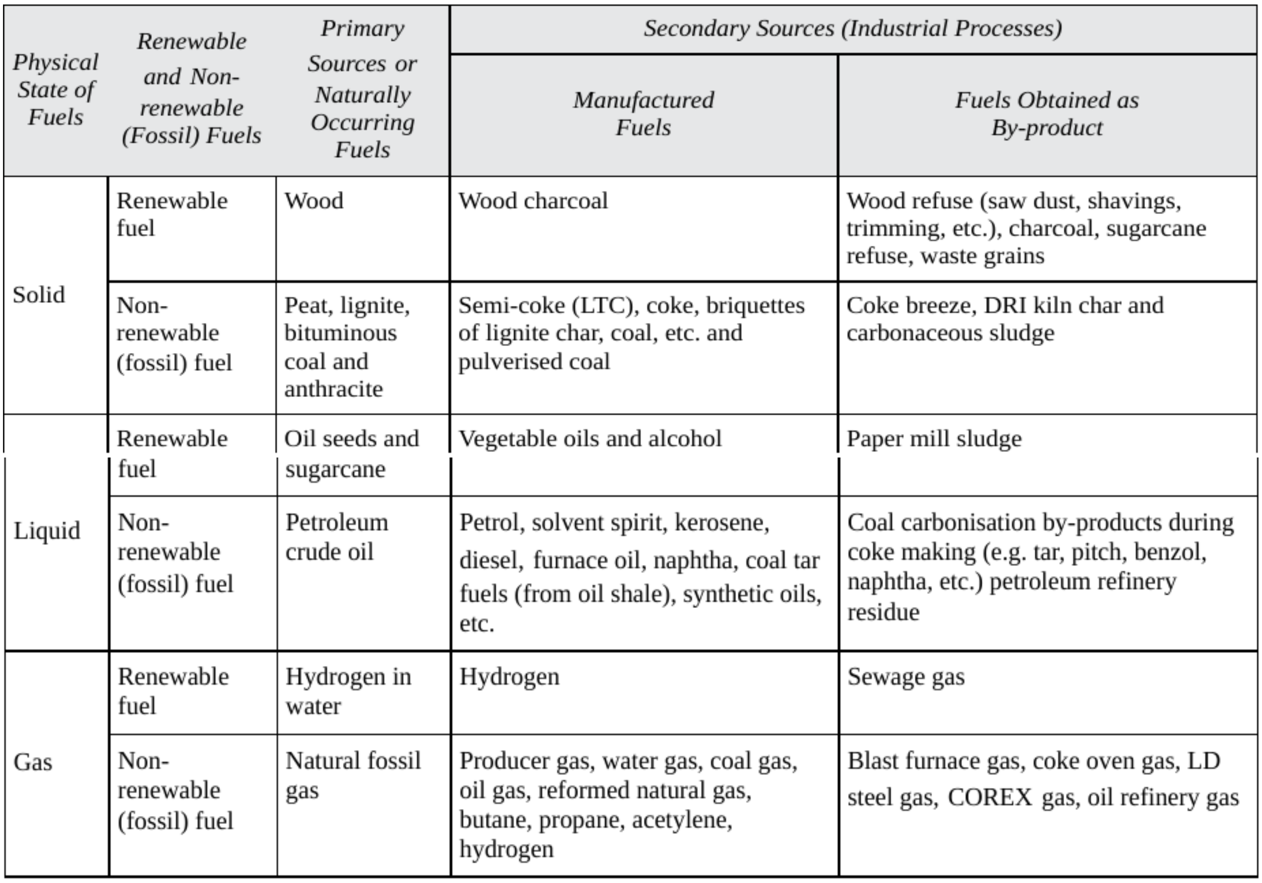
- Physical state of fuel, i.e., solid (coal, coke, charcoal, etc.), liquid (petrol, diesel, etc.) and gas (methane, hydrogen, etc.).
- Source of fuel, i.e., primary sources like coal, crude oil, and natural gas which occur in nature or secondary sources like coke, diesel, hydrogen, etc. which are prepared by some industrial processes.
- Process of production, i.e., purposefully manufactured fuel like metallurgical coke or by-product fuel like blast furnace gas.
- Nature of fuel—Non-renewable (fossil) fuels like coal, crude oil, natural gas or renewable fuels like hydrogen, biomass, etc.

PROPORTIES OF FUEL:

The various properties of liquid fuels are given below.

- Chemical composition: Carbon content, water content, ash content, sulphur, nitrogen, hydrogen content etc.
- Density
- Specific gravity
- Viscosity
- Flash point
- Pour point
- Specific heat
- Calorific value

The primary and secondary sources for solid, liquid and gaseous fuels, classified as renewable and non-renewable (fossil) fuel.



Physical State of Fuels	*Renewable and Non-renewable (Fossil) Fuels*	*Primary Sources or Naturally Occurring Fuels*	*Secondary Sources (Industrial Processes)*	
			Manufactured Fuels	*Fuels Obtained as By-product*
Solid	Renewable fuel	Wood	Wood charcoal	Wood refuse (saw dust, shavings, trimming, etc.), charcoal, sugarcane refuse, waste grains
	Non-renewable (fossil) fuel	Peat, lignite, bituminous coal and anthracite	Semi-coke (LTC), coke, briquettes of lignite char, coal, etc. and pulverised coal	Coke breeze, DRI kiln char and carbonaceous sludge
Liquid	Renewable fuel	Oil seeds and sugarcane	Vegetable oils and alcohol	Paper mill sludge
	Non-renewable (fossil) fuel	Petroleum crude oil	Petrol, solvent spirit, kerosene, diesel, furnace oil, naphtha, coal tar fuels (from oil shale), synthetic oils, etc.	Coal carbonisation by-products during coke making (e.g. tar, pitch, benzol, naphtha, etc.) petroleum refinery residue
Gas	Renewable fuel	Hydrogen in water	Hydrogen	Sewage gas
	Non-renewable (fossil) fuel	Natural fossil gas	Producer gas, water gas, coal gas, oil gas, reformed natural gas, butane, propane, acetylene, hydrogen	Blast furnace gas, coke oven gas, LD steel gas, COREX gas, oil refinery gas

Liquid Fuels

Liquid fuels are mainly oils, tars and pitches and are derived from the following sources:

- Petroleum
- Oil Shales
- Coal, by carbonization
- Coal, by hydrogénation

At present petroleum provides the majority of our liquid fuel requirements. The reserves of oil shales are immense, however, and these will probably increase in importance in the future. The liquid and tarry products of carbonization are used by industry near coalfields and carbonizing centres and, as a result, the steel industry employs these in fairly large quantities.

Hydrogénation of coal has been exploited mainly by the Germans using lignites. It competes economically with oil only with great difficulty but the process has had strategic significance.

Refining of Petroleum:

Refining is the fractionation of the petroleum into its components and the first stage is a simple fractional distillation as follows:

- Natural gas—Boiling range below 30°C. This is usually removed under reduced pressure at the oilfield, initially to permit safe handling of the crude oil.
- Gasoline—Boiling range 30-200°C. This is "petrol" and may be further divided into aviation spirit (30-150°C), motor spirit(40-180°C), and vaporizing oil (110-200°C) for tractors, etc.
- Naphtha—Boiling range 120-200°C. There is usually a surplus at the top end of the gasoline range which is used for further processing. This is the fraction which is reformed to high octane gasoline and supplied to petrochemical plants as feedstock. It was also used for making into town's gas during the 1960s.
- Solvent spirit—Boiling range 120-250°C. This is white spirit or turpentine substitute and is used as a solvent, a cleansing agent and in paint manufacture.
- Kerosene—Boiling range 140-290°C. This fraction includes domestic paraffin oil (140-250°C) and heavier slow-burning fractions used as illuminants in railways (signal oil) and in lighthouses.
- Gas oil—Boiling range from 180°C and leaving a residue of carbon at 350°C. This is used as a carburetting oil in the gas industry and also in diesel engines.
- Fuel oils—Boiling above 200°C. Beyond this point vacuum distillation is necessary to avoid cracking of these heavy oils with the formation of lighter oil and carbon residue.
- Light fuel oil—Boiling above 200°C.
- Heavy fuel oil—Boiling above 250°C These are fractions of interest to furnace operators—for use in ships, land boilers, metallurgical furnaces, etc.
- The residue from these stages is becoming very thick and yields on further treatment, if paraffinic, wax (paraffin wax), mineral jelly ("Vaseline"), and lubricating oils and greases or, if asphaltic, bitumens and lubricants.

Tests for liquid fuel:

Two main tests done for liquid fuel are:

- Flash point: It is the minimum temperature at which the oil will catch fire if exposed to a naked flame
- Viscosity: It is also determined in standard equipment as a check on specification as regular behaviour in pipelines and burners is desirable. Viscosity varies logarithmically with temperature and would best be determined over a range of temperature.

- Pour Point: The pour point of a fuel is the lowest temperature at which it will pour or flow when cooled under prescribed conditions. It is a very rough indication of the lowest temperature at which fuel oil is ready to be pumped.

Uses:

The uses of oils are as varied as those of gas and include domestic heating and lighting, steelmaking, all kinds of engines, the generation of electricity, and the production of gas.

- Oil is also used as a raw material in the chemical industries. It can be almost as clean as gas in use but spillage and leaks of thick oil and tar are unpleasant features of many plants.
- The need for steam for warming the storage tanks and pipelines and for injection through the burners involves the use of space and money and the delivery of oil in quite small and very frequent batches by road tanker necessitates some careful organization and numerous checks on quality.
- Liquid fuels like furnace oil and LSHS (low sulphur heavy stock) are predominantly used in industrial applications.

Gaseous Fuel

Gas fuels are the most convenient because they require the least amount of handling and are used in the simplest and most maintenance-free burner systems. Gas is delivered "on tap" via a distribution network and so is suited for areas with a high population or industrial density. However, large individual consumers do have gas holders, and some produce their own gas.

Types of gaseous fuel

The following is a list of the types of gaseous fuel:

- Fuels naturally found in nature:
  - Natural gas
  - Methane from coal mines
- Fuel gases made from solid fuel
  - Gases derived from coal
  - Gases derived from waste and biomass
  - From other industrial processes (blast furnace gas)

- Gases made from petroleum
  - Liquefied Petroleum gas (LPG)
  - Refinery gases
  - Gases from oil gasification
- Gases from some fermentation process

Gaseous fuels in common use are liquefied petroleum gases (LPG), Natural gas, producer gas, blast furnace gas, coke oven gas etc. The calorific value of gaseous fuel is expressed in Kilocalories per normal cubic meter (kCal/Nm^3) i.e. at normal temperature (20 degree C) and pressure (760 mm Hg).

Properties of gaseous fuels:

Since most gas combustion appliances cannot utilize the heat content of the water vapour, gross calorific value is of little interest. Fuel should be compared based on the net calorific value. This is especially true for natural gas since increased hydrogen content results in high.

Fuel Gas	Relative Density	Higher Heating Value kcal/Nm^3	Air/Fuel ratio- m^3 of air to m^3 of Fuel	Flame Temp. ^{o}C	Flame Speed m/s
Natural Gas	0.6	9350	10	1954	0.290
Propane	1.52	22200	25	1967	0.460
Butane	1.96	28500	32	1973	0.870

LPG:

LPG is a predominant mixture of propane and Butane with a small percentage of unsaturates (Propylene and Butylene) and some lighter C_2 as well as heavier C_5 fractions. Included in the LPG range are propane (C_3H_8), Propylene(C_3H_6), normal and iso-butane (C_4H_{10})and Butylene(C_4H_8). LPG may be defined as those hydrocarbons, which are gaseous at normal atmospheric pressure, but may be condensed to the liquid state at normal temperature, by the application of moderate pressures. Although they are normally used as gases, they are stored and transported as liquids under pressure for convenience and ease of handling. Liquid LPG evaporates to produce about 250 times volume of gas.

LPG vapour is denser than air: butane is about twice as heavy as air and propane about one and a half times as heavy as air. Consequently, the vapour may flow along the ground and into drains sinking to the lowest level of the surroundings and be ignited at a considerable distance from the source of leakage. In still air vapour will disperse slowly. Escape of even small quantities of the liquefied gas can give rise to large volumes of vapour / air mixture and thus cause considerable hazard. To aid in the detection of atmospheric leaks, all LPG's are required to be odorized. There should be adequate ground level ventilation where LPG is stored. For this very reason LPG cylinders should not be stored in cellars or basements, which have no ventilation at ground level.

Natural gas:

Methane is the main constituent of natural gas and accounting for about 95% of the total volume. Other components are: Ethane, Propane, Butane, Pentane, Nitrogen, Carbon Dioxide, and traces of other gases. Very small amounts of sulphur compounds are also present. Since methane is the largest component of natural gas, generally properties of methane are used when comparing the properties of natural gas to other fuels. Natural gas is a high calorific value fuel requiring no storage facilities. It mixes with air readily and does not produce smoke or soot. It contains no sulphur. It is lighter than air and disperses into air easily in case of leak. A typical comparison of carbon contents in oil, coal and gas is given in the table below.

Module-II

Solid fuel:

Solid fuel refers to various forms of solid material that can be burnt to release energy, providing heat and light through the process of combustion.

Solid fuels can be contrasted with liquid fuels and gaseous fuels. Common examples of solid fuels include wood, charcoal, peat, coal, Hexamine fuel tablets, wood pellets, corn, wheat and other grains.

Solid fuels are mainly classified into two categories,

- Natural fuel : naturally occurred

  Example -wood, coal, etc. and

- Manufactured fuels: manufactured by human being/human made/

  Example: charcoal, coke, briquettes, etc.

Different types of solid fuels are

a. Wood
b. Biomass
c. Peat
d. Coal
e. Coke
f. Municipal waste
g. Fossil fuels

Properties of Solid Fuel:

Specific Heat:

Specific heat is the amount of kCals needed to raise the temperature of 1 kg of oil by 1 degree C.

The unit of specific heat is kcal/kg degree C. It varies from 0.22 to 0.28 depending on the oil specific gravity. The specific heat determines how much steam or electrical energy it takes to heat oil to a desired temperature. Light oils have a low specific heat, whereas heavier oils have a higher specific heat.

Calorific Value:

The calorific value is the measurement of heat or energy produced and is measured either as gross calorific value or net calorific value. The difference is determined by the latent heat of condensation of the water vapour produced during the combustion process. Gross calorific value (GCV) assumes all vapour produced during the combustion process is fully condensed.

Net calorific value (NCV) assumes the water leaves with the combustion products without fully being condensed. Fuels should be compared based on the net calorific value.

Ash Content:

The ash value is related to the inorganic material or salts in the fuel oil. The ash levels in distillate fuels are negligible. Residual fuels have higher ash levels. These salts may be compounds of sodium, vanadium, calcium, magnesium, silicon, iron, aluminum, nickel, etc.

Carbon Residue:

Carbon residue indicates the tendency of oil to deposit a carbonaceous solid residue on a hot surface, such as a burner or injection nozzle, when its vaporizable constituents evaporate. Residual oil contains carbon residue of 1 percent or more.

Coal:

Coal is a naturally occurring carbonaceous rock. The coal is formed from vegetal matter over a long period on the geological time scale. There are many varieties of coal occurring in nature. The coal suitable for making of coke is designated as coking coal. Every coking coal does not yield coke suitable for metallurgical applications and thus, coals yielding coke for metallurgical applications are termed as metallurgical coal.

Origin and formation of coal:

Coal occurs in nature as sedimentary rock where the carbonaceous matter is present with many other minerals. The structural examination of the coal shows confirmed evidence of its formation from vegetal matter. The fossil imprint of leaf, bark and other tree components on the coal provide evidence of its vegetal origin. The micro-structural examination of the thin section of coal reveals the presence of spores, pollens, resins and other essential components of vegetal matter which help in confirming and identifying the type of tree from which such coal is originated in the nature. It is believed that the large forest vegetation growing long ago got buried in the ground and was fossilised to become coal.

There are two theories for origin of coal: ‘In-situ’ theory and ‘Drift’ theory.

- The ‘in-situ’ theory describes it as natural growth of trees in swamps, their death and accumulation as peat over long period of time followed by its coalification to coal due to some geological action in nature, sustained for long duration of time.

- The ‘drift’ theory differs in first part of the process of coal formation to deposit peat at other location than its growth, while the second stage process is identical to the ‘in-situ’ theory. The ‘drift’ theory describes the growth of trees in high regions, and these are transported by river water after they die and get uprooted down to estuary where they get deposited as peat due to lower velocity of water. This deposited peat gets converted to coal by long geological action of the earth. Such peat formation can be noticed even now in Sunderban area of West Bengal which is the delta region of Ganges river.

Thus, the process of coal formation could be divided in two periods:

a. Peat formation and
b. Conversion of peat into coal.

Peat Formation (Biochemical Period)

- The forests grow in tropical climate. The swamps provide ideal place for the thick growth of the vegetation.
- The trees germinate from the fallen seeds on the soil. The tender tree grows fast in tropical climate and dies on maturity. When the tree dies, it falls on the ground and starts decomposing or decaying.
- This decomposition (or rotting) process is the disintegration of plant molecular structure aided by bacteria, moisture and air. When the process of decay of the dead tree is in progress and if another dead tree falls over it then the partially decayed tree gets buried in the soft swamp soil and the decay process is slowed down or arrested depending on the supply of oxygen necessary for the bacterial growth. This partially decayed vegetal matter is termed as peat.
- During the process of peat formation, the various constituents decay at different rate. The protoplasm and oils in the plant matter decay rapidly. The carbohydrates like cellulose, lignin, etc. decay slowly, whereas the spores, pollens, resins and waxes resist decay action.
- Thus, the nature of vegetation, its constituent and extent of decay will decide the peat composition and properties. This process of tree germination, growth, maturity death and partial decay process continues to form peat and its accumulation as layers buried under soft swamp soil.
- The peat layer thickness depends on the period of peat formation which may be hundreds of years. This peat layer awaits some geological action to cause its conversion into coal.

Conversion of Peat into Coal (Dynamo-chemical Period)

- The earth crust is dynamic in nature, and it undergoes depression or elevation at any given point due to movement of plates in the earth crust. It may be possible that at some time the area having peat deposit underwent depression causing peat layer buried at considerable depth with a formation of large depression of surface on its top.
- This depressed land filled with rain water would destroy all growing vegetation and would look like a huge water lake.
- In every rainy season, the flowing water to the lake would bring soil and get deposited at the bottom of lake. This soil silting process may continue for long time to eventually fill the lake and make it a plain ground over which the vegetation may start growing again with peat formation and accumulation to give another layer of peat deposit.
- It may also happen that another earth movement may push the buried layer of peat upward creating a mountain like elevated topology. In this process of geological action, the peat layer buried in the soil may be subjected to considerable pressure and temperature, rendering chemical and physical changes in peat properties.
- The chemical changes due to application of temperature and pressure would be the loss of moisture and evolution of carbon dioxide and methane.
- The oxygen content of the carbonaceous matter would be decreased with increase in temperature and time. These conversion changes get reflected in physical nature of the deposit.
- The colour, hardness and density keep changing with the advancement of the conversion from peat to anthracite.
- The peat has more than 90 percent of water and can be squeezed by hand. This water content is reduced in lignite which can be felt as wet.
- The bituminous and anthracite coal have very little moisture to be felt by hand. The brown colour of the peat becomes dark brown in lignite which further turns black when it becomes bituminous and anthracite.
- The coal hardness also increases with conversion from lignite to anthracite stage. The lignite is friable in nature, while bituminous is hard, but soils the hand with black carbon. Anthracite is quite hard and does not soil hand on rubbing on its surface.

TYPE, RANK, CLASS AND GRADE OF COAL

The words like type, rank, class and grade of coal are commonly used to differentiate its nature which has specific meaning.

Type of coal

The word type of coal indicates whether it is anthracite, bituminous or lignite coal.

All these three types of coal have distinct properties which render their identification.

(i) Lignite:

It is brown/black in colour with considerable amount of moisture to soil the hand. It is fibrous in nature and crumbles easily on pressing. It has high porosity. It contains high volatile constituents with low fixed carbon.

(ii) Bituminous coal:

It has characteristic layers of bright and dull banded matter. It has typical cubic fracture. It is relatively hard (3–4 Mohs scale) in nature. It burns easily with smoky yellow flame. It has many commercial applications. The coking coals falling under this type are used for coke making.

(iii) Anthracite:

It is a hard and compact variety of coal with pitch like appearance. It breaks with irregular fracture and does not soil the finger on rubbing. Anthracite ignites with difficulty, but once ignited, it burns and gives intense local heat with very short and non-luminous flames. Anthracite does not have caking property and is unsuitable for coke making. It has limited industrial use as fuel, but often used to make artefacts.

Rank of coal

The word rank denotes the degree of coalification the peat has undergone to yield coal. The carbon content and calorific value of coal increase with rank, while the volatile matter is found to decrease. The different coals with increasing rank can be shown as:

lignite → bituminous → anthracite.

Class of coal

The term class is retained for its actual use such as coking coal, steam raising coal, gas making coal, etc.

Grade of coal

The grade refers to the degree of purity of the coal. The coals with higher ash and moisture content are referred as lower grade coals, while high grade coal, means coal with low ash and moisture content.

COAL CONSTITUENTS

The coal contains various constituents to render specific properties which cause its selection for various applications. These constituents could be grouped in three categories viz.

- Petrological constituents,
- Elemental constituents and
- Constituents important for its use.

These are discussed in the following sections.

Petrological Constituents in Coal

The coal contains various constituents which can be identified under geological microscope. These petrological constituents are known as macerals. These macerals differ significantly in their properties present in various coals. These macerals are grouped as vitrinite, exinite and inertinite.

- **Vitrinite:**

It is a primary constituent of coal. It usually occurs in bands. It is bright, black and brittle having conchoidal fracture. It is derived from woody tissues of the plant from which it was formed. Chemically, it is rich in polymers, cellulose ($C_6 H_{10} O_5$)n and lignin ($C_{30} H_{33} O_{11}$). It burns easily during combustion.

- **Exinite:**

These group of macerals are minor component of coal. These are rich in volatiles and hydrogen content that render it most reactive.

- **Inertinite**

It is oxidised organic material or fossilised charcoal. It is found as tiny flakes, generally forming 1–3 per cent in coal seam. It is least reactive group of macerals. The most common inertinite maceral is fusinite.

The natural minerals of different types are also found to be present in coal. These minerals get incorporated in early stage of peat formation. The intrinsic mineral matter originates from minerals present in the wood, since trees need various minerals as nutrient. These mineral constituents are finely sized and remain distributed in the whole coal body as fine particles. Such fine size mineral matter cannot be separated from coal by washing methods. The extrinsic mineral matters are those which get incorporated with peat during its formation and collection process. The extrinsic mineral matters are present in bulk and could be separated by coal cleaning methods. These mineral matters are un-combustible constituents and remain as ash after coal combustion. These mineral matters are not desired in coal.

Elemental Constituents in Coal

The major elements present in coal are carbon, hydrogen and oxygen. The minor elements include nitrogen, sulphur and phosphorus. In addition, any known element could be present in trace quantity. This elemental analysis is done using different instrumental techniques. The results of the analysis is reported as weight per cent of each element present in coal including major (in bulk percent), minor (in per cent) and trace constituents (in ppm, i.e., parts per million and ppb i.e. parts per billion) depending upon its need. Such elemental analysis of coal is reported as ultimate analysis.

The ultimate analysis of coal is useful in estimating air requirements for its combustion, flue gas analysis along with estimation of its calorific value. The presence of minor constituent like sulphur (wt.%) helps in deciding pollution abatement methods caused by its emission. The trace elements in coal would be discharged along with ash and flue gases. The presence and quantity of trace elements in coal help in providing adequate management systems to avoid hazards caused by toxic elements like Hg, As, Cd, Pb, Cr and radioactive elements.

Constituents Important for Coal Use

The coal contains moisture, incombustible inorganic matter and volatile constituents in addition to carbon. These constituents affect the use of coal. The proximate analysis of coal deals with the determination of following constituents by weight per cent:

- Moisture
- Volatile matter
- Ash, and
- Fixed carbon

The knowledge of these constituents is useful in the selection of coal for a given purpose.

Moisture

The moisture is present in every type of coal in varying amount (0.5 wt.% to 20 wt.%). In peat, the moisture content could be 90 per cent. It is an undesired constituent in solid fuels. The moisture present in the solid fuel is removed during use at the expense of its heating value. The moisture could be present in free (surface), adsorbed (inherent) or combined (chemical compound) state.

- **Free or surface moisture**

As the name suggests, this kind of moisture is loosely present on the surface or in the pores of coal. This moisture is derived from rain during storage, transportation and washing of coal. When water saturated coal is left in air for sometime, the excess free water evaporates and the moisture content in the coal attains equilibrium with the atmospheric humidity. The per cent weight loss of free water by air drying at room temperature is termed as free or surface moisture.

- **Inherent moisture**

The water molecules adsorbed on the external surface and internal open pore surface is termed as inherent moisture. Its value would depend on porosity and atmospheric humidity. As the lower rank coals possess high porosity, therefore, the inherent moisture content would also be more in lower rank coals compared to higher rank coals.

The coal sample when heated to 110 ± 5 °C temperature for sometime, then the adsorbed (inherent) moisture molecules are detached and get removed. However, if the coal sample is left again in open atmosphere for longer time, then it may regain its inherent moisture content. This regaining tendency for inherent moisture will be more for high rank coals, while this readsorption will be less in lower rank coals, since their cell walls may breakdown during drying stage due to weak structure. This reduces the number of pores available for readsorption of moisture, causing lower inherent moisture in coal sample which has been heated and cooled.

This inherent moisture content in coal cannot be avoided. However, a lower value would be appreciated.

- **Combined moisture**

Coal contains mineral matter which, sometimes, contains water molecules that are chemically attached. Such chemically bonded water molecules do not evolve when the coal is heated at 100°C. This kind of moisture can be removed only when the coal is heated at higher temperature. Such combined moisture forms the part of volatile matter, and it is not determined separately. However, the presence of combined water in coal is not appreciated as it consumes some heat for its own dissociation, rendering lower net calorific value of coal for use.

Volatile matter

It is the part of coal which is evolved as volatile (gaseous) product when the coal is heated in the absence of air. As the quantity of volatile product is dependent on temperature, time, surface area, etc., therefore, a specified procedure is adopted to make the result reproducible and comparable.

The quantity of volatile matter in coal may range from 2 wt.% to 40 wt.%, while it is below 2 wt.% in coke and wood char. The volatile matter content plays an important role during its selection for a given application. Its higher content could be useful in gas making coals, but may not be appreciated in coking coal. The knowledge of volatile matter content helps in designing combustion system to provide appropriate primary and secondary air.

Mineral matter and ash

Coal contains various minerals which are uncombustible part of coal, called ash. It is common to state that coal contains ash, but technically coal contains mineral matter and yields ash on combustion. Chemically, mineral matter is different from ash. The coal may have following minerals in varying quantities in addition to oxides of sodium and potassium:

- Shale or silt (Hydrated silicates of aluminium)
- Pyrite (FeS_2)
- Gypsum ($CaSO_4.2H_2O$)
- Lime stone ($CaCO_3$)
- Siderite ($FeCO_3$)
- Magnesite ($MgCO_3$)
- Apatite ($Ca_5(PO_4)_3$ (F, Cl, OH)

Some of these minerals originate from the vegetal mass from which the coal was formed. These minerals are required by the tree for its growth. Such mineral matter is known as intrinsic mineral matter and is present in very fine form in the matrix of coal which cannot be liberated or separated by coal cleaning methods. The bulk of the mineral matter present in coal is incorporated during peat formation stage and termed as extrinsic mineral matter. These could be present in coarser form which could be removed by coal cleaning methods.

When the coal is heated or burned, the minerals undergo changes depending upon temperature to yield ash. The ash content in a given coal is determined by observing the weight of uncombusted matter left after exposing the coal sample to oxidising condition at 800 °C. In Indian coals, which contain low 'sulphur' and 'carbonate' minerals, the mineral matter (M % wt.) is given by:

$$\mathbf{M = 1.1\,A}$$

where, A is the ash (wt.%) determined by proximate analysis of coal sample assuming the sulphur and carbonate are very low.

Fixed carbon

Fixed carbon content in the coal is considered to be useful for a given application, e.g. combustion, reduction, etc. There is no direct method for its determination.

It is estimated as:

$$\textbf{Fixed carbon} = 100 - [M + VM + A]$$

where, M, VM and A are moisture, volatile matter and ash content in coal determined experimentally.

This fixed carbon value is not the total carbon in coal. A higher fixed carbon content in coal increases its commercial value.

COAL CLASSIFICATION

The coal occurring in nature differs in their properties due to various factors affecting its formation. All such coals are classified to help the users in their selection. The proximate analysis (volatile matter and fixed carbon) and heating value or the ultimate analysis (carbon, hydrogen and oxygen) of coal are used for its classification. There are different systems of coal classification followed in various parts of the world, developed in the past. These are as follows.

Regnault–Gruner system

The first attempt to classify coal was made in UK in 1837 by Regnault, which was modified by Gruner in 1874. This classification system was based on carbon, hydrogen and oxygen content (%) in coal which were correlated with volatile matter obtained during carbonisation.

Parr's system

The American coals were classified by S W Parr in 1928. This classification of coal was based on volatile matter percentage and calorific value based on unit coal basis (coal free from moisture and mineral matter.

Seyler's system

A comprehensive classification system was developed by C.A. Seyler in 1900. This system was based on calorific value, volatile matter, maximum inherent moisture and swelling number correlated with carbon and hydrogen content derived from coal analysis based on dry ash free basis [see section 2.5.2(iv)]. In this graphical presentation of coal classification, the different coals were found to occupy position within fairly defined curved band of data points.

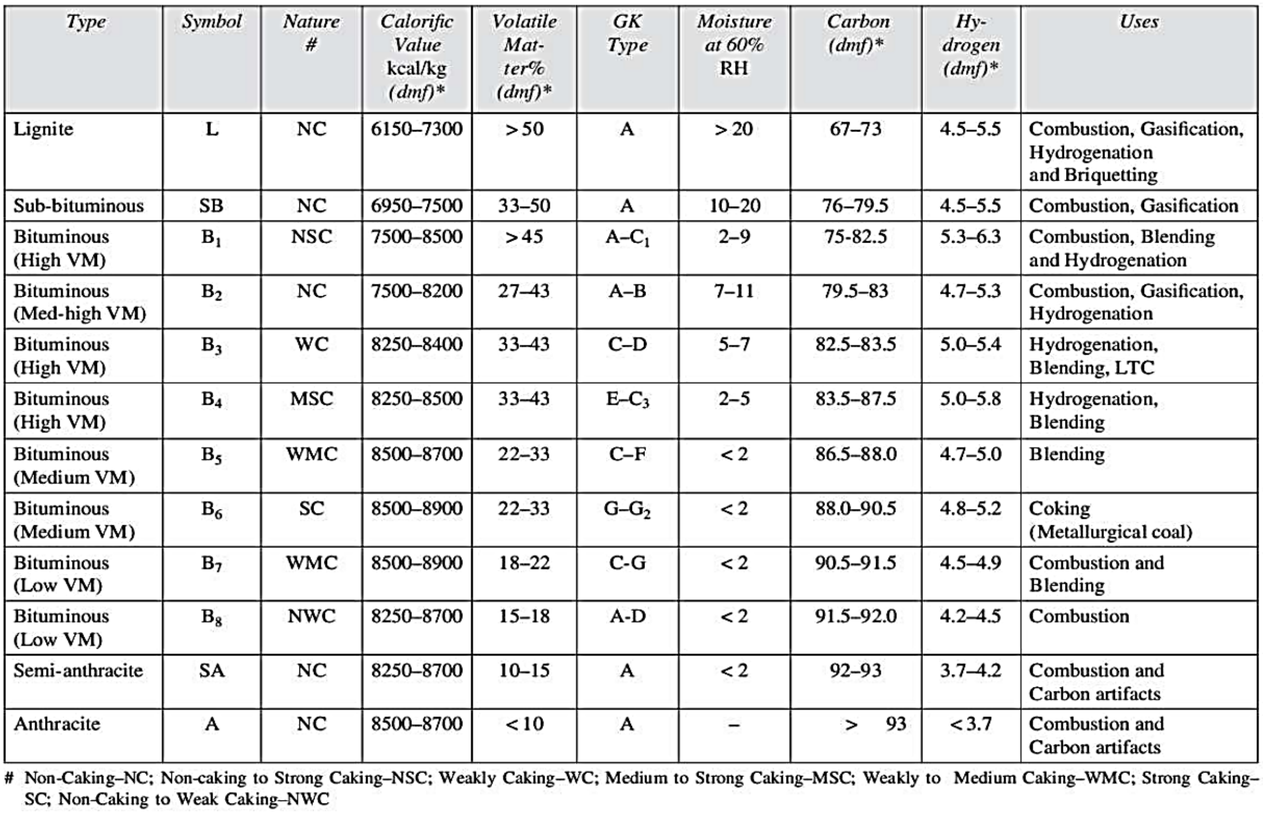
British National Coal Board system

The British National Coal Board attempted to classify Bristish coals in 1950s. Their classification was based on volatile matter content and appearance of solid residue of coal heated to 600°C (Gray King Assay). ASTM (American Society for Testing Materials) system

The ASTM system was developed for American and Canadian coals by E Sherlock in 1949. This system was based on proximate analysis and calorific value of coal containing its natural bed moisture excluding any visible surface moisture. The 'weathering' behaviour of coal was also used as parameter to classify coal based on its nature to breakdown in pieces when exposed to atmosphere for longer period.

Indian Standards Institution system

The Indian coal and lignites were first tentatively classified by Indian Standards Institution (IS-770-1955) in 1955, which was published in 1964 (IS-770-1964) followed by IS-5018-1968. This was further revised in 1977 (IS-770-1977). The Indian classification is based on gross calorific value and volatile matter content on dry mineral matter free basis together with GK Assay.



Type	*Symbol*	*Nature #*	*Calorific Value* kcal/kg *(dmf)**	*Volatile Matter% (dmf)**	*GK Type*	*Moisture at 60%* RH	*Carbon (dmf)**	*Hydrogen (dmf)**	*Uses*
Lignite	L	NC	6150–7300	> 50	A	> 20	67–73	4.5–5.5	Combustion, Gasification, Hydrogenation and Briquetting
Sub-bituminous	SB	NC	6950–7500	33–50	A	10–20	76–79.5	4.5–5.5	Combustion, Gasification
Bituminous (High VM)	B_1	NSC	7500–8500	> 45	A–C_1	2–9	75-82.5	5.3–6.3	Combustion, Blending and Hydrogenation
Bituminous (Med-high VM)	B_2	NC	7500–8200	27–43	A–B	7–11	79.5–83	4.7–5.3	Combustion, Gasification, Hydrogenation
Bituminous (High VM)	B_3	WC	8250–8400	33–43	C–D	5–7	82.5–83.5	5.0–5.4	Hydrogenation, Blending, LTC
Bituminous (High VM)	B_4	MSC	8250–8500	33–43	E–C_3	2–5	83.5–87.5	5.0–5.8	Hydrogenation, Blending
Bituminous (Medium VM)	B_5	WMC	8500–8700	22–33	C–F	< 2	86.5–88.0	4.7–5.0	Blending
Bituminous (Medium VM)	B_6	SC	8500–8900	22–33	G–G_2	< 2	88.0–90.5	4.8–5.2	Coking (Metallurgical coal)
Bituminous (Low VM)	B_7	WMC	8500–8900	18–22	C-G	< 2	90.5–91.5	4.5–4.9	Combustion and Blending
Bituminous (Low VM)	B_8	NWC	8250–8700	15–18	A-D	< 2	91.5–92.0	4.2–4.5	Combustion
Semi-anthracite	SA	NC	8250–8700	10–15	A	< 2	92–93	3.7–4.2	Combustion and Carbon artifacts
Anthracite	A	NC	8500–8700	< 10	A	–	> 93	< 3.7	Combustion and Carbon artifacts

Non-Caking–NC; Non-caking to Strong Caking–NSC; Weakly Caking–WC; Medium to Strong Caking–MSC; Weakly to Medium Caking–WMC; Strong Caking–SC; Non-Caking to Weak Caking–NWC

Module-III

Furnace:

A furnace is an equipment used to melt metals for casting or to heat materials to change their shape (e.g. rolling, forging) or properties (heat treatment).

Since flue gases from the fuel come in direct contact with the materials, the type of fuel chosen is important. For example, some materials will not tolerate sulphur in the fuel. Solid fuels generate particulate matter, which will interfere the materials placed inside the furnace.

For this reason:

- Most furnaces use liquid fuel, gaseous fuel or electricity as energy input.
- Induction and arc furnaces use electricity to melt steel and cast iron.
- Melting furnaces for nonferrous materials use fuel oil.
- Oil-fired furnaces mostly use furnace oil, especially for reheating and heat treatment of materials.
- Light diesel oil (LDO) is used in furnaces where sulphur is undesirable.

Furnace ideally should heat as much of material as possible to a uniform temperature with the least possible fuel and labour. The key to efficient furnace operation lies in complete combustion of fuel with minimum excess air. Furnaces operate with relatively low efficiencies (as low as 7 percent) compared to other combustion equipment such as the boiler (with efficiencies higher than 90 percent. This is caused by the high operating temperatures in the furnace. For example, a furnace heating materials to 1200 degree C will emit exhaust gases at 1200 degree C or more, which results in significant heat losses through the chimney.

Basic Features of Furnace:

The basic purpose of a furnace is to have a chamber or enclosure where required working temperature with suitable atmosphere could be maintained with acceptable thermal efficiency, which would be economical in operation and use. In view of this, a furnace will have following features:

- Furnace name: The furnace has a name to identify its features necessary for performing some processes.

- Furnace purpose: The process performed in the furnace has a purpose which could be physical (heating, melting, etc.), chemical (calcination, roasting, smelting, etc.) or physicochemical (e.g. sintering) in nature.
- Furnace temperature: The furnace should have thermal zone which could be low (< 1000 °C), high (> 1400 °C) or very high (~ 2000 °C).
- Energy source: The furnace uses some energy sources like coal, coke, oil, fuel gas or electricity. (e) Furnace shape: The furnace has a typical shape like rectangular chamber, circular tower (shaft), long chamber (tunnel), rotating drum (rotary kiln), etc.
- Furnace material: The furnace has a structure made of a refractory material or combination of refractory materials which would sustain high temperature working conditions.
- Furnace charging and discharging: The furnace structure is designed in such a manner that it facilitates charging and discharging of the processed material.
- Energy conversion method: The furnace has some means to convert the inherent energy in the fuel into thermal energy like grate combustion, pulverised coal burner, oil or gas burner, electrical current flow through resistance or arc gap.
- Heat transfer mode: The furnace uses some means of heat transfer from source to object like thermal conduction, convection or radiation.
- Air supply mode: The furnace gas flow could be due to natural draft or forced draft.
- Batches or continuous operation: The furnace operation could be in batches or made to function continuously.
- Furnace atmosphere: The furnace atmosphere could be made oxidising, reducing or inert in nature.
- Furnace control: The furnace could be controlled manually or made automated.
- Furnace flue gas treatment: The method of discharging flue or waste gases could be after cleaning or without cleaning.

Types of furnaces and classification:

In metallurgical industries, the furnaces are used for applications like drying, calcinations, roasting, agglomeration, reduction/smelting, refining, melting, metal heating for hot deformation, and metal heat-treatment. In these furnaces, various energy sources are used including solid fuel, liquid fuel, gaseous fuels, electrical energy and inherent chemical energy present as carbon, sulphur, phosphorus, silicon and manganese.

In the following sections, some furnaces are described as illustration for using such different energy sources.

A. Solid Fuel based Furnaces

The solid fuels like coal, coke, petro-coke and charcoal find application in metallurgical furnaces as energy source to meet thermal and chemical energy needs. The furnaces using such solid fuels are illustrated in the following sections:

Coal based furnaces

- **Sponge iron (DRI) rotary kilns**

The rotary kilns have emerged as a very popular furnace for making sponge iron using non-coking coal as reductant and thermal energy source. India is the major user of such furnaces in the world due to availability of resources (rich iron ore and non-coking coal).

- **COREX iron making technology**

This is a new smelting reduction (SR) technology developed in 1980s as an alternative method of iron making based on the use of coal. This SR method has distinct advantage of producing liquid hot iron unlike sponge iron (DRI) technology, which delivers solid iron and needs further melting operation. The SR technologies have been developed to get liquid iron using easily available non- coking coal, instead of scarce metallurgical grade coke. Such iron making units differ in design from conventional blast furnace. In India, this technology is adopted only by JSW Steel at Bellary.

- **Rotary hearth furnace for sponge iron**

This is a sponge iron making furnace based on using coal fines as a reductant mixed with iron ore fines in the form of composite pellets. The main advantage of this furnace is its ability to accept weak dry ore coal mixed pellet on the hearth to cause reduction and strengthening before discharging out in one single hearth rotation. The compact nature of the furnace to produce DRI using plant waste is another advantage, responsible for its promotion by many new emerging DRI processes (Commet, ITmk3, Finmet, CPR, etc.). It is limited by its size and smaller production capacity.

- **Steam raising boilers**

The boilers use coal to raise steam for various applications in metallurgical plants such as power generation, humidification of blast in blast furnace, operation of valves, power source, etc. The steam boilers using coal are available in various capacities ranging from very smaller one using coal on grate to larger boilers using pulverised coal combustion for power generation. The coal must be non-caking in nature for the combustion process.

- **Producer gas unit**

This is a coal based furnace where coal is burnt partially by limited air supply to generate gas rich in carbon monoxide along with some hydrocarbons evolved from coal volatile matter. The non-coking bituminous coals are used in the furnace which is lined with fireclay bricks.

Coke based furnaces

- **Blast furnace**

The blast furnaces are used for the production of pig iron using coke as major fuel and reductant. This is a tall shaft type reactor which is fed with ferrous burden (iron ore/iron ore sinter/iron ore pellet or their combinations), coke and lime stone from the top, and hot air is blown through tuyers in the lower part of the shaft.

- **Cupola**

The cupola is a melting furnace for cast iron. It is the most common melting furnaces used by ferrous foundries. The cupola furnace can be easily obtained or fabricated to melt pig iron and cast iron scrap giving liquid iron (0.5–5 ton/hour) for sand casting. It is common to express cupola size as melting capacity (ton/hour) or its internal diameter (meters) size. A five ton cupola is understood to have a melting capacity of 5 ton per hour during regular melting operation. The cupola is a widely used cast iron melting unit by ferrous foundries due to its ease of construction and low cost of operation with very low maintenance cost.

- **Foundry pit furnace**

This is a coke based melting unit in foundries for small scale (5–10 kg) use. The melting capacity of the furnace depends on the manual handling ability of crucible filled with hot melt. Its simple construction and operation make it a popular furnace (temperature 1100–1400 °C) for melting cast iron, copper and copper alloys like brass and bronze used for making artefacts in cottage industry. The furnace uses 10–15 mm size coke in pit furnace lined with fireclay bricks.

- **Foundry pot furnace**

This is a coke based small scale furnace for melting non-ferrous metals and alloys which melt below 600–700 °C. The metals like aluminium, aluminium base alloys, tin, lead, cadmium and low melting alloys are melted on small scale in cast iron pot heated by burning coke on grate. The melt is poured out by using spoon or pot tilting arrangement.

Petro-coke using furnaces

Petro-coke is a by-product of oil refineries as solid residue left after crude oil refining process. It is virtually free from ash, and has very high carbon content (~ 98%) with very low reactivity. It is used as a reductant for the production of ferroalloys like, ferrosilicon, ferromanganese, ferrochrome, ferrovanadium, etc. using submerged arc furnace.

Charcoal using furnaces

Charcoal is a renewable energy source obtained by carbonisation of wood. It is the best type of solid fuel and reductant having least ash content (< 4 wt. %), high fixed carbon (~ 94 wt. %) and practically very low volatile matter (~ 2 wt. %). Unfortunately, the use of charcoal is not being used due to its non-systematic production, currently rendering it as banned item in many countries. The systematic agroforestry on waste lands (desert, saline, marshy, rocky, etc.) in tropical locations having sun shine more than 300 days/year can yield solid

Carbon (biomass or wood) due to photosynthesis of atmospheric carbon monoxide, moisture and solar radiation (photon) by hard wood plants. This hard wood yields very good charcoal for metallurgical use which has been studied and experimented in Brazil and India. This has a potential for use in future when metallurgical coke will be scare. The biggest limitation with charcoal is its poor crushing strength which limits the size of shaft furnace (iron blast furnace) using it as a fuel.

B. Liquid Fuel based Furnaces

The liquid fuels like furnace oil, diesel and coal tar fuels (CTF) are very commonly used in various furnaces for melting and heating applications. The various melting units (e.g. crucible furnace, skelner furnace, mixer, open hearth furnaces) and heating furnaces (e.g. forging furnace and re-rolling mill furnaces) are described briefly in the following sections:

Melting furnaces

- **Crucible furnace**

Oil fired crucible furnaces are common melting furnaces used by non-ferrous foundries in locations where solid fuel is not usable for reasons like lack of storage space, problem of ash disposal, high cost of transportation, availability and other difficulties for its use. In such oil fired furnaces, the heat transfer from flame to the melt is poor, since crucible acts as heat barrier resulting in very low thermal efficiency. In spite of low thermal efficiency, such furnaces, are very common in jobbing foundries working on small scale to melt non-ferrous alloys like brass, bronze, aluminium alloys, etc. These furnaces are popular with industries located in prime land areas, hilly and cold regions, isolated locations like island towns, etc.

The furnace appears like a pit furnace with difference that it is oil fired using a burner. The size of the furnace depends on the size of crucible, which can be handled manually or by a portable crane. These furnaces provide 1200 to 1300 °C temperature, and fireclay refractory lining serves the purpose.

- **Skelner furnace**

The non-ferrous reveberatory or the Skelner furnaces are highly durable and used for large scale melting by non-ferrous foundries. These are available in manual and hydraulic tilting arrangement for pouring melt out from the furnace. These furnaces have a melting chamber lined with fireclay refractory, and equipped with burners and recuperator. The oil consumption is approximately 80–100 liter/ton of molten metal in continuous operation.

- **Mixer unit for liquid iron storage**

The oil fired 'mixer unit' in integrated steel plants is used to store liquid iron produced in blast furnaces. This unit serves various functions like:

a. It stores liquid iron produced continuously by blast furnaces when the steel converters are not operating.
b. It homogenises the melt composition from various batches of liquid iron tapped to have a better converter blowing schedule.
c. In case of long shut down in steel making unit, it keeps the liquid iron hot using oil burners.
d. It also serves to remove sulphur by suitable lime slag during holding period.

The 'mixer' is a large cylindrical drum-shaped vessel which can be rotated by certain degree for pouring out liquid melt. The pouring in of the hot metal by ladle is done in vertical position having its spout facing the sky. The fall in temperature is checked by heat energy supply by oil burners. The holding capacity of mixers varies from 150 to 1000 ton liquid pig iron. The pig iron is held at 1450 °C, which requires a good refractory lining. The main requirements of the refractory lining are:

a. Resistance to pig iron erosion and corrosion caused by the slag
b. Thermal shock resistance
c. Volume stability
d. Heat capacity (specific heat of the refractory material) to increase heat storage.

Such requirements are met by the use of refractories like silica-alumina, alumina or alumina-silicon carbide-carbon composite bricks.

- **Open hearth furnace or Siemens-Martin furnace**

The oil fired open hearth furnace is an established old furnace design since 1900 AD for steel making, and it is still being retained. Currently, this furnace is mainly used by heavy steel casting units in the world due to its ability to supply quality steel melt in quantities more than 100–500 ton in one batch for making extra heavy castings like chemical reactor chamber. Such large tonnage of steel melts in one batch is not feasible by any other steel making furnace. However, these open hearth furnaces have lost their importance for common grades of steel due to their very slow steel production rate and poor thermal efficiency compared to pneumatic and electric steel making units.

The open hearth furnace has many merits and few limitations. These are discussed in the following section.

Merits

a. It can use cold steel scrap or hot liquid melt from mixers holding blast furnace or cupola melt.
b. It can use oil or gas burners to supply heat during steel making.
c. It can be lined by acid or basic refractory, depending on the slag chemistry involved during steel making.
d. It can be designed to prepare molten steel in quantity ranging 50–500 tons.
e. The quality of steel made is very high in terms of composition and cleanness with temperature control which is needed for large tonnage steel castings.

Limitations

a. It is a very slow process of steel making.
b. It offers very slow heat transfer rate from heat source to metal bath through insulating slag layer floating on the top of the molten steel.
c. It needs high energy input as oil or gaseous fuel.

Heating furnaces:

The oil fired reheating furnaces are common in steel forging and re-rolling units, since they operate independently in locations away from integrated steel works.

The LDO (light diesel oil) is the most easily available furnace oil exploited by such units due to its low sulphur content. Such furnaces operate with efficiencies as low as 7 per cent as against up to 90 per cent achievable in other combustion equipment such as boiler. This is because of the high heat losses at high operating temperature with flue gases. The furnaces of different types are adopted depending on the nature of job to be performed. Some typical furnaces are described in the following sections.

- **Forging furnace**

The oil fired forging furnaces are used for pre-heating billets and ingots to 'hot forge' temperature in the range of 1200–1250 °C. Forging furnaces use an open fireplace system, and most of the heat is transferred by thermal radiation. The typical loading in a forging furnace is ~ 5 ton with the furnace operating for 16 to 18 hours daily. Specific fuel consumption depends upon the type of material and number of 'reheats' required.

- **Batch type re-rolling mill furnace**

The oil fired furnaces are used by steel re-rolling mills. These mills use a box type furnace for reheating steel in batches. The furnaces basically use scrap, small ingots and billets weighing 2 to 20 kg for re-rolling. The charging and discharging of the 'rolling stock' are done manually, and the final product is in the form of rods, strips, etc. These furnaces are normally operated at ~ 1200–1250 °C with pre-heated stock load capacity of about 10–15 tons per day.

Continuous pusher type re-rolling mill furnace

This is similar to batch–type furnace with the difference that pusher type furnace is longer in length and the stock is pushed at one end to discharge out one billet at another end for rolling. In between the fresh billet pushed in the furnace and the hot billet pushed out, there are some billets which are being pre-heated and soaked at working temperature (~ 1250 °C). These furnaces can pre-heat ~ 20–25 ton steel stock. The thermal efficiency of these furnaces is better than batch furnace, because the hot flue gases are partially recirculated through rolling stock before exit.

The merits and limitations of these furnaces are as follows:

Merits

a. Low capital and maintenance costs
b. Heating of top and bottom face of the stock

Limitations

a. Frequent damage of refractory hearth and skid marks on rolling stock
b. Energy losses from water cooling the skids and stock supporting structure
c. Discharging must be synchronised by charging
d. Stock sizes and weights with furnace length are limited by friction
e. The stock pile-ups is common
f. Heating of the rolling stock on all sides is not possible

Walking hearth and walking beam furnaces

The walking Hearth and Walking Beam furnaces are furnaces where the heating stock can be moved forward by mechanical movement. The mechanism of heating is identical in both cases.

In case of walking hearth furnace, a section of refractory lined hearth is used to raise the rolled stock and move it towards the discharge end in walking fashion. The mechanism of moving the product is identical in both cases except the type of mechanical arrangement. These furnaces are suited for reheating alloy steel stock with thinner cross-sections. The design of such furnaces provides better heat distribution in the furnace. The capacity of such furnaces ranges from 30 to 70 ton per hour. The charge size ranges from 0.15 to 0.3 m2 cross-section and 6 to 12 m long billets. These furnaces generally use furnace oil (32 liter per ton steel), but can be operated with CNG, coal gas or LPG.

C. Gaseous Fuel based Furnaces

The gaseous fuels are known for their merits, and hence are used in different types of manufacturing processes. Some applications like coke oven heating, BF stoves, soaking pit furnace, reheating furnaces and heat treatment furnaces are described in the forthcoming sections.

- **Coke oven heating:**

The coke oven utilies its own gas mixed with blast furnace gas to provide thermal energy to coking process. The gaseous fuels are combusted in combustion chamber located between two coke ovens.The coke oven heating generally uses a mixture of coke oven and blast furnace gas for the following reasons:

a. To utilise the fuel gases (coke oven and BF gas) generated in the steel plant
b. The mixing lighter coke oven gas (specific gravity 0.44) with heavy blast furnace gas (specific gravity 1.02) helps in giving better flame propagation.
c. The mixing rich coke oven gas (5100 kcal/m3) and lean blast furnace gas (818 kcal/m3) enhances the gas quality.

The producer gas (1450 kcal/m3) is sometimes used when the coke oven and blast furnace gas are not available.

- **BF stoves**

The blast furnace stoves supply hot blast to blast furnaces. These stoves work on regenerator principle.

- **Soaking pit furnace**

The soaking pits are gas fired large sized deep rectangular furnaces used for reheating steel ingots for hot working. The soaking pit furnace aims to heat large steel ingots having uniform temperature across its cross-section without overheating the surface within minimum period with least material loss due to scale formation.

These furnaces were the part of old integrated steel plants where ingot casting was a common practice. The modern integrated steel plants having continuous billet casting or thin strip casting practice do not require such soaking pit furnaces. However, these soaking pits find use by non-integrated steel units or independent hot rolling mills in steel sector. The steel ingots made by scrap melting in electric furnaces (arc and induction) are used by hot rolling mills which need soaking pits for ingot pre-heating to hot working temperature.

D. Furnaces based on Electricity

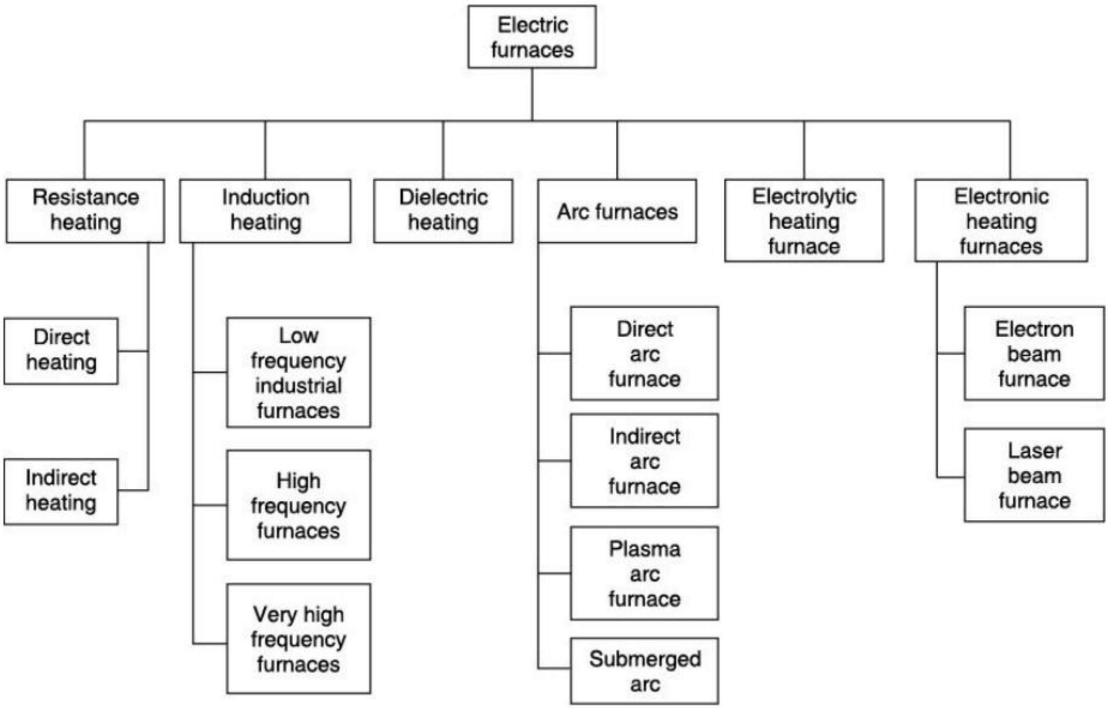
The furnaces using electrical energy are very popular in metallurgical industries for various operations like drying, heating, melting and smelting. The furnaces are associated with several merits and limitations as discussed below:

Merits

a. Clean energy source without any kind of pollution
b. Highly energy efficient
c. Better temperature control and uniform heating
d. Can be used for wide temperature processes up to 2000 °C
e. Concentration of high energy in small volume can result in very high temperature
f. Heating can be combined with other operation like electrolysis or electro- corrosion
g. Selective zone heating is possible by using induction coil for case hardening
h. Furnace can be easily automated
i. Less floor area requirement by the heating system

Limitations

a. Expensive energy source with less availability in many parts of the region
b. Initial high cost of installation including transformer cost, sub-station cost, cable cost, etc.
c. Furnace operation is subjected to power quality in terms of continuity of supply voltage, frequency, etc.
d. Power failure due to variety of reasons can interrupt furnace operation.



Industrial application of furnaces:

- Use in molding
- Use in ceramic industry
- Glass industry
- Annealing purpose
- Debinding purpose
- Use in sintering process
- Use in calcination process
- Use in brazing
- Use in metallizing
- Thermal cycling

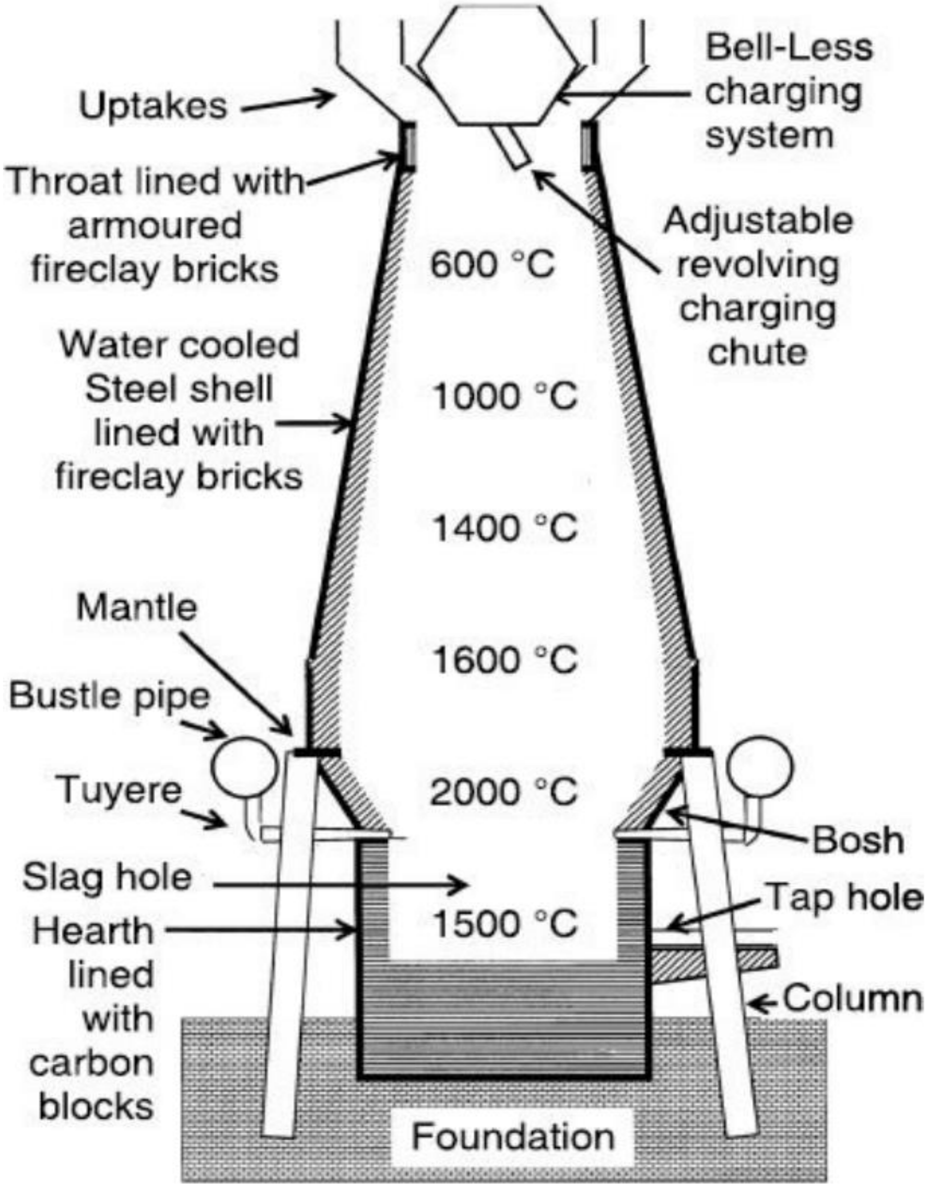
Design and construction aspects of furnaces:

All furnaces have the following components:

- Refractory chamber constructed of insulating materials to retain heat at high operating temperatures.
- Hearth to support or carry the steel, which consists of refractory materials supported by a steel structure, part of which is water-cooled.
- Burners that use liquid or gaseous fuels to raise and maintain the temperature in the chamber.
- Coal or electricity can be used in reheating furnaces.
- Chimney to remove combustion exhaust gases from the chamber
- Charging and discharging doors through which the chamber is loaded and unloaded. Loading and unloading equipment include roller tables, conveyors, charging machines and furnace pushers.

A Blast Furnace:

The blast furnaces are used for the production of pig iron using coke as major fuel and reductant. This is a tall shaft type reactor which is fed with ferrous burden (iron ore/iron ore sinter/iron ore pellet or their combinations), coke and lime stone from the top, and hot air is blown through tuyers in the lower part of the shaft.



Design:

The various components of the blast furnace and its profile are depicted in above figure. The profile of the blast furnace indicates variation in its diameter from top to bottom. Such profile of the blast furnace has been achieved due to operational requirements. The 'throat' at the top is a short cylindrical section where the charging device is fitted. The upper section, known as 'stack', is a tall frustum of cone whose larger diameter is at lower end and matches with 'belly/bosh' diameter. The stack smaller diameter matches with 'throat' diameter.

The increase in diameter size with downward height is indicated by ‘inwall batter’ in mm for every 1 m depth. The angle between sloping ‘stack’ wall and horizontal is known as ‘stack angle’. The section joining ‘stack’ and ‘bosh’ is known as ‘belly’, which is a short height cylindrical section. The lower section ‘bosh’ is again a frustum of cone with down end smaller diameter, matching with ‘hearth’ diameter and upper wider end diameter matches with ‘belly’ diameter. The increasing stack diameter serves to provide easy solid material decent under gravitational force, and also provides extra volume to accommodate the increased volume of expanding burden due to thermal expansion and chemical reactions (iron ore swelling behaviour under reduction). The ‘belly’ is cylindrical in shape as the burden material is mostly reduced, hot and fused mass which can decent down under overburden load. The following ‘bosh’ section is inverted cone with decreasing diameter as in this section the solid reduced ferrous burden and slag gets molten due to high temperature occupying lesser volume.

The blast furnaces are designed to produce hot metal under varied conditions of raw material quality and many other considerations. These varied factors result in blast furnace having working volume ranging from 100 to 5000 m3 and yielding ~ 300 to 10000 ton hot metal per day. The increasing size of the blast furnace increases demand for quality of raw materials including coke quality and the refractory quality, which have not only to sustain high temperature but have to bear high working load along with erosive and corrosive conditions prevailing inside the blast furnace due to counter current movement of solid burden materials and escaping hot reducing gases.

Working:

The ferrous burden with coke and limestone descend down in the blast furnace against upward flow of hot reducing gas. This hot reducing gas, rich in carbon monoxide, is generated at tuyers level by the reaction of hot coke and oxygen in air blown into it. The reducing gas causes reduction of ferrous burden, and the iron oxide is converted into metallic iron which melts to get collected in the hearth. The unreduced oxides in the burden, ash in coke, lime, etc. combine to form slag, which is also collected in the hearth in molten form floating on the top of the liquid bath. The liquid hot metal and slag both are tapped out periodically through respective tap hole and slag notch.

Chimney design:

The chimney is a structure which provides draft for hot flue gases from a boiler, stove, furnace or fireplace to the atmosphere. The chimneys are tall vertical structure to provide exit to flue gas or waste gas from a furnace system.

The operating principle of the chimney depends on the type of method adopted for the draft of gases, i.e., ‘natural draft’ or ‘forced draft’.

- The natural draft chimney works under draft due to buoyancy created by the hot gases in the chimney. The furnace exit gases are hot and have density lower than gas at lower temperature. The hot gases with lower density have upward movement in the chimney which creates a natural draft and cold gas (air) from the atmosphere enters the furnace system due to negative pressure (draft) created by hot rising gases. The rate of flow of gases would depend on the draft (pressure difference) created and area of cross-section of the chimney. The typical example of using such chimney is building red brick kilns which require slow draft for gradual combustion of coal and slow firing rate of clay bricks.
- The forced draft is common with industrial furnace where large volumes of flue gases have to be removed and discharged at higher heights for diffusing the gases in the atmosphere to minimise pollution effect. This requires blower fans of suitable capacity to force the gases in the chimney under pressure greater than atmospheric pressure to cause movement in tall chimneys.

The height of a chimney influences its ability to transfer flue gases to the external environment due to forced draft effect. The dispersion of pollutants at higher altitudes helps in reducing their impact on the immediate surroundings. In the case of chemically aggressive output, a sufficiently tall chimney can allow for partial or complete self-neutralisation of air-borne chemicals before they reach ground level. The dispersion of pollutants over a greater area can reduce their concentrations and facilitate compliance with regulatory limits. The chimney structure is made of steel or steel-cement-concrete depending on the nature of flue gases and structural considerations, keeping seismic factor in view for safety.

Process efficiency:

A furnace’s efficiency increases when the percentage of heat that is transferred to the stock or load inside the furnace increases. The efficiency of the furnace can be calculated in two ways, similar to that of the boiler: direct method and indirect method. Both methods are explained below.

Direct method

The efficiency of a furnace can be determined by measuring the amount heat absorbed by the stock and dividing this by the total amount of fuel consumed.

$$\text{Thermal efficiency of the furnace} = \frac{\text{Heat in the stock}}{\text{Heat in the fuel consumed for heating the stock}}$$

Indirect method

The furnace efficiency can also be determined through the indirect method, similar to the evaluation of boiler efficiency. The principle is simple: the heat losses are substracted from the heat supplied to the furnace.

Typical thermal efficiencies for common industrial furnaces are as follows:

Furnace type	**Typical thermal efficiencies (percent)**
1) **Low Temperature furnaces**	
a. 540 – 980 °C (Batch type)	20-30
b. 540 – 980 °C (Continous type)	15-25
c. Coil Anneal (Bell) radiant type	5-7
d. Strip Anneal Muffle	7-12
2) High temperature furnaces	
a. Pusher, Rotary	7-15
b. Batch forge	5-10
3) Continuous Kiln	
a. Hoffman	25-90
b. Tunnel	20-80
4) Ovens	
a. Indirect fired ovens (20 °C –370 °C)	35-40
b. Direct fired ovens (20 °C –370 °C)	35-40

Module-IV

Refractories:

The refractory is an essential requirement for any furnace to sustain high temperature. These refractory materials must possess sufficiently high fusion temperature to retain their shape at working temperature. Further, such materials must have required porosity, strength at high temperature, thermal conductivity, resistance against corrosion and erosion with many other properties at affordable cost. The production of quality refractory with low cost has always posed challenge to ceramic industries. The larger high temperature metallurgical units (e.g. blast furnaces producing more than 4000 ton hot metal per day) constructed these days for economic reasons, demand very stringent quality of refractory materials.

The refractory materials are required to possess many properties. Refractory materials should have the ability to:

a. withstand high temperature
b. withstand corrosive action of molten slag and hot gasses
c. withstand abrasion and erosion by moving solid charge, flowing liquids and blowing gases
d. withstand working load during service
e. retain dimensional stability at working temperatures
f. sustain repeated thermal cycling
g. sustain thermal shock (sudden change in temperature)
h. conduct/resist heat flow as needed during use
i. store heat in the system

In addition to the above properties, the availability of refractory at suitable cost would be a desirable factor for its use.

Properties and testing methods of Refractories

- **High Temperature Behaviour:**

The refractory materials are required to serve at high temperature, and hence they must have sufficient strength at working temperature to retain their shape and size. This high temperature strength becomes more important when the size of the furnace is large and load on the hot refractory structure becomes high. It must be noted that strength measured at room temperature is not the indication for its fitness to use the refractory at high temperature. As we know that any solid material when heated starts becoming soft at some temperature due to fusion/melting at grain boundaries, and eventually it becomes liquid at its melting point. This requires the knowledge of maximum temperature for safer use of the refractory. This high temperature behaviour of the refractory is tested by measuring the following properties:

a. PCE (Pyrometric Cone Equivalent) value
b. RUL (Refractoriness Under Load) value
c. Creep at high temperature
d. High Temperature Modulus of Rupture (HMOR)
e. Thermal shock resistance

   – Spalling test

   – Loss in MOR strength

f. Reversible thermal expansion
g. PLC (Permanent Linear Change) test

a. PCE (Pyrometric Cone Equivalent) value

It is the measure of refractory's ability to sustain high temperature without fusion or deformation. This is measured by heating a standard size cone made of the material to be tested in a furnace along with another standard cone having refractoriness very close to the test material (determined by a pre-test), and noting the furnace temperature at bending (9' or 3' o'clock positions viewed upside down) of the cone inclined at one end due to its own weight.

b. RUL (Refractoriness Under Load) value

It is the capability of a brick to sustain itself without breaking at high temperature under pressure of overlying load. This working load could be due to burden, liquid metal or its own structural weight. In simple words, RUL is the crushing strength of a brick at elevated temperature. The crushing strength of the refractory brick is lowered at elevated temperature due to fusion/melting of grain boundaries.

c. Creep at high temperature

Creep is a property which indicates deformation of the refractory at high temperature which is subjected to stress for longer period.

d. High Temperature Modulus of Rupture (HMOR)

It is the maximum stress that a rectangular test piece of defined size can withstand when it is bent in a three point bending device. It is expressed as N/mm2 or MPa.

e. Thermal shock resistance

Thermal shock resistance is a measure of refractory property when it is exposed to alternate heating and cooling. This thermal shock leads to breaking of refractory particles which is termed as ‘spalling’ and loss of strength due to micro-cracks and is noted as MOR value after thermal treatment.

f. Thermal expansion

The increase in volume of the material due to heating is called thermal expansion. This expansion process is reversible in nature, and material regains its size on cooling, hence, it is also called reversible thermal expansion . It is the inherent property of all the materials. This property is measured as linear expansion with heating due to practical reasons. Figure 7.8 shows the thermal expansion of some refractory items.

g. PLC (Permanent Linear Change) test

The materials expand on heating, but they regain original shape on cooling (reversible thermal expansion). The permanent linear/volume change refers to non-reversible expansion in the refractory materials due to heating process.

This permanent linear/volume changes could be due to the following reasons:

a. Phase changes in the refractory due to allotropic forms having different specific gravity.
b. Chemical reactions causing formation of new compound having different specific gravity. This could be due to chemical attack by gas or slag in the system leading the formation of different compounds with changed properties.
c. Sintering of the material causing densification and shrinkage.
d. Melting of some phase causing densification and shrinkage.

➢ Corrosion Resistance

It is the wear and tear of refractories caused by static chemical attack of slag. The eating away of refractory material due to chemical reaction between refractory and molten fluid (slag) at high temperature is termed as ‘refractory corrosion’.

➢ Erosion Resistance

The ability of a refractory to sustain the mechanical erosive action of sliding burden, moving products (liquid melt and slag), flowing gases (e.g. hot flue gases laden with solid particles) is termed as ‘erosion resistance’.

- **Thermal Conductivity**

Thermal conductivity is defined as the quantity of heat that will flow through a unit area in a direction normal to the surface area in a given time with a known temperature gradient under steady state thermal conditions. It is indicative of heat flow characteristics of the refractory and depends upon the nature of mineralogical constituents as well as the physical properties of the refractories.

- **Porosity**

Porosity is a measure of the vacant space as pores and voids/cavities in the refractory material. The pores and cavities could be differentiated on their length to diameter ratio. The pores have longer length and their length to diameter ratio is more than the cavity. The pores present in refractory are of three types: open pores, inter-connected pores and sealed pores. These are explained in the following sections:

a. Open pores

These have one of their ends on the outer surface of the particle. This open end allows the movement of fluids (gas/liquid) to the interior location of the particle permitting chemical reaction and adsorption/absorption processes. The liquid metal may penetrate under pressure and get solidified to cause refractory failure. The refractory with large sized open pores are undesirable for places facing liquid metal or slag.

b. Interconnected pores

These have both of their ends opening to the outer surface of the refractory. This allows a free movement of fluids (gas/liquid) and offers site for chemical reactions and adsorption/absorption of fluids. Such pores are useful in manufacturing ceramic filters, but are not desirable in refractory brick used in furnaces which may cause leakage of gases in the furnace.

c. Sealed pores

There are deep seated and do not open up to the surface of the particle. These sealed pores do not offer any site for chemical reaction nor allow adsorption/absorption of fluids. However, these sealed pores act as a good thermal barrier and increase the heat insulating power of the material. Such sealed pores are useful while making heat insulating materials.

- **Density**

The refractory is a porous material, and therefore its density is seriously affected by pore volume. Following three terms are used to differentiate various types of density values:

True density

This refers to the ratio of mass to volume of solid particle without any pores or cavities.

Apparent density

It refers to the ratio of mass to volume of a single solid particle including closed pores (i.e., volume of solid material + volume of closed pores within the particle).

Bulk density

It refers to the ratio of bulk mass to total bulk volume (solid volume + pore volume + void volume) of the refractory brick.

- **Cold Crushing Strength (CCS)**

The cold crushing strength (CCS) represents the ability of a refractory to resist failure under compressive load at room temperature. The compressive load is applied on the refractory block till its fracture. The CCS is then calculated as total load applied divided by the surface area.

Types of Refractories:

Classification of Refractory based on Chemical Nature

The furnaces use several types of refractory bricks made from refractory materials. The refractory materials are generally classified on the basis of their chemical behaviour, i.e., their reaction to the type of slag. Accordingly, refractories can be classified as: acid, basic and neutral.

Acid refractories

Acid refractories are those which are attacked by basic slag. These are not affected by acid slag, and hence it can be used in furnaces having acidic work environment. The following types of refractories fall in this group:

(a) Silica (most acidic)

(b) Semi silica

(c) Alumino-silicate refractories (e.g. high alumina (as exception since it reacts with slag), Fireclay group refractory (e.g. LHD-Low Heat Duty, HHD-High Heat Duty, SD-Super Duty and Grog), Kyanite, Sillimanite and Andalusite.

Basic refractories

Basic refractories are those which are attacked by acid slag. These refractories are of considerable importance for furnace linings where the environment is basic, for example, basic steel making and furnaces for non-ferrous metallurgical operations. The following refractories fall in this category:

(a) Magnesite

(b) Magnesite-Chrome

(c) Chrome-Magnesite

(d) Dolomite

(e) Forsterite

Neutral refractories

These refractories are attacked neither by acid nor by basic slag. The following refractories are known for their inertness:

(a) Graphite (most inert)

(b) Chromites

(c) Synthetic refractories (e.g. zirconium carbide and silicon carbide)

➢ Classification of Refractory based on Other Considerations

The refractory materials find high temperature applications in many forms and shape. These refractory materials could be classified as: Special refractories, Insulating refractories and Cermets.

Special refractories

These refractory materials are specially manufactured using synthetic (fused/sintered) grains free from impurities under highly controlled production parameters for special applications. They are used for purposes like fabrication of crucible, some parts of furnaces and research and developments. These applications of the refractory do not consider cost as a factor for selection. The refractories included in this group are:

(a) Alumina,

(b) Pure sialons (Si-Al-O-N),

(c) Thoria (ThO_2),

(d) Beryllia (BeO),

(e) Zirconia,

(f) Boron nitride,

(g) Spinel, etc.

Insulating refractories

These are high porosity refractories having low thermal conductivity used for reducing the rate of heat flow (heat losses) to maximize heat conservation within the furnace. The development and application of a wide variety of insulating refractory materials are gaining importance with increasing energy costs in present days. The production of brick shape refractories utilises China clay, asbestos (kieselguhr), glass wool, mica (vermiculite), bubble alumina, carbon, paper wool, ceramic fibers, saw dust, etc. as raw materials.

Cermets

The refractories produced from the mixtures of high purity refractory oxides, carbides, borides, and metals or alloys fall under this category. Depending on the composition and quality, they are used as abrasives (cutting, grinding, boring tools), in parts of spacecrafts, missiles, atomic power plants, etc.

RAW MATERIALS FOR REFRACTORY MANUFACTURE

The refractory preparation exploits natural resources together with synthetic materials. These refractory raw materials can be broadly divided into two categories: clay based and non-clay based.

Clay based Refractory Raw Materials

The naturally occurring clays having high percentage of refractory constituents find use in refractory industry. These include fireclay and high alumina clays.

Fireclay

It is generally defined as a “mineral aggregate composed of hydrous silicates of aluminium ($Al_2O_3 . 2SiO_2 . 2H_2O$) with or without free silica”. It is also known as kaolinite. It is generally found as white in colour, but sometimes red, blue or brown tints come from impurities.

High alumina clay

It is composed of bauxite riched or other raw materials that contain 50 to 87.5% alumina. High alumina refractories are generally multipurpose, offering resistance to chipping and higher volume stability. High alumina refractories are used to produce brick and insulating refractories.

Non-clay based Refractory Raw Materials

These refractory materials are prepared from naturally occurring minerals and synthetically processed materials.

Magnesite

It is a mineral with the chemical formula $MgCO_3$ (magnesium carbonate). It is found as colourless, white, pale yellow, pale brown, faintly pink, lilac-rose mineral having conchoidal fracture, possessing hardenss of 3.5–4.5 on mohs scale.

Extra-high alumina

It is prepared predominately from bauxite or alumina ($Al_2 O_3$). The extra-high alumina refractories contain 87.5% to 100% alumina and offer good volume stability. They are typically poured into special shapes using a fused casting process.

Mullite

Mullite ($Al_6 Si_2 O_{13}$) is made from kyanite, sillimanite, and alusite, bauxite or mixtures of alumina silicate materials. The mullite refractories contain ~ 70% alumina. It possesses specific gravity of 3.11–3.26 and hardness 6–7 on Mohs scale. They maintain a low level of impurities and high resistance to loading in high temperatures.

Silica

The quartz mainly containing silica is used for this purpose. The silica refractories are characterised by a high coefficient of thermal expansion between room temperature and 500 °C. Silica bricks are prepared in three grades: super-duty (low alumina and alkali), regular, and coke oven quality. Silica compositions can be used for hot patching, shrouds, and bricks.

REFRACTORY MANUFACTURING PROCESS:

Refractory manufacturing process basically consists of four steps:

(i) Raw material processing

This step involves crushing and grinding of raw materials obtained from various sources followed by their classification according to particle size by screening and sieving. These raw materials also sometimes need washing, calcinations and drying operations to meet the chemical specifications. The dry refractory powder of one size is mixed with other size to meet specific grain size distribution along with other chemical constituents desired for specific need. The dry refractory powder is packed and marketed as such for various applications. This dry refractory powder mass with specific size mix serves as feed for making refractory bricks and other components.

(ii) Shaping

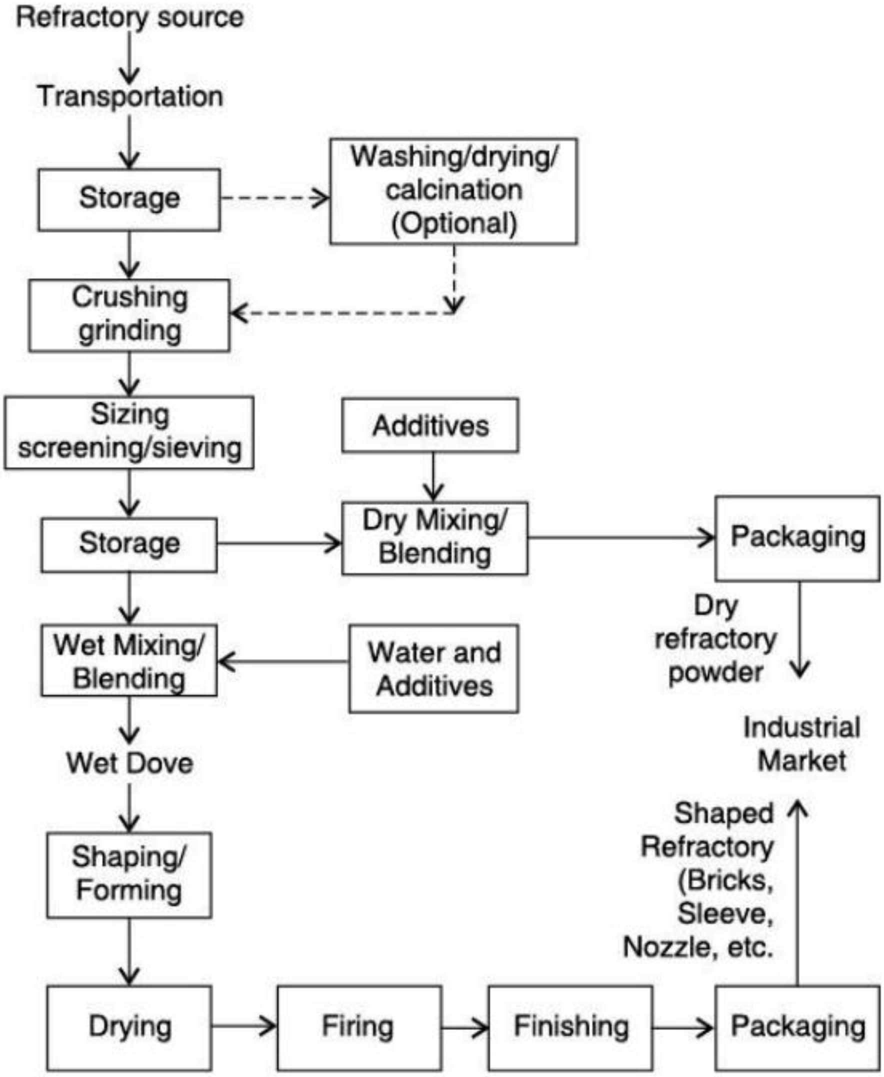
The dry powder is mixed with water and other additives to prepare wet dove for giving shape to the refractory using different types of machines and technique. The shaped refractory is air dried before firing.

(iii) Firing

The shaped refractory is subjected to firing to cause heat hardening by ceramic bonds and bring desired phase changes to have a stabilised refractory. This firing is done in kilns having high temperature caused by combustion of fuels mostly gaseous in nature for better quality product.

(iv) Final processing

The final processing step includes milling, grinding, and sand blasting of the final product to give finished and desired surface quality. The certain products may also need impregnation with tar/pitch or armouring by some other material like steel sheet. Finally the products are packaged for safe transportation.



Monolith:

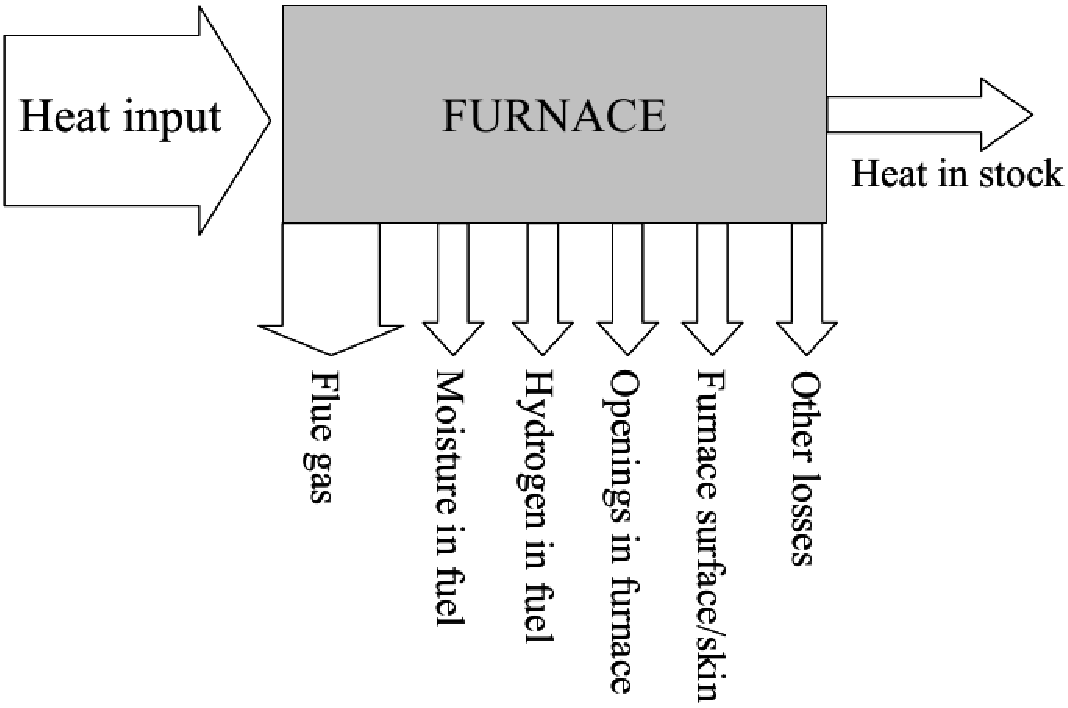
Monolithic refractories are single piece casts in the shape of equipment, such as a ladle. They are rapidly replacing the conventional type fired refractories in many applications including industrial furnaces. The main advantages of monolithics are:

- Elimination of joints which is an inherent weakness
- Faster application method
- Special skill for installation not required
- Ease of transportation and handling
- Better scope to reduce downtime for repairs
- Considerable scope to reduce inventory and eliminate special shapes
- Heat savings ƒ Better spalling resistance
- Greater volume stability

Monolithics are put into place using various methods, such as ramming, casting, gunniting, spraying, and sand slinging. Ramming requires proper tools and is mostly used in cold applications where proper consolidation of the material is important. Ramming is also used for air setting and heat setting materials. Because calcium aluminate cement is the binder, it will have to be stored properly to prevent moisture absorption. Its strength starts deteriorating after 6 to 12 months.

Energy conservation in furnaces:

Ideally, all heat added to the furnaces should be used to heat the load or stock. In practice, however, a lot of heat is lost in several ways.



These furnace heat losses include:

- Flue gas losses: part of the heat remains in the combustion gases inside the furnace. This loss is also called waste-gas loss or stack loss.
- Loss from moisture in fuel: fuel usually contains some moisture and some of the heat is used to evaporate the moisture inside the furnace
- Loss due to hydrogen in fuel which results in the formation of water
- Loss through openings in the furnace: radiation loss occurs when there are openings in the furnace enclosure and these losses can be significant, especially for furnaces operating at temperatures above 540°C. A second loss is through air infiltration because the draft of furnace stacks/chimneys cause a negative pressure inside the furnace, drawing in air through leaks or cracks or when ever the furnace doors are opened.
- Furnace skin / surface losses, also called wall losses: while temperatures inside the furnace are high, heat is conducted through the roof, floor and walls and emitted to the ambient air once it reaches the furnace skin or surface.
- Other losses: there are several other ways in which heat is lost from a furnace, although quantifying these is often difficult. Some of these include

− Stored heat losses: when the furnace is started the furnace structure and insulation is also heated, and this heat only leaves the structure again when the furnace shuts down. Therefore this type of heat loss increases with the number of times the furnace is turned on and off

− Material handling losses: the equipment used to move the stock through the furnace, such as conveyor belts, walking beams, bogies etc, also absorb heat. Every time equipment leave the furnace they loose their heat, therefore heat loss increases with the amount of equipment and the frequency by which they enter and leave the furnace

−Cooling media losses: water and air are used to cool down equipment, rolls, bearing and rolls, but heat is lost because these media absorb heat

-Incomplete combustion losses: heat is lost if combustion is incomplete because unburnt fuel or particles have absorbed heat but this heat has not been put to use

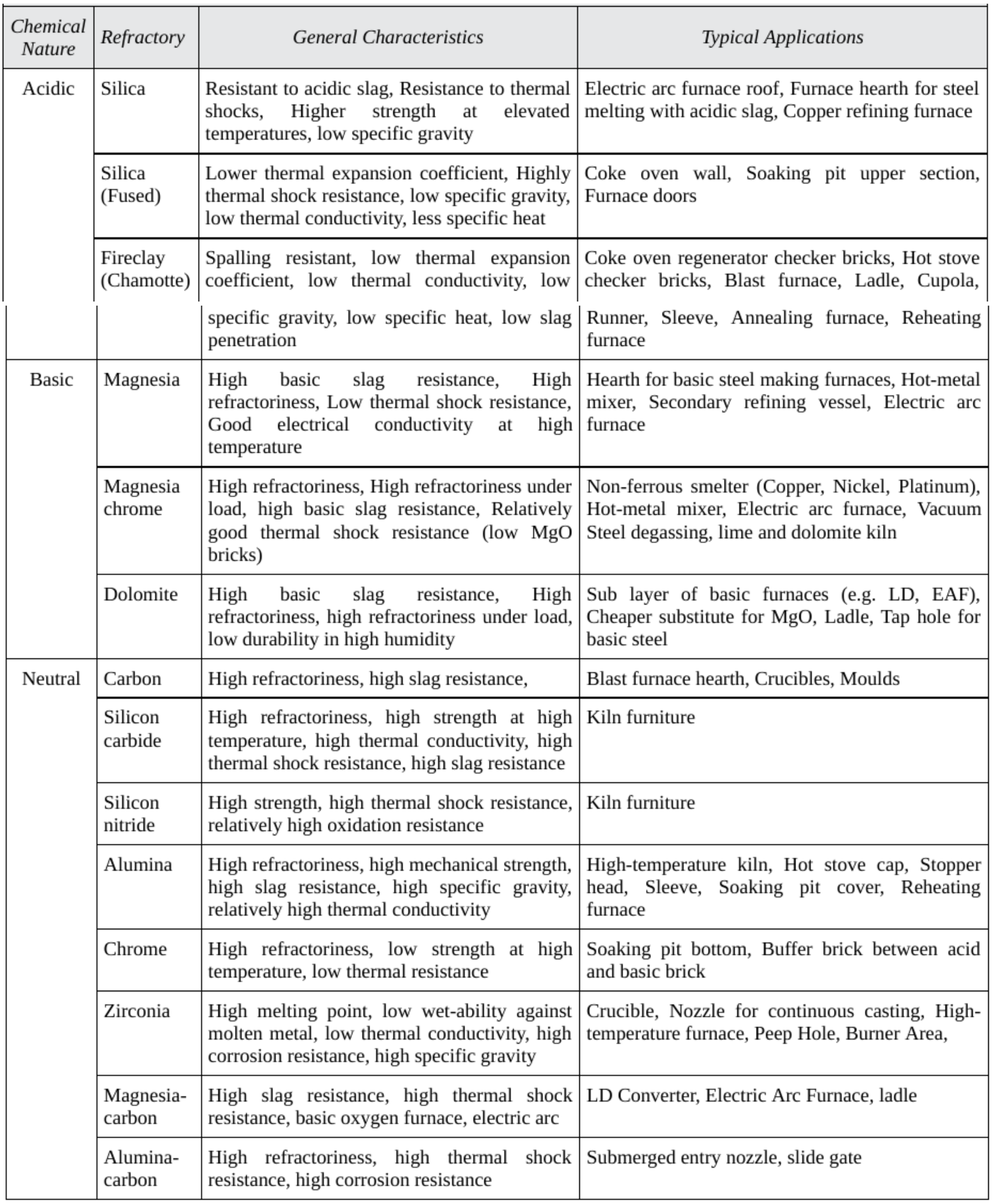
-Loss due to formation of scales

ROLE OF REFRACTORY:

a. A good refractory reduces the heat loss from the furnace
b. Reduce the energy requirement

c. A good refractory can sustain repeated thermal cycling and hence help less fuel consumption.
d. By sustaining sudden change in temperature reduces need of controlling the temperature more times
e. Can store heat in the system

Uses of Refractory:



Chemical Nature	*Refractory*	*General Characteristics*	*Typical Applications*
Acidic	Silica	Resistant to acidic slag, Resistance to thermal shocks, Higher strength at elevated temperatures, low specific gravity	Electric arc furnace roof, Furnace hearth for steel melting with acidic slag, Copper refining furnace
	Silica (Fused)	Lower thermal expansion coefficient, Highly thermal shock resistance, low specific gravity, low thermal conductivity, less specific heat	Coke oven wall, Soaking pit upper section, Furnace doors
	Fireclay (Chamotte)	Spalling resistant, low thermal expansion coefficient, low thermal conductivity, low specific gravity, low specific heat, low slag penetration	Coke oven regenerator checker bricks, Hot stove checker bricks, Blast furnace, Ladle, Cupola, Runner, Sleeve, Annealing furnace, Reheating furnace
Basic	Magnesia	High basic slag resistance, High refractoriness, Low thermal shock resistance, Good electrical conductivity at high temperature	Hearth for basic steel making furnaces, Hot-metal mixer, Secondary refining vessel, Electric arc furnace
	Magnesia chrome	High refractoriness, High refractoriness under load, high basic slag resistance, Relatively good thermal shock resistance (low MgO bricks)	Non-ferrous smelter (Copper, Nickel, Platinum), Hot-metal mixer, Electric arc furnace, Vacuum Steel degassing, lime and dolomite kiln
	Dolomite	High basic slag resistance, High refractoriness, high refractoriness under load, low durability in high humidity	Sub layer of basic furnaces (e.g. LD, EAF), Cheaper substitute for MgO, Ladle, Tap hole for basic steel
Neutral	Carbon	High refractoriness, high slag resistance,	Blast furnace hearth, Crucibles, Moulds
	Silicon carbide	High refractoriness, high strength at high temperature, high thermal conductivity, high thermal shock resistance, high slag resistance	Kiln furniture
	Silicon nitride	High strength, high thermal shock resistance, relatively high oxidation resistance	Kiln furniture
	Alumina	High refractoriness, high mechanical strength, high slag resistance, high specific gravity, relatively high thermal conductivity	High-temperature kiln, Hot stove cap, Stopper head, Sleeve, Soaking pit cover, Reheating furnace
	Chrome	High refractoriness, low strength at high temperature, low thermal resistance	Soaking pit bottom, Buffer brick between acid and basic brick
	Zirconia	High melting point, low wet-ability against molten metal, low thermal conductivity, high corrosion resistance, high specific gravity	Crucible, Nozzle for continuous casting, High-temperature furnace, Peep Hole, Burner Area,
	Magnesia-carbon	High slag resistance, high thermal shock resistance, basic oxygen furnace, electric arc	LD Converter, Electric Arc Furnace, ladle
	Alumina-carbon	High refractoriness, high thermal shock resistance, high corrosion resistance	Submerged entry nozzle, slide gate

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