LECTURE NOTES
ON
FUELS & REFACTORIES

Compiled by:

RUEIGVED MAHANAND

METALLURGICAL ENGINEERING

GOVT. POLYTECHNIC SONEPUR

FUEL

A fuel may be defined as which produce heat is called fuel. The heat may be produce either by combustion or nuclear fission and fusion.

STATE OF FUEL

1) solid fuel -> coal, wood, coke
2) Liquid fuel -> Petroleum.
3) Gaseous fuel -> CNG, LPG

CLASSIFICATION OF FUEL

1) fossil fuel
2) chemical fuel
3) By product
4) Nuclear fuel

1) Fossil fuel

The fossil fuel may be defined as are those which have being divided from fossil remain of plants and animals are found in crust of earth is called as fossil fuel

Example:- coal, petroleum, Natural gas

2) chemical fuel

The chemical fuel may be defined as exotic nature normally not use conventional process is called as chemical fuel

Example:- Ammonia, flourine.

By product

By product may be defined as sum of regular manufacture to produce co-product is called as by product.

$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO_{1-x} \rightarrow FeO \rightarrow Fe$.

Nuclear fuel

The nuclear fuel may be defined as which release heat by fission and fusion process.

Characteristics of fuel

i) it should be readly available is cheap
ii) it should be easy and safe to handle store and transport and at low cost
iii) It is storing and tranport cost is low.
iv) It should be produced high heating calorific value
v) It should be moisture content is low
vi) It should process moderate the rate of combustion should be high.
vii) It should have moderate ignition temprature.

Ranking of coal

In ranking of coal there are different stages.

Peat → lignite → Bituminous → Anthracite.

Peat

characteristics of peat

- It is the first stage of product in the formation of coal from wood under the action of heat & pressure.
- It is basically used in domestic fuel for power generation.
- It is used for fuel under fertilizer.

Lignite

- It is the second stage of coal product
- It's carbon content is 70-75%.
- It has low calorific value.
- It is used in gas production & metallurgical furnance.

Bituminous

- It is the third stage of coal product
- It's carbon content is 75-90%.
- It is black in colour
- Bituminous coal is basically used in themal planlation and domestic use.
- It is harder and dense medium.

Anthracite

- It is the fourth stage of coal product
- It's carbon content is 85-90%.
- This is most mature coal on the higest rank of coal.

- It is basically used in metallurgical furnance.

Flash point

A flash point may be defined as a temprature at which vapour of fuel will ignite in form of flash when it come contact with fire is called as flash point.

Fire Point

Fire point is a temprature at which vapour of fuel will ignite for long time where it come contact with fire is called as fire point

carbonization of coal

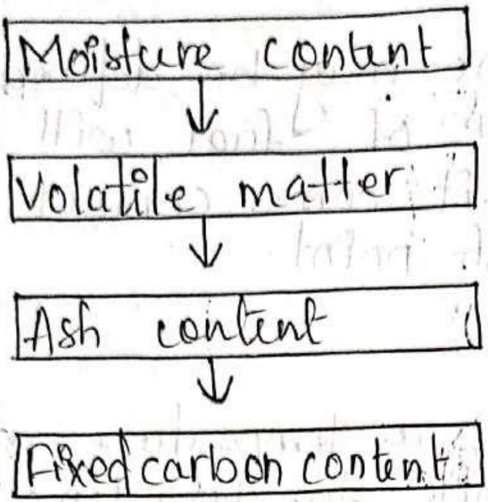
The carbonization of coal healing of coal in the absence of ~~at~~ air at high temprature to produce coke is called as carbonization of coal.

Proximate analysis

Proximate analysis may be defined as to be measurement ranking/testing of coal is called proximate analysis.

The proximate analysis depends upon coal factors like:
i) Moisture content
ii) Volatile matter
iii) Ash content
iv) Fixed carbon.

Flow chart



<u>Moisture content</u>

$$\frac{\text{loss of carbon content}}{\text{Original carbon content}} \times 100$$

<u>Volatile matter</u>

used in muffed furnance at 920 ± 20°c for 7 minutes.

<u>Ash content</u>

Again taken in muffle furnance at 700 ± 50°c for 1 hour

<u>Fixed carbon</u>

100 - (% Moisture + % volatile matter + Ash content)

Melting point of copper - 1084°c
Iron melting point - 1539°c
Aluminium melting point - 660°c
Tin melting point - 232°c

Moisture content

- It has generally higher moisture content in coal under desirable because it is reduce the calorific value of fuel.
- It is increase consumption of coal for fitting purpose.

Volatile matter

- The coal with higher volatile matter content.
- It has low calorific values.
- It is used only more quantity of coke when it is absence of air.

Ash content

- Ash is a combustion product mineral matter present in coal
- It is harder and stronger
- It is lower calorific value.
- It is mainly Alumina, silicate, ferric oxide.

Fixed carbon content

It is the pure carbon present in coal higher the fixed carbon of coal with higher calorific value.

ULTIMATE ANALYSIS OF COAL

Ultimate analysis of coal is determined by of that carbon as H, N_2, O_2 and s percentage of coal to be measure is called as ultimate analysis of coal.

Calorific value.

Amount of the heat reject by the complete combustion of 1kg of fuel is called as calorific value of coal.

Petrol - 45.8 mj
Deisel - 45.3 mj

TYPE OF CALORIFIC VALUE

(i) Highrer calorific value / Gross calorific value
(ii) Lower calorific value / Net calorific value.

i) GROSS CALORIFIC VALUE

The amount of heat liberated the unit mass by volume at fuel burn completely and product of combustion have been cooled at room temprature.

ii) NET CALORIFIC VALUE

The amount of heat liberated unit mass by volume of fuel burn completely and product of combustion and of allow escape.

CARBONISATION

- The heat of coal in absence of air to produce the coke is called as carbonisation.
- It is mainly purposed by is to produce the coke whereas the coke product is called coke oven gas. for various liquid product coal

tar, Naphthalene etc.

TYPES OF CARBONISATION

There are mainly two types of carbonisation depending upon temproature up to the coal heated absence of air.

(i) Lower temprature carbonisation
(ii) Higher temprature carbonisation.

(i) Lower temprature carbonisation

- It is carried out at high ~~teer~~ temprature 700°c
- It is produced semicoal which is used as smokeless domestic fuel it can some time used in boiler also avoid smoke.
- The yeeld of coke oven gas is less in Lower temprature carbonisation coal is about 150-160 Nm/gas /tonne of dry coal.
- yield after the coal tar is high to low temprature carbonisation is about 10% of dry coal.
- The calorific value as Lower temprature carbonisation range is 6000-6500 Kcal/Nm³.

Higher temprature carbonisation.

- It is carried out at high temproture 1100°c
- It is produced metallurgical coal used in blast furnance cupoals for foundary purpose.
- The coal tar is lesser here it is about 3% of dry coal charge.
- The calorific value range is about 4200-4400 Kcal/Nm³
- yield of coke oven gas is HTC (higher Temprature carbonisation due to more cracking hydrocarbons. The yield about 230-300 Nm³.

Physical chemical properties of metallurgical coake

Depending upon properties there are various factors of metallurgical coal.

(i) Ash and moisture content of coke
(ii) Density and porosity
(iii) Hardness strength
(iv) Shatter index
(v) Micum index of coke
(vi) Abrasion index of coke
(vii) Reactivity of coke
(viii) coke reactivity index
(ix) coke after strength of reaction

(i) Ash and moisture content of coke
- The lower moisture and ash content are desirable in the metallurgical coke
- The metallurgical coke should contain greater 15% of moisture
- Maximum desirable ash contain in metallurgical coke as 8-10%
- High as coke and high resistance absorbation high strength.
- Each additional 1% of ash in blast furnance coke increase by the fuel consumption 2%.

(ii) Density and porosity
- The more completed the coal the volatile of more the closely density of coke approach that of graphite
- The coke content as hydrogen matter of coal
- It is absolute density never reaction on graphite
- The porosity contain high temprature coke varies from 40-50%.
- The blast furnance that contain on high strength consider.

Hardness and strength

- It is defined as the resistance power of material to breakage by impact strength.
- Hardness, strength of coke are measured by micum index

Shatter index

- It is measured the resistance of coke to breakage by impact and strength
- The desirable value of shatter index of coke is 80%
- The hinged box of based of the box. release sudden through the

Micum index

- This is measured of both ~~hardn~~ hardness and strength of coke
- The percentage of coke retained of M40 index
- High M10 contain the value of desirable on metallurgical coke.
- The percentage of coke that posesses through 10mm screening to be found M10 index.

Abrasion index of coke

- It is measure by hardness of coke
- Abrasion index is increase by 1% of for increase 0.2% of to be increase by shatter index
- A high abrasion index means a high resistance of abrasion.

· Reactivity of coke

- The ability of coke react with oxygen water, etc.
- The coke of high reactivity ignite is easy.
- The strongly coking high rank of coal produce by coke produce by low reactivity coke.

Coke reactivity Index

- It is more losses of weight of the coke reactivity is more.
- Ideal about CRI value of wood the blast furnance is about should be 20%
- The loss percentage of weight the coke prepare by of coke reactivity index.

Coke strength after reaction

- The let out of the coke from the CRI determination reactant for 10-relation of micum index
- CSR of the index the indian blast furnance about 60-65%

Ingrediant of specification coke contain in metallorgical coke.

1) Ash content - 20-30%
2) Abrasion index - 77-82%
3) Porosity - 35-45%
4) ~~por~~ CRI - 20%
5) Density - 1750 - 2000 kg/m^3
6) ~~CRI~~ CSR - 65%
7) volatile matter content - 2%

Hardness may be defined as to be depth of penetration is called as Hardness test.

There are different types of hardness test

i) vicker

ii) Rockwell, mass.

There are different type of scale

A scale - 60kg

B scale - 100 kg

C scale - 150 kg

Properties of liquid fuel

Density
viscosity
flash point
pour point
calorific value
specific value
sulphur content
water content
Ash content
carbon content

Liquid fuel

Liquid fuel are those energy generating molecules that can be harnessed to create mechanical energy usually producing kenetic energy.

- They must take the shape of their container.

$$PE = Mgh$$

$$KE = \frac{1}{2} MV^2$$

Density

- Density may be defined as the ratio between mass and volume.
- It is useful for determining the fuel quantity and quality
- The ratio of the fuel mass to be volume at 15°c

Viscosity

It is measure of fuel internal resistance of flow.

It is mostly used in storage capacity used.

It decrease temprature and increase temprature

Flash point

A flash point may be defined as the temprature at which vapour. of fuel will ignite ~~for~~ in form of flash when it come contact with fire is called as flash point.

Pour point

- The lowest temprature at which fuel will flow
- It is used for indication fuel temprature.

Calorific value

Amount of the reject by the complete combustion of 1kg of fuel is called as calorific value of coal.

Specific value

It is defined as the ratio of weight of volume to weigh of same water volume at a given temp.

- It is used to measure Hydrometer.
- The specific gravity of water is 1.

Sulphur content

- The sulphur content depend on source of crude oil and less on refinning process.
- The furnance oil the sulphur content (2-4%)
- The sulphur acid caused by corossion.

Water content

Normally in f/c oil supplied greater than 1% of refined oil

- It can damage the f/c surface and impact fail.

Ash content

- Ash is a combustion product mineral matter present in coal.
- It is harder and stronger
- It has low calorific value
- It is mainly Alumina, silica, ferric oxide.

Carbon residue.

- The tendency of oil to diposited carboneous the solid residue on a hot surface.
- The residue of oil is greater than 1%

COAL TAR

coal tar is a black to brown oily & viscous fuel of fuel of characteristics produce during low-high temprature carbonisation of coal during coke manufacturing is called as coal tar.

Difference between low temprature coal tar and High temprature coal tar.

LTCT	HTCT
(i) It is produce during low carbonisation of coal at 700°c and is also called primary coal tar	(i) It is produce during high temprature carbonisation of coal at 1100°c and is called as secondary coal tar.
(ii) It is specific gravity at 1.02 - 1.06	(ii) The specific gravity is higher 1.10 - 1.15
(iii) It is viscocity is better than fluidity	(iii) It is viscocity of comparatively higher hence it has poor fluidity.
(iv) It is mostly paraffini in ~~matter~~ nature it is little aromatics	(iv) It is mostly aromatic in nature
(v) It contain very little amount of Naphthalene	(v) It contain higher amount of Naphthalene
(vi) It has higher content of tar acidic about 35%	(vi) It has very low percentage of acidic 3%
(vii) Pitch yeild of lower than 35%	(vii) Pitch yield higher 65%

USES OF COAL TAR

(i) It is mainly used in road construction.
(ii) It is used in medical purpose
(iii) It is used in synthetic fibre
(iv) It is used as furnance fuel
(v) It is used for corossion protection
(vi) In presence of solid impurities such as coke dust which may be used as the burner of pipe lines.

COAL TAR FUEL

The coal tar fuel at the liquid fuel obtained by mixing the different different coal tar to produced coal tar fuel.

There are six type of coal tar fuel.

i) CTF-50
ii) CTF-100
iii) CTF-200
iv) CTF-250
v) CTF-300
vi) CTF-400

USES OF COAL TAR FUEL

- It is basically used in metallurgical furnance
- It is produced by Power generation
- It is basically used in DRI process.

Specific gravity

- The specific gravity is dimensionless quantity that is defined as the ratio of density of substance to density of water of a specific temprature and pressure.
- It is mathematically expression as

$$\frac{\text{density of substance}}{\text{density of water}}$$

Cloud point

When an oil is cooled of a specific rate of temprature at which it become cloudy or hazy is called as cloud point.

Difference between cloud point and pour point.

Cloud point	Pour point
i) The temprature in which wax in fuel tends to cloudy	i) The lowest temprature at which the fuel continous to blow at lowest temp. below which fuel loses it flow characteristics.
ii) The comparative value of oil is high	ii) Comparatively a low value.
iii) Comes to beginning solidification oblained faster upon chilling	iii) It is oblain low chilling.

OCTANE NUMBER

- It is the measure performance of fuel
- Octane number is given for gasoline
- Important for the knocking of engine
- Octane rating is done considering the octane number iso-octane number is 100.

CETANE NUMBER

- It is measure of delay of the ignition of fuel.
- Cetane number is given for disel
- Important for the ignition of an engine
- The cetane ~~is~~ rating is done considering the ignition of cetane.

ANILINE POINT

- Aniline point is the minimum equilibrium solution temperature for equal volume of aniline & oil sample.
- It is aeromatic hydrocarbons have a tendency to dissolve natural rubber and certain type of synthetic rubber.
- It is determined by mixing mechanical equal volume of aniline of oil sample.

REFRACTORIES

Refractory are material which withstand to high temprature are doesn't feels. even at very high temprature.

TYPES OF REFRACTORIES

i> Acid refractory
ii> Basic refractory
iii> Neutral refractory

~~Depending upon three.~~
Refractory depend upon three factors.

a) physical-
b) chemical-
c) thermal-

CHARACTERISTICS OF REFRACTORY

- Resistance against corossion should be high temprature
- availability to withstand high load
- should not undergo deformation
- uniform expansion and contraction.

Depending upon the temprature range there are 3 factors

i> Low temprature
ii> high temprature
iii> super saturated temprature

Low temprature - 1580°C - 1780°C
High temprature - 1780°C - 2000°C
Super saturated temprature - above 2000°C

∴ Basic are brown in colour because Iron oxide is present

SiO_2 -> grey

NEUTRAL REFRACTORIES

- Neutral ~~resource~~ refractory are inorganic non-metallic material that are derived from natural ores and are capable to withstand high temprature and moderated load.

  Eg - chromite, carbon, graphite.

- They can used in ~~[illegible]~~ construction with acid or basic product.
- Those refractories which attack by acid slag & basic refractories are included

BASIC REFRACTORIES

- Basic refractories consist of basic oxide without free SiO_2
- Shouldn't come in contact with acidic product.
- Eg - Bauxite, Limestone, Al_2O_3, Dolomite.

ACIDIC REFRACTORIES

- Those refractories are attack by basic slag are called Acidic refractories.
- It should be allow to come in contact with Basic product to avoid the refractories.
- Eg - SiO_2,

HESS LAW

Hesses law state that if a process can be express as the sum of two ore more steps enthalphy change for overall process the sum of each ~~ea~~ enthalphy value of every steps.

$H = U + PV$

where H = enthalphy

U = internal energy

P = pressure

V = volume

S = entropy

$\boxed{\text{unit} = \text{Joule}}$

FIRST LAW OF THERMODYNAMICS

It state that the energy cannot be created nor destroyed

$$\boxed{d_E = S_q - S_w}$$

d_E - internal energy

S_q - heat

S_w - Workdone

ΔG - gibbs free energy.

Enthalphy - Enthalphy is a thermodynamic property that measure the energy in the system by adding the system internal energy to the product of pressure and volume

Entropy - Entropy is a ~~measin~~ measing system disorder or random ness and the amount of thermal energy in a system that is unavailable for useful work.

$\boxed{\Delta H - \Delta H_1 + \Delta H_2}$ Mathematical expression of Hess law.

Example: Combustion of carbon dioxide can be done in two ways:
Path I: $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -393.5$ KJ

Path II: $C + O_2(g) \rightarrow CO(g)$ $\Delta H_1 = -110.5$ kJ
$CO(g) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_2 = -2830$kJ

In both the cases, $\Delta H_1 + \Delta H_2 = 393.5$ kJ

Kirchhoff's law: There are two laws.

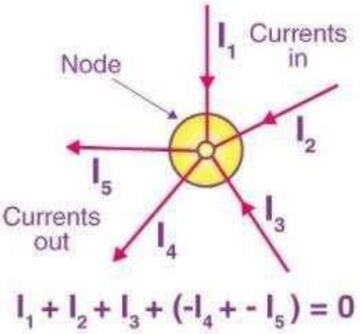
a) 1st law (KCL)
b) 2nd law (KVL)

a) Kirchhoff's current law (KCL):

Kirchhoff's current law state that total charge entering a Junction is equal total charge leaving it. Thus, it tells about the conservation of charge.

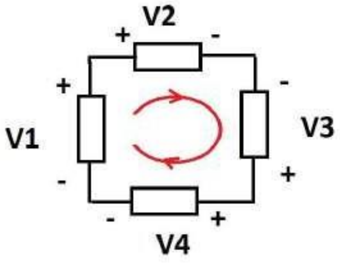
Incoming=Outgoing

$I_1 + I_2 + I_3 = I_4 + I_5$



At the node point, algebraic summation is zero.
Kirchhoff's 1st law is related to conservation of current.

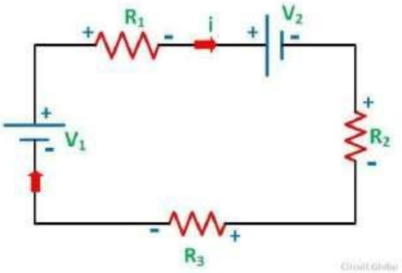
b) Kirchhoff's voltage law (KVL):



V1 + V2 + V3 + V4 = 0

ΣV = 0

2nd law (KVL) states that, in any closed path of an electric circuit the algebraic sum of all potential is zero.



$$V1 + V2 + (-IR_1) + (-IR_2) + (-IR_3) = 0$$

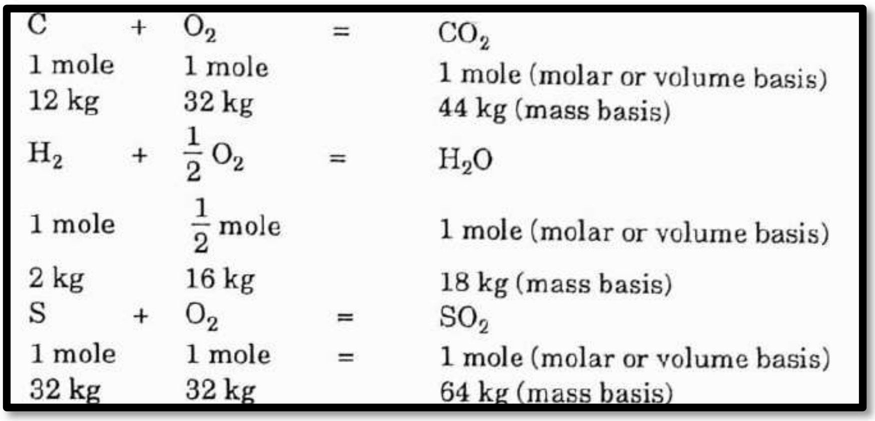
$$V1 + V2 = IR_1 + IR_2 + IR_3$$

(algebraic sum of voltage source = algebraic sum of voltage drop)

Kirchhoff's voltage law also states that the algebraic sum of voltage source is equal to the sum of voltage drop.

5.2. Combustion calculation:

Basic complete combustion reactions are: $CH_4 + 2O_2 = CO_2 + 2H_2O$



C	+	O_2	=	CO_2
1 mole		1 mole		1 mole (molar or volume basis)
12 kg		32 kg		44 kg (mass basis)
H_2	+	$\frac{1}{2}O_2$	=	H_2O
1 mole		$\frac{1}{2}$ mole		1 mole (molar or volume basis)
2 kg		16 kg		18 kg (mass basis)
S	+	O_2	=	SO_2
1 mole		1 mole	=	1 mole (molar or volume basis)
32 kg		32 kg		64 kg (mass basis)

Important points to remember for combustion calculation:

Steps:

1) Write down combustion reactions for the elements present in the fuel.
2) Calculate the weight of oxygen required for combustion.
3) Subtract oxygens if already present in the fuel.
4) C, H_2, S, CO and hydrocarbons are the combustible substances present in fuel.
5) N2, ash, CO2 and water vapor are incombustible substances present in the fuel.
6) Calculate weight and volume of air.
7) In case of weight of air multiplication factor is 100/23 and in case of volume of air multiplication factor is 100/21.

Example 1. *Calculate the weight and volume of air required for complete combustion of 1Kg. coal with following compositions, C = 85%, H = 10%, O= 5%.*

Solution: Combustion Reactions

a) $$\underset{12kg}{C} + \underset{32kg}{O_2} \longrightarrow \underset{44kg}{CO_2}$$

For 1kg of C need $\frac{32}{12}$ kg O_2 for complete combustion.

In the fuel we have 85% C that is $\frac{85}{100}$ =0.85kg of C

For 0.85Kg of C in coal, O_2 will be required =0.85 × $\frac{32}{12}$= **2.26 kg**

b) $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$

2kg 16kg 18kg

For 1kg of H_2 need $\frac{16}{2}$=8kg O_2 for complete combustion.

In the fuel we have 10% H_2 that is $\frac{10}{100}$ =0.1kg of H_2

For 0.1Kg of H_2 in coal, O_2 will be required =0.1 × 8 = **0.8 kg**

Total amount of oxygen required = 2.26 kg + 0.8 = **3.06 kg**

But, in fuel some O_2 is also present.

In the fuel we have 5% O_2 that is $\frac{5}{100}$ = **0.05kg** of O_2

Final oxygen required is = 3.06 kg – 0.05 = **3.01 kg**

Weight of air required for complete combustion is $3.01 \times \frac{100}{23}$ = 13.08 kg (Ans)

Volume of air required for complete combustion:

29 molecular weight of air have 22.4 lit volume in STP

So,

13.08 kg of air has volume of air = $13.08 \times \frac{22.4}{29}$ **= 10.10 lit (Ans)**

Example 2. *Calculate the amount of air required for theoretically complete combustion of 100kg of coal of the following composition, C = 82%, H_2 = 6%, O_2 = 4%, ash= 8%, S = 2%.*

Solution: Combustion Reactions

a) $C + O_2 \longrightarrow CO_2$

12kg 32kg 44kg

For 1kg of C need $\frac{32}{12}$kg O_2 for complete combustion.

In the fuel we have 82% C that is $\frac{82}{100}$ =0.82kg of C

For 0.82Kg of C in coal, O_2 will be required =0.82 × $\frac{32}{12}$= **2.187kg**

b) $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$

2kg 16kg 18kg

For 1kg of H_2 need $\frac{16}{2}$=8kg O_2 for complete combustion.

In the fuel we have 6% H_2 that is $\frac{6}{100}$ =0.06 kg of H_2
For 0.06Kg of H_2 in coal, O_2 will be required =0.06 × 8 = **0.48 kg**

c) $S + O_2 \longrightarrow SO_2$
32kg 32kg 64kg

For 1kg of S need $\frac{32}{32}$=1kg O_2 for complete combustion.
In the fuel we have 2% S that is $\frac{2}{100}$ = 0.02 kg of H_2
For 0.02kg of H_2 in coal, O_2 will be required = 0.02 × 1 = **0.02 kg**

Total amount of oxygen required = 2.187kg + 0.48 + 0.02 = **2.669 kg**

But, in fuel some O_2 is also present.
In the fuel we have 4% O_2 that is $\frac{4}{100}$ = **0.04kg** of O_2

Final oxygen required is = 2.669 kg – 0.04kg = **2.629 kg**

Weight of air required for complete combustion is 2. 629 × $\frac{100}{23}$= 11.43 kg

For 100kg of coal air required = 11.43 × 100 = 1143kg (Ans)

Example 3. *Calculate the amount of air required for theoretically complete combustion of 100Nm*^{3} *of blast furnace gas of the following composition (by volume),* CO_2*= 17%, CO=22.1%,* H_2 *= 4.9%,* N_2*= 55.8%,* O_2 *= 0.2%.*

***Solution**:* Combustion Reactions

a) $CO + \frac{1}{2}O_2 \longrightarrow CO_2$
1Nm^3 0.5Nm3

For 1Nm^3 of CO need 0.5Nm^3 O_2 for complete combustion.
In the fuel we have 22.1% CO in 1Nm^3 of coal = 0.221Nm^3 of CO
For 0. 221Nm^3 of CO in coal, O_2 will be required =0.221 × 0.5 = **0.1105 Nm^3**

b) $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$
1Nm^3 0.5Nm3

For 1Nm^3 of CO need 0.5Nm^3 O_2 for complete combustion.
In the fuel we have 4.9% H_2 in 1Nm^3 of coal = 0.049Nm^3 of H_2
For 0.049Nm^3 of H_2 in coal, O_2 will be required =0.049 × 0.5 = **0.0245 Nm^3**

Total amount of oxygen required = **0.1105 Nm^3** + **0.0245 Nm^3** = **0.135 Nm^3**

But, in fuel some O_2 is also present.
In the fuel we have 0.2% O_2 that is $\frac{0.2}{100}$ = **0.002 Nm^3** of O_2

Final oxygen required is = **0.135 Nm^3** - **0.002 Nm^3** = **0.133 Nm^3**

Volume of air required for complete combustion is $0.133 \times \frac{100}{21} = 0.634$Nm^3

For 100Nm^3 of coal air required = 0.634 × 100 = 63.4 Nm^3 (Ans)

Assignment

1) A Sample has the following composition coal by weight C= 78%, H_2 = 6%, N_2 = 2%., 0_2=9%, S = 2%, ash = 3%. Find out the weight of air Required for complete combustion of 1kg of coal.

2) *A coal has following composition by weight: C = 80.3%. H_2 = 5.7%, S=1%, N_2=1%, ash = 12%. Calculate the amount of air required for complete combustion of 100 kg of coal.*

3) A Sample has the following percentage composition coal by weight C= 77.7%, H_2 = 6.8%, N_2 = 1.2%., 0_2=8.8%, S = 2.2%, and incombustible = 3.3%. Determine the minimum quantity of air Required for complete combustion of 1kg of coal.

4) The percentage analysis by volume of a producer gas is H_2 = 18.3%, CH_4=3.4%, CO=25.4%, CO_2 = 5%, N_2 = 47.8%. Calculate the volume of air required per m^3 of the above producer gas for complete combustion.

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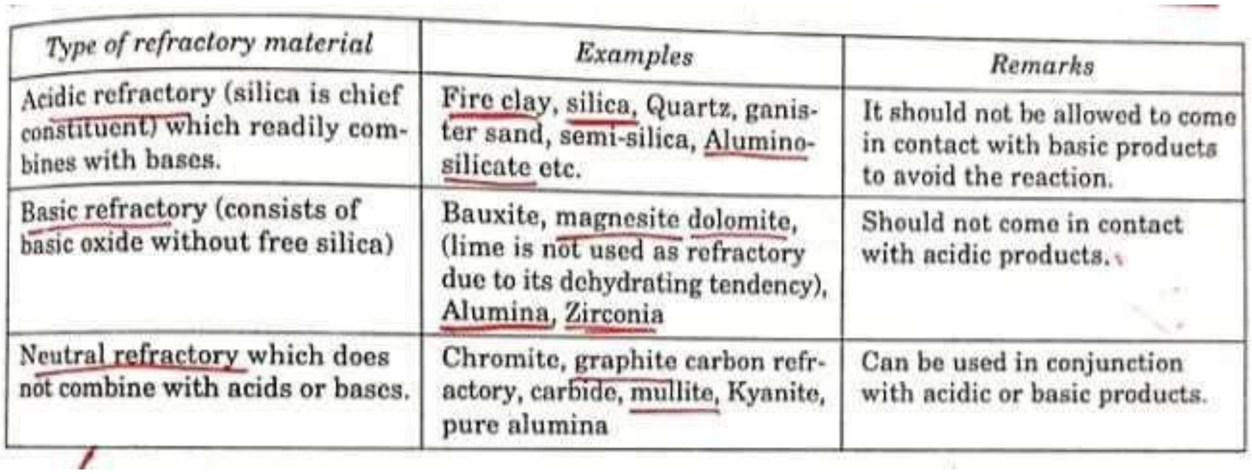
6.Refractories

6.1 Definition: Refractories are materials which withstand high temperature and do not fuse even at a very high temperature e.g. fire clay, silica, chromite, magnesite etc.
6.1 Classification. Three types of refractory materials exist depending upon their chemical nature as given below:



Type of refractory material	*Examples*	*Remarks*
Acidic refractory (silica is chief constituent) which readily combines with bases.	Fire clay, silica, Quartz, ganister sand, semi-silica, Alumino-silicate etc.	It should not be allowed to come in contact with basic products to avoid the reaction.
Basic refractory (consists of basic oxide without free silica)	Bauxite, magnesite dolomite, (lime is not used as refractory due to its dehydrating tendency), Alumina, Zirconia	Should not come in contact with acidic products.
Neutral refractory which does not combine with acids or bases.	Chromite, graphite carbon refractory, carbide, mullite, Kyanite, pure alumina	Can be used in conjunction with acidic or basic products.

Based on the method of manufacture, refractories are classified as:
- Dry pressed
- Fusion cost or electrocast
- Hand moulded
- Formed (Normal, fired/burned or chemically bonded)
- Unformed (Monolithics-plastics, Ramming mass, Gunning, Castable, Spraying)

ACID REFRACTORIES

Those refractories which are attacked by basic slags (.e. bases) are called acidic refractories and include:

a) **Aluminium-silicate refractories** like fireclay bricks, high alumina bricks, kyanite, sillimanite, bauxite, diaspore, mulite, andalusito etc. These refractories vary widely in their physical, chemical and mineralogical characteristics depending on the nature and proportion of silica and alumina present in them. Free silica (SiO_2,) should be as little as possible as it lowers the fusion point of these refractories. Addition of grog (ground pre-fired fireclay grains) improves the shrinkage properties of these refractories.

b) **Silica refractories** consisting mainly of silica (and very low in alkalis and metallic oxide). Raw materials of various graded of silica refractories (containing silica upto 97%, alkalis <0.3% and alumina < 10%) include natural rock, prepared mass quartz sand (ganister), quartzite, electrically fused quartz etc.

BASIC REFRACTORIES

Those refractories which are attacked by acid slags (acid) are called basic refractories and include:

a) **Alumina (Al_2O_3)** refractories manufactured from burnt bauxite, electrocast bruxite or electro fused corundum.

b) **Dolomite refractories** produced by calcining natural dolomite which is mainly a mixture of lime and magnesia.

c) **Magnesite refractories** produced from dead burnt magnesite or magnesia (MgO). Chrome-magnesite and Magnesite-chrome refractories which are mixture of calcined magnesite and chromium oxide in various proportion necessary to develop required properties in them.

NEUTRAL REFRACTORIES

Those refractories which are not attacked either by basic slag/bases or acid alag/acids are called neutral refractories and include.

a) chromite, carbon and graphite refractories
b) artificially produced refractories like silicon carbide, zirconium carbide, titanium carbide etc.
c) Metals used as refractory like thorium, tungsten, sirconium, platinum, nickel, iron, molybdenum, copper, vanadium, tantalum etc.

Alumino-silicate refractories are sometimes classified as neutral refractories but when exposed to basic slag, they exhibit acidic reaction.

INSULATING REFRACTORIES

A refractory suitable for minimising heat losses and thus achieving heat conservation in the furnaces is called insulating refractories. They have high porosity, low thermal conductivity and high thermal insulation properties and are produced from asbestos, fireclay, kieselguhr etc. At low temperature, slagwool, glasswool and vermiculite are also used as insulating materials. For high temperature thermal insulation applications foam ceramics. and ceramic fibre and wool are used.

6.3 SPECIAL REFRACTORIES

These are very expensive refractory materials used for making crucibles and furnaces for special/experimental purposes where cost of refractory is no consideration. They are not very common due to their manufacturing limitation. Special refractories include pure oxides (e.g. magnesia, silica, alumina, beryllia, thoria etc), borides, nitrides, silicides, carbides etc. Other special refractories are Sialons, sircon, carborundum, alundum (a mixture of fased alumina and clay), sillimanite, electrocant blocks of mullite, magnesia and mixtures of chromite, bauxite and magnesia.

CERMET REFRACTORIES

This refractory is a combination of ceramic materials (e.g. oxide, nitride, carbide, borides etc.) and metallic/metallic alloys materials. It has the combination of good properties of both metallic and ceramic materials e.g. high strength and resistance to high temperature. Cermets are used in nuclear reactors, missiles and space crafts etc.

6.2 PROPERTIES OF REFRACTORIES

Important properties of refractories are resistance to high temperature, heavy load, fluxes, corrosive fluids like slag, thermal shocks due to rapid change in temperature (also called spalling resistance) etc.
Other properties are strength, specific gravity thermal and electrical conductivity etc.

Porosity and Slag Permeability. The higher the porosity of the refractory, the greater is the succeptibility of refractory to chemical attack of molten slags, gases etc. By decreasing the porosity, strength and thermal conductivity of the refractory is increased but spalling resistance (thermal shock resistance) is decreased the inner pore space for absorbing contraction and expansion is reduced.

Refractoriness or fusion point. It is the temperature at which the refractory fuses It should be much higher than the operating temperature of the refractory. Fusion point decreases when refractory is under load and this is called refractoriness under lood (RUL).

Strength. It is the resistance of the refractory to compressive lands, tension and shear stresses. Refractoriness under lead (RUL) is important as some refractories fail at a lower temperature when subjected to load. In taller furnaces, the refractory has to support a heavy load, hence strength under the combined effect of temperature and load is important.

Specific gravity. It should be low to produce more number of bricks per unit weight. Also lighter bricks in the lower part of a tall structure will not be subjected to a heavy load.
Cost of bricks of higher specific gravity is more than that of lower specific gravity (assuming the price of raw material being same per unit). Increase in bulk density of refractory increases its volume stability, heat capacity and resistance to stag penetration

Spalling. It is the fracture of refractory due to its uneven expansion an account of heat when they are subject to rapid heating and cooling. For reducing spalling, a refractory should be well fired and its porosity should be more.

Thermal Conductivity. Ordinary furnaces block should have low thermal conductivity but refractory used in coke oven, regenerators, muffle furnace should have high heat conductivity. Thermal conductivity is increased when the porosity of refractory bricks decreases i.e. when the air entrapped in refractory decreases. Insulating bricks (of low thermal conductivity) are maintained at high temperature and hence their life is short.

Electrical Conductivity. For electrical furnaces, the electrical conductivity of refractory material should be low. Except, graphite, all other refractories are had conductors of electricity. The electrical resistivity of the refractory drops rapidly with rise in temperature.

Chemical Composition. The chemical composition of the refractory should be such that the surroundings do not chemically attack the refractory and corrode it. Acidic refractory should not be used in a furnace heating a basic material, otherwise the brick will react with the furnace stock and get eroded and hence its life will be reduced.

Slag Resistance. Slag attacks the refractory particularly at high temperature by forming mixture or new compounds with the refractory substance in contact with. Slag dissolves some of the refractory material and forms a viscous slag film whose melting temperature may be higher or lower. Resistance of refractory to slag action depends on the nature of slag and the refractory. Relative alas resistance of various refractories depend upon temperature, change in slag composition (on combining with refractories) and the nature of contact with the slag i.e. whether the slag is moving, stationary or is carried as fine particles by the gases/fame.

A basic slag attacks an acidic refractory while an acid slag attacks a basic refractory very rapidly. Rate of slag attack is accelerated by the following factors

i. defective joints and cracks in the refractory structures.
ii. presence of fusible glass of refractories
iii. rough and porous surfaces of refractories
iv. moving slag as compared to stationary slag.

Rate of slag attack is reduced, if the refractory is dense and woll vitrified (c.a. offering smoother surface) and the slag is stationary.

Abrasion Resistance. A refractory is subjected to wear, when it comes in contact with a moving charge an in case of blast furnace, descending charge materials result in abrasion wearing away of the refractory lining material. Abrasion resistance of refractory in increased by using a dense (low porosity), fine grained and wear resistant refractory lining.

Erosion Resistance. Erosion (damage due to mechanical action) occurs when metal or gas carrying dust and stag particles hit against the refractory lining resulting in 'chipping off of particles from the refractory. Splashing of slag erodes the refractory lining whereas slag particles entrained by flame/gases erode particularly the arches and bends of the structure.

Size and Shape. It is a part of the design of furnace, since it affects the stability of the furnace structure. Accurate refractory size is important to properly fit the refractory shape inside the furnace and to minimise space between construction joints.

6.3 SELECTION OF REFRACTORIES

The selection of refractories for any particular application is made with a view to achieving the best performance of the equipment, furnace, kiln or boiler and depends on certain

properties of the refractories.
Further, the choice of a refractory material for a given application will be determined by the type of furnace or heating unit and the prevailing conditions e.g. the gaseous atmosphere, the presence of slags, the type of metal charge etc. Therefore, temperature is not the only criterion for selection of refractories.

Any furnace designer or industry should have a clear idea about the service conditions which the refractory is required to face. The furnace manufacturers or users have the following points, before selecting a refractory to consider

- Area of application.
- Extent of abrasion and impact.
- Stress due to temperature gradient in the structures and temperatures fluctuations
- Working temperatures:
- Structural load of the furnace.
- Chemical compatibility to the furnace environment.
- Heat transfer and fuel conservation.
- Cost considerations

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4.0 GASEOUS FUEL

Gaseous fuels are those which are burnt in gaseous state in air or oxygen to give heat for utilisation in domestic/commercial sector.

A remarkable feature of gaseous fuels is the absence of mineral impurities, consistency in quality and convenience and efficiency in use. On industrial scale, a gas handling system is the least costly of all the fuels.

Some important gaseous fuels are as mentioned below:

(a) Methane from coal mines i.e. CBM-coal bed methane
(b) Wood Gas
(c) Gobar Gas
(d) Sewage Gas
(e) Gas from underground gasification of coal
(f) Natural Gas
(g) Liquified Petroleum Gas (LPG)
(h) Refinery Gas
(1) Producer Gas
(j) Water gas and Carburetted Water Gas
(k) Blast Furnace Gas
(1) Coke Oven Gas
(m) LD. Converter (or BOF) Gas
(n) Coal Gas from Coal Gasification Processes
(o) Oil Gas from Oil Gasification Processes.

Two more important fuels namely hydrogen and acetylene find wide use in metal cutting, welding etc.

Gaseous fuels are termed as *rich gas* (if calorific value is > 4000 kcal/Nm^3) and *lean gas* (if C.V. is < 1500 kcal/ Nm^3).

Hydrocarbon gases and coal gas are example of rich gas, while blast furnace gas and producer gas are example of lean gas.

The classification of gaseous fuel does not solely depend on the calorific value of gas. Both the calorific value (CV) and specific gravity (Sp. gr.) of a gaseous fuel determine the thermal output of a heating appliance.

These two factors are combined to give a CV dimensional group, called Wobbe number or Wobbe index which is $\frac{CV}{\sqrt{sp.gr}}$.

METHANE FROM COAL BED/MINES (CBM):

- Methane is associated with coal in mines as it (coal) adsorbs the methane formed- during coalification process.
- At the time of coal mining, the gas is gradually desorbed and it must be removed by proper ventilation otherwise it forms explosive gas-air mixture.
- It is a source of dangerous explosion in gassy mines and the gas is often called as 'firedamp'.
- The methane rich gas from coal mines may be recovered through a system of

boreholes and may be used as a fuel. Methane rich mine gas have been recovered in U.K., France, Germany but the recovery process has not been developed on a wide scale due to availability of natural gas on a large scale.

- The composition of methane gas from coal mines is variable but it is essentially a highconcentration methane gas as shown below.

  CH_4= 93-99% C_2H_6 = 0-3%
  CO_2 =0-4% N_2 = 2-6%
- Hydrogen and rare gases are present in traces. In India, this gas is not being recovered in any coal mine for use as a fuel and this is a potential source of fire in mines under the crust of earth.
- Recently, exploration of coal bed methane (CBM) has been started at *Telgharia near Bokaro Steel city in Jharkhand.*

WOOD GAS:

- Wood gas is obtained either by carbonisation of wood in metal retorts or by gasification of wood. It is a medium calorific value gas not of much commercial interest.
- Wood gas is also produced by gasification of logs, chips etc. in many countries similar to the principle of producer gas generation from coal.
- Gas yield in typical wood gasification process is about 194 Nm^3/ton dry wood. Crude methyl alcohol is also recovered (0.5% of dry wood) in gasification. A typical wood gas composition (produced by gasification) is:

  CO_2=6%, CO=29%, CH_4= 2.5%
  C_mH_n=0.7%, H_2 = 14.5%, O_2=0.3%, N_2 = 47%
  C.V. 1660 kcal/Nm^3, Sp. gravity= 0.85 (Air = 1)

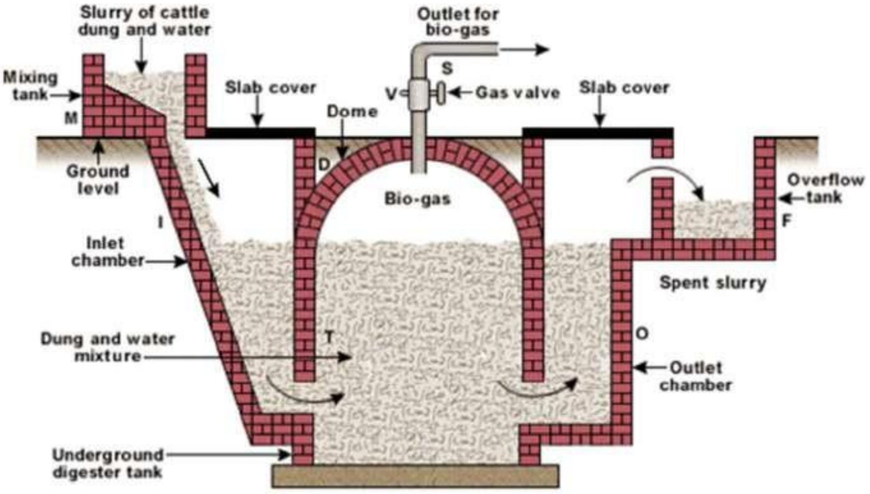
- About 50% of the wood gas is consumed in gas producer while rest 50% is available for use elsewhere e.g. in thermal power plant. India does not have commercial generation facility for wood gas.

GOBAR GAS:

- Gobar gas is obtained by the fermentation of gobar (dung) in absence of air. Gobar gas (cattle dung) is derived from cattle dung (called 'gobar' in Hindi).
- In a gobar gas plant, fuel value of the dung is extracted while the refuse can still be used as a fertiliser.
- ***Operating Principle-*** Gobar gas is produced by the fermentation of dung and other organic materials in absence of air. It consists mainly of CH_4 and CO_2. The extraction of CH_4 does not affect the fertiliser value of the dung. Rather, after the dung is processed in Gobar gas plant, the mannure becomes rich in nutrients and odourless. In addition, it becomes free from flies and other sources of infection. Gobar gas burns with a blue flame without smell at an efficiency five times greater than that of burning cowdung cakes. Hence, this plant provides improved fuel and

organic mannure from the dung.

- The plant comprises of a digestor to ferment cowdung and any other finally chopped -left-over fodder or vegetable efficiently. The digestor is covered by a gas holder which collects and diverts the gas produced into the gas pipe at correct pressure.
- Cattle dung and urine is collected and dumped into the mixing tank, where it is mixed with water and fed to the inlet pipe. This slurry, when enters the digestor will discharge an equal quantity of ripe slurry through the outlet pipe which is let into the compost pit and covered with the farm sweepings and other organic wastes from the household which is finally used as a fertiliser. Gobar gas plant is shown in Fig. 30.1.



Fixed-dome type bio-gas plant.

Fig: Gobar gas plant

- **Utilisation of Gobar Gas Plant Products:** Two main products of gobar gas plant are fuel gas and mannure.
- *Fuel Gas:* Presence of substantial quantity of methane (55-60%) makes it a very suitable fuel gas.
- *Mannure*: The outlet slurry from the plant which is rich in nitrogen (>2%) and humus can be applied directly to the land by mixing with irrigation water.

SEWAGE GAS:

- Sewage gas is produced during sewage disposal by way of aneorobic decomposition of organic wastes (by suitable bacteria). Sewage gas is a methane rich gas which can be used as a town gas component if available in commercial quantity.
- Composition and Properties of Sewage Gas

CH_4 = 58.5–76.5%, CO_2= 30–41%
N_2=3-8%, O_2= 0-1.8%
H_2= 0-4.5%, H_2S=0.1%
C.V= 5700-7400 kcal/Nm^3 (dry), Sp. gravity= 0.7-0.85, (Air = 1)

Gas yield=8-30 liters per capita of population per day

- Higher HS in sewage gas makes its use difficult in gas engines or boilers without purification.
- Gases similar to sewage gas are produced by fermentation of agricultural wastes (carbonaceous) of plants of animal origin (e.g. straw, fruit peeling etc.) under aneorobic conditions. Residue left after the fermentation of sewage and agricultural waste is a good manure (fertiliser).

COAL GAS FROM UNDERGROUND GASIFICATION OF COAL:

- Coal in the underground mines can be gasified in situ even without mining it out of the crust of the earth. This is termed as underground gasification of coal and the gas thus produced is called coal gas from underground gasification of coal.
- Composition and Properties of coal gas produced by underground gasification of coal:

  $CO = 10.7\%$, $H_2 = 8.4\%$, $CH_4 = 1.8\%$, $N_2 = 67.4\%$, $CO_2 = 10.5\%$, $C_mH_n = 0.3\%$, $O_2 = 0.9\%$
  C.V = 820 kcal/Nm^3 (dry), Sp. gravity = 0.95 (Air = 1).

- Some commercial plants in USSR produce gas by this method for electricity generation. Bituminous, sub-bituminous and mature brown coal deposits are suitable for underground gasification using air and oxygen as gasifying medium.
- India does not have any such commercial gasification system.
- The principle of underground gasification of coal has been shown in the Fig.

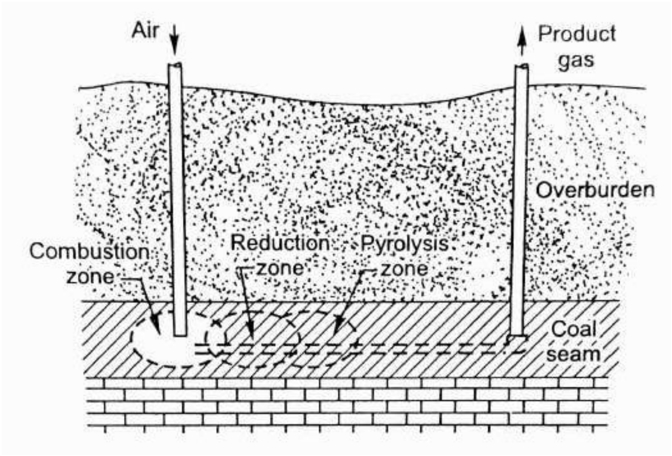


Fig: Principle of underground coal gasification.

NATURAL GAS

- It is a mixture of *paraffinic hydrocarbons,* in which *methane* is the main constituent. It occurs in the gas field (under the crust of earth) and also in association with crude petroleum in oil fields.
- After delivery from wells, natural gas/is processed to remove the solids. It is then treated for recovery of *gasoline and liquified natural gas (LNG).*
- When natural gas contains very less recoverable condensate (< 15 gm/m^3), it is known as dry natural gas while it is termed as wet natural gas if recoverable condensate is more (> 50 gm/m^3).
- This condensate is recovered and is known as *natural gasoline* which is used as a blending agent for motor fuel.
- The condensate (*natural gasoline*) recovery from gas is done by compressing & cooling or adsorption on a porous solid.
- Natural gas of some localities contains large quantity of N_2 and CO plus recoverable amount of helium. Sometimes H_2S are also present in the gas which is recovered as elemental sulphur. (H_2S free gas is called a *sweet gas*.
- Natural gas is used as a fuel for cooking, domestic and industrial heating, process furnace and boilers. It is also used for fertiliser production and as a source of carbon and hydrogen in chemical industries.

Uses of Natural Gas: Natural gas is used for

- Enriching the gaseous fuels of low calorific value e.g. Lurgi gas.
- Internal combustion (I.C.) engine as its high anti-knocking qualities permits use of high compression ratios possible resulting in improved engine efficiency.
- Gas turbines also use natural gas as a fuel.
- Producing carbon black by burning in a limited quantity of air in the presence of cooled metal surfaces. Carbon black is a pigment as well as a reinforcing agent for rubber.
- Making water gas as its methane content can be reacted with steam for this purpose.
- Making synthesis gas (by reaction with steam) which is further used for the production of methyl alcohol or gasoline (by Fischer-Tropsch-process) or hydrogen for ammonia synthesis.
- Partially converting into hydrogen, methane, benzene and other aromatic compounds by pyrolysis which are all valuable chemicals.
- The production of methyl alcohol and formaldehyde by controlled oxidation of methane present in it.
- Producing methyl chloride by the chlorination of methane present in it.

In USA, natural gas is widely used in domestic heating & cooking and a wide network gas pipeline has made it available to almost each and every home. In India natural gas is available from Gujarat, Assam and Bombay high oil wells. A 1700 km long pipeline (HBJ pipeline) running from Hazira to Jagdishpur via Bijapur supplies natural gas to fertiliser plants and thermal power stations enroute.

Liquefied natural gas (LNG) is shipped also. Oil and Natural Gas Corporation Ltd. in India has set up a bottling plant at Uran (Near Bombay High) for filling LNG in cylinders.

Compressed Natural Gas (CNG): Natural gas has a very low energy density; hence to use it as an alternative fuel for a spark ignition engine on board the vehicle/car, it has to be either compressed to a high pressure of 200 atm or cooled to - 160°C to liquefy it for storage.
Hence, it is used as compressed natural gas (CNG).

Advantages of CNG over petrol as a S.I. engine fuel.

- Octane number of CNG is 130, hence it does not need anti knock additive like TEL, which causes pollution.
- Its combustion is more regular and it rapidly disperses into atmosphere at normal pressure and temperature.
- It is a light weight gas with a high ignition temperature and is no more dangerous than petrol.
- Emission of carbon monoxide and unburnt hydrocarbons is comparatively less in the exhaust.
- CNG is insoluble in engine oil, hence lubricating oil retains its properties for longer duration resulting in longer interval between oil changes.
- CNG fired engines have longer life, as it does not carbonise spark plugs or wash out lubricating oil films.
- It has a comparatively better cold starting characteristics, because unlike petrol, it does not first have to be vaporised and it does not condense on cold engine parts.

Disadvantages of CNG:

- CNG storage tanks add weight because heavy cylinders are required for the storage of natural gas at high pressures.
- CNG storage tanks take up five times higher trunk space for comparable energy storage.
- Refuelling station cost of CNG is very high.
- Compared to petrol driven vehicles, CNG driven vehicles have shorter operating range.

LIQUIFIED PETROLEUM GAS (LPG)

- It is mainly a mixture of *propane and butane* used mainly as cooking gas in domestic ovens as well as for industrial heating in furnaces (e.g. heating of annealing furnaces).
- C_3 (propane etc.) and C_4(butane etc.) hydrocarbons are easily liquified at room temperature with the application of very low pressure.

- Hence, propane and butane is liquified, stored and transported in light cylinders. Generally, a mixture of about 80% butane and 20% propane is used for filling in LPG cylinders (also called bottled gas).
- LPG is prepared from wet natural gas and refinery gases.
- Even pure butane and propane are also liquified and used as fuels.
- LPG is a highly volatile liquid, which expands 247 times its volume as vapor (1 litre Liquid = 247 litres of vapor). It is non-toxic, does not support life and is heavier than air.
- LPG have high calorific value, high specific gravity, high air requirement and low flame speeds.
- *Since, LPG is odorless, hence odorants like mercaptans (50 ppm) or sulphides are added to detect its leakage from cylinders by smell as mercaptans have very pungent smell.*
- The lighter grade LPG commercially available contains 90% propane and 10% butane.
- LPG is a popular domestic fuel because of the fact that a large concentration of thermal energy is contained in a small portable cylinder. LPG is quite popular fuel for industrial heating also where alternative fuel is not available. There are more than 100 LPG bottling plant in the country. It is also used as a fuel in I.C. engine as well as for welding & cutting.
- Propane and butane are also used for enriching the low C.V. gases in a town gas supply system abroad up to limits of permissible specific gravity.
- A mixture of 20% butane and 80% air has a CV of 6136 kcal/ Nm^3 and is outside the limit of inflammability of butane in air.
- The amount of air/inert gas added is such that it is well outside the limit of inflammability (explosion limit) of LPG which is about 1.8-8.5% of LPG in LPG/air mixture.
- Density of liquid LPG, which is non-corrosive to steel, copper, copper alloys and aluminium is, half that of water. LPG is slightly toxic & anaesthetic, if inhaled in very high concentration It has no lubricating property and is colorless in either liquid or vapour phase.
- It is used also for welding, cutting, soldering, brazing and portable blow lambs.

- Propane and butane are also used in the production of petrochemicals. LPG being heavier than air has a tendency to settle down while leaking from cylinder. At times methane rich natural gas is also liquified and sold as bottled gas in cylinders. In that case, it is called Liquified Natural Gas (LNG).

For industrial grade LPG (80% butane + 20% propane): -

- C.V. = 29275 kcal/Nm^3 (11200 Kcal/Kg)
- Sp gravity=19 (Air = 1),
- Theoretical combustion air requirement = 29 Nm^3/Nm^3 of LPG

And for domestic grade LPG (70% propane + 30% butane):

- C.V. 25775 kcal/Nm^3
- Sp. gravity= 1.65 (Air = 1)
- Theoretical Combustion air requirement = 26 Nm^3/Nm^3 of LPG

Use of LPG as a S.I. engine fuel: Use of LPG in a *spark ignition engine* offers following *advantages.*

- LPG is readily miscible with air and can burn at leaner air/fuel ratios.
- Being resistant to preignition, it leaves less combustion chamber deposits.
- It has an excellent cold starting & warm up performance and gives lower emission of pollutants like unburnt hydrocarbons & carbon monoxide.
- Its anti-knocking properties are excellent provided large amount of unsaturates are not present in it.

However, LPG suffers from the following *disadvantages*:

- LPG has to be stored & transported in bulky tanks capable of withstanding very high pressure.
- Some of the unsaturated compounds present in LPG have a comparatively poor octane number and are prone to causing high speed knock.

PRODUCER GAS

- It comprises mainly of CO & N_2 and is produced (in a furnace called 'producer') by blowing air or a mixture of air & steam through hot bed of solid fuels (coal/coke).

- In the simple gas producer, dry air is blown through a bed of coal/coke of sufficient depth and at a sufficiently high temperature. Gas obtained consists of CO and N_2 in the ratio of 1:2 by volume, with traces of CO_2 and H_2.

- Producer gas made from either coke or coal, under normal operating condition has a com- position (volume %) within the range given below:
  CO_2 = 4-6%, CO = 20-30%, H_2 = 11-20%, CH_4 =0-3%, N_2 = 46-53%
  Calorific value (C.V) = 1250-1550 kcal/Nm^3
  Sp. Gravity (Air = 1) =0.85-0.90.

  Combustion Air requirement 1-1.3 Nm^3/Nm^3 of producer gas.
- The producer gas may also contain steam, tarry vapors, sulphur compound, NH_3 in minor quantity.
- The commonest types of gas producer is a vertical cylindrical chamber into which the fuel is fed continuously from the top. Air is blown through a grate at the base, and the gas exit is at the top. Ash and clinker are discharged at the grate. The chamber may be lined with fire brick or may have an annular water jacket in which steam is raised for addition to the blast.
- Principal chemical reactions in producer gas plant using coal/coke as fuel and moist blast (air + steam) for gasification.

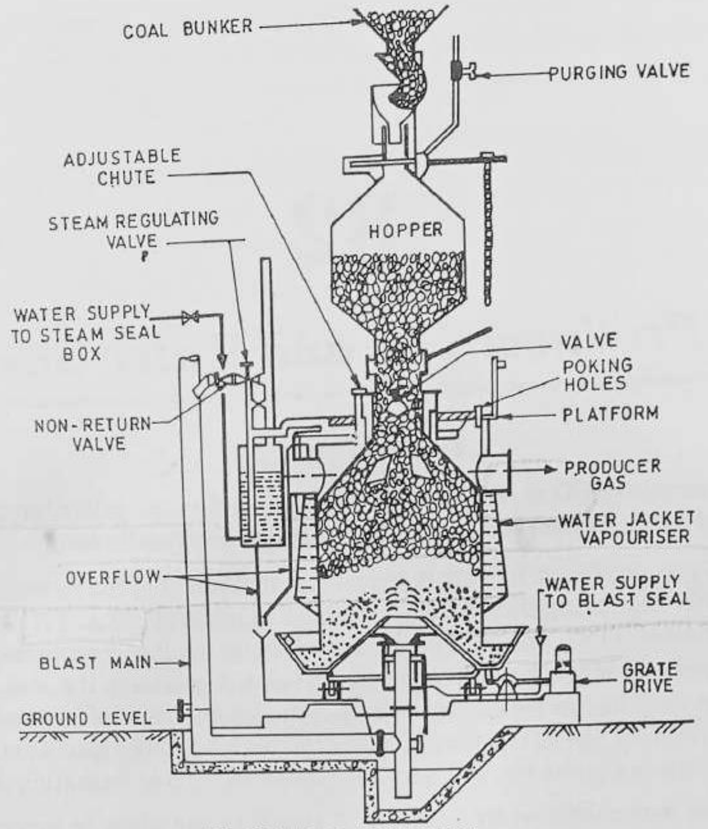


Fig. 32.1. Producer gas plant.

USES OF PRODUCER GAS:

- It is used for firing in furnaces (glass melting and steel making in open hearth furnaces), coke oven heating and in internal combustion engines.
- Producer gas for firing in glass melting and open hearth furnaces.
- Producer Gas for Use in Internal Combustion Engines.

WATER GAS

It is a medium calorific value gas (about 2800 kcal/Nm^3) comprising mainly of CO and H_2. It is prepared by action of superheated steam on a bed of hot coke/coal at about 1000 Ca per the reaction

$$C+H_2O=CO+H_2 \qquad \Delta H = 28 \text{ kcal/mol (endothermic reaction)}$$

Since the above reaction is endothermic the coal cools down after a few minutes and the reaction proceeds in a different way to form carbon dioxide and hydrogen instead of water gas ($CO + H_2$).

$$C + 2H_2O \longrightarrow CO_2 + 2H_2, \quad \Delta H = +19000 \text{ kcal/kmol (endothermic reaction)}$$

In order to avoid the above undesirable reaction, the current of steam is intermittently replaced by a blast of air. The following reactions now occur.

$$C+O_2 \rightarrow CO_2,\ \Delta H = -97000\ kcal/mol$$
$$2C+O_2 \rightarrow 2CO,\ \Delta H = -29000\ kcal/kmol$$

Thus due to exothermic reaction the temperature of carbon again rises and when the temperature increases to 1000°C air entry is stopped and steam is again passed. Thus in modern gas plants steam and air are blown alternatively. The period of steam blow, (cold blow) is usually 4 minutes while the period of air blow (hot blow), is very short about 1-2 min.

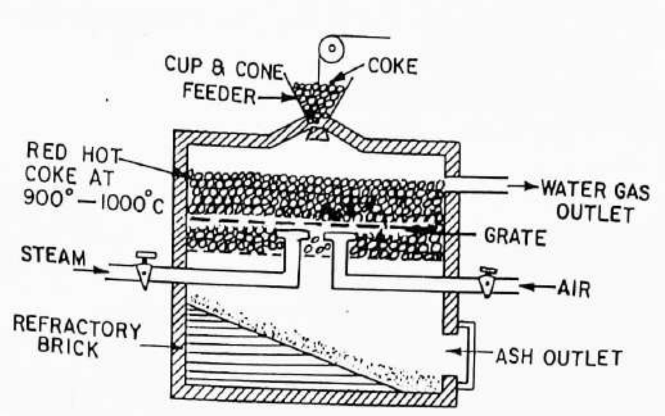


Fig. 32.3. Manufacture of water gas.

During the steam blow, water gas is produced. This is led out through the water gas outlet. On the other hand, nitrogen, carbon dioxide and carbon monoxide are formed during the air blow. These are allowed to escape in the atmosphere. Thus the manufacture of water gas is intermittent.

The best fuel for water gas manufacture is hard cake and anthracite. A typical composition rater gas is

H_2 = 48-51%, CO = 40- 42%, CH_4 = 0.1-0.05%, CO_2 = 3-5%, N2 = 3-6%

Theoretical combustion air requirement = 2-25 Nm^3/Nm^3

CV = 2500-2800 kcal/Nm^3

Sp. gravity (Air=1) = 0.5-0.55

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

Uses of water gas:

- It is used as a fuel in furnaces.
- Normally, it is enriched by adding hydrocarbon gas (oil gas) and the mixture is *carburetted water gas* which has a high C.V.
- It is also used as a sourer of hydrogen for ammonia synthesis in fertiliser plant.

When water gas is specifically produced for ammonia synthesis, a proportion of air is added to the steam so as to get a mixture of H_2, CO, CO_2, und N_2. This is called *semi water gas.*

CARBURETTED WATER GAS

- CV of water gas is too low for being an effective gaseous fuel in town gas distribution system, However, it can be enriched to make 'carburetted water gas'' by mixing with hydrocarbon oil vapor having a high C.V. of 10000-13000 kcal/Nm^3).
- Process of making carburetted water gas involves both gasification of coal as well as oil and then mixing them (oil gas+ coal gas).
- That means carburetted water gas a mixture of ***water gas and oil gas.***
- Carburetted water gas is made by passing water gas through a hot chamber called carburettor) into which hydrocarbon oil is sprayed. The oil cracks and produces methane ethane, ethylene, propane and other unsaturated hydrocarbons which have high calorific values.
- The resultant gas mixture is the carburetted water gas with a high C.V. up to 4300 kcal/Nm^3. A typical composition and properties of carburetted water gas is given below

  CO_2=5.6%, C_mH_n = 7%, O_2 = 0.4%, CÓ = 30.5%, H_2 =37.0%
  CH_4 = 14%, N_2=5.5%, Gross C.V. = 4770 kcal/Nm^3 dry
  Sp. gravity (Air = 1) = 0.63, Cold gas efficiency = 65% (with light oil)
  Theoretical combustion air requirement = 4.27 Nm^3 /Nm^3 gas

- The cyclic process of carburetting water gas is synchronised with the parent water gas
- generation process. And, the resultant gas is passed out of the plant through a wash box.
- Part of the heat produced by blow gas in carburettor and superheater is fed back to the fuel bed by carrying out back run. Steam is blown through superheater and carburettor into the top of the fuel bed. Oil is sprayed into the steam which cracks on passage through the fuel bed. This back-run increases the thermal efficiency of the plant.
- Production of 1 Nm^3 of carburetted water gas typically requires steam -0.65 kg, coke-0.45 kg, oil-0.3 kg, air-1.5 Nm^3.

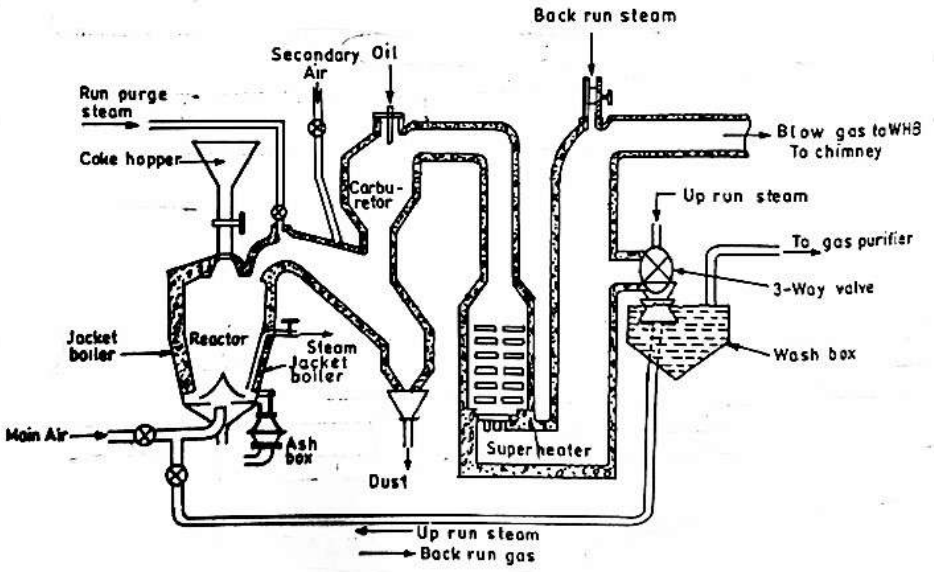


Fig: carburetted water gas plant

- Production of 1 Nm^3 of carburetted water gas typically requires steam -0.65 kg, coke-0.45 kg, oil-0.3 kg, air-1.5 $Nm^{3.}$
- A schematic diagram of carburetted water gas plant is given in above fig. Carburetted water gas is mainly used as an ingradient of town gas and as substitute of coal gas to meet peak loads of gas supply."

BLAST FURNACE GAS

- It is a low grade producer gas made by partial combustion of coke used in the blast furnace and modified by the partial reduction of iron ore.
- It is a by-product of the iron blast furnace. During the manufacture of pig iron, when the air enters the tuyeres, its oxygen reacts with the coke.
- The resulting gas passes up through the shaft of the furnace which has been charged with coke, iron ore, manganese, quartz, limestone, dolomite, sinter etc., and after a number of chemical reactions, issues as a heated dust laden, lean, combustible gas.

Yield of B.F.gas: About 2.5-3 tons of blast furnace gas is generated for one ton of pig iron produced, the coke rate in the furnace being 550-700 kg/ton pig iron. Volumetric is about 1800-2000 Nm^3/ton pig iron or about 3000-3200 Nm^3 /ton of coke charged in B.F.

Composition of B.F: Gas. A typical range of composition is given below:
CO = 21-23%, H_2 = 4-5%, CO_2 = 18-20%, N_2 = 53-55%, O_2 = 0.2-0.5%

Properties of B.F: Gas. It is a very poisonous gas due to the presence of high amount of carbon monoxide in the gas. B.F. gas pipes and vessels should be leakproof.

Characteristics of B.F. Gas:

- It has a very low calorific value of 800 to 850 kcal/ Nm^3, depending upon blast furnace coke consumption rate.
- It has got a low theoretical flame temperature.
- It has a low rate of flame propagation-relatively lower than any other common gaseous fuels.
- It has a high specific gravity (highest of all common gaseous fuels.)
- It burns with a non-luminous blue flame.

Uses of B.F. Gas: Though it has a very low calorific value, yet because of the large quantity of the gas produced, it is one of the most important fuels in an integrated iron and steel plant.

It is used as such or after preheating in:

- Hot dip galvanising line (HDGL) furnace
- Foundary ovens
- Blast Furnace stoves
- Soaking pits
- Annealing furnaces

- Reheating furnace -Billet heating
- Boilers
- Coke oven underfiring

Great care is taken in its utilisation, because of its toxic & poisonous nature and the surplus gas may be stored in gas holders or bled out in the atmosphere after burning it, as the case may be.

COKE OVEN GAS

It is produced during high temperature carbonisation of *coking coal*. It is the most important fuel in an integrated steel plant.
Yield of coke oven gas is 290-300 Nm^3 of gas/ton of dry coal Carbonised.

A typical volumetric composition of clean coke oven gas is given below:
CO = 7-8%, H_2 = 58-60%, CH_4 = 23-25%, N_2 = 2-3%, CO_2 = 2-4%, O_2 = 0.5-0.8%, C_mH_n = 2-3%

About 20% of the sulphur in coal is evolved with the distillation products. Much of this remains in the coke oven gas as H.S. Gases high in sulphur content are undesirable for metallurgical purposes as they cause brittleness of surface while rolling the steel after hot scarfing
the slabs of steel.

FACTORS AFFECTING THE COMPOSITION OF COKE OVEN GAS:

Composition of coke oven gas varies with the temperature of carbonisation, time Effect of temperature and rank & type of coal.

Effect of temperature: With increase in the temperature of carbonization,

- hydrogen content of the coke oven gas increases because of cracking of hydrocarbon
- methane and other hydrocarbon content of the gas reduces due to their cracking.
- carbon monoxide content of the gas increases because of the reaction $CO_2+C=2CO$ (carbon is produced from cracking of hydrocarbons).
- yield of the gas increases due to volatalisation and cracking of liquid hydrocarbons (mainly tar).
- calorific value of the gas decreases because of substantially large reduction in hydrocarbon content
-

Effect of time: With increase in the time of carbonisation at a given temperature, the hydrogen and the hydrocarbon content decreases resulting in the greatly reduced calorific value.
Effect of rank of coal: With increasing rank, the proportion of hydrocarbon decreases and the proportion of hydrogen increases e.g. the composition of the gas obtained by carbonising anthracite resembles that obtained in the final stage of carbonisation of bituminous coal and is of the gas rich in hydrogen.

Effect of type of coal: Black durains and cannel coals yield gases containing high proportion of hydrocarbons (particularly unsaturates) of high illuminating value.

Characteristics of Coke Oven Gas:

- Unlike B.F. gas, surplus coke oven gas can be bled into atmosphere without burning as it is not that toxic.
- It burns with a luminous to semi-luminous flame depending upon the degree of mixing of gas and air.
- Its rate of flame propagation is considerably higher than that of natural gas, producer gas and blast furnace gas.
- It has a low specific gravity-lowest of all the pure gaseous fuels used in steel industry.
- It has high theoretical flame temperature-little higher than that of natural gas even.
- Its explosive range is about twice of natural gas.

Uses of Coke Oven Gas:

Coke oven gas has a more extended use than B.F. gas, because of

- relatively low distribution cost due to its low specific gravity, high calorific value and cleanliness,
- its ability to develop extremely high temperature by combustion.
- high heat release rate thereby eliminating excessively large combustion chamber furnaces.

Coke oven gas is used mostly in mixture with B.P. gas in the iron and steel works itself for Blast Furnace Stoves heating Coke Oven heating the following usage:

- Boilers of captive thermal power plant
- Sinter Machine furnace
- Soaking pits, reheating furnaces, annealing furnaces etc.
- Forge furnaces and foundry ovens
- Blast furnace runner and laddle drying
- Calcination kilns

MIXED GAS

- It is a mixture of blast furnace gas and coke oven gas in different ratios to have a gas fuel of a desired calorific value and combustion characteristics.
- There are a number of applications where neither B.F. gas nor coke oven gas, when used alone, develop the desired flame characteristics or temperature level for optimum results. By mixing the two fuels of great variance in characteristics, a more ideal fuel can be obtained free specific applications with specific properties.

- The calorific value and the speed of combustion is very high for coke oven gas and very low for blast furnace gas. The desired speed and calorific value can be attained by the proper proportioning and mixing of the two fuels.

L.D. CONVERTER GAS (BOF GAS)

- It is mixture of mainly CO & CO, and is produced in L.D. converter during the process of steel making. When oxygen is blown to remove carbon from pig iron in L.D. converter, the converter gas is produced ($C + O_2 = CO_2$, $C+O = CO$).
- The converter gas having a very high concentration of carbon monoxide (up to 80% during peak period) in earlier L.D. converter used to be burnt at the mouth of the converter itself thereby eliminating its toxicity by conversion of CO into CO_2 (viz. $CO+\frac{1}{2}O_2 =CO_2$).
- However, in modern steel making process, the converter gas is recovered as such by suppressing its combustion at the mouth of the converter. It is cooled, cleaned of dust and stored in gas holder for use as a fuel gas.

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5.0 Combustion

5.1 Principles of Combustion:

All conventional fossil fuels (solid, liquid or gaseous) contain basically carbon, hydrogen and sulphur which, when burnt react with oxygen of air form carbon dioxide, carbon monoxide, water vapour and sulphur dioxide respectively.

All the fuels contain basic elements such as carbon, hydrogen, sulphur or its compounds. The combustion of fuel is described with the help of few simple chemical equations as given below:

$C+O_2= CO_2$ -97650 kcal/Kmol → exothermic reaction

$C+\frac{1}{2}O_2 = CO$ -29430 kcal/kmol → exothermic reaction

$CO +\frac{1}{2}O_2 =CO2$ -68220 Kcal/kmol → exothermic reaction

$H_2+\frac{1}{2}O_2 =H_2O$ -57810 Kcal/kmol → exothermic reaction

$S+O_2= SO_2$ -69800 kcal/Kmol → exothermic reaction

$CH_4+2O_2= CO_2 +2H_2O$ -192400 kcal/Kmol → exothermic reaction

Combustion Process:

In the combustion process the rapid chemical combination of oxygen with the combustible portion of the fuel results in heat release.

The most common fuels contain carbon and hydrogen, either as elements or as parts of compounds. These combustible elements and compounds react with oxygen to form carbon dioxide (CO_2) and water vapour (H_2O). Carbon monoxide (CO) can also be formed. Sulphur is usually present in some fuels.
Combustion on fuel produces *flue gases* which are also called as exit gas, exhaust gas or chimney gas.

The Requirements for Combustion are:

- Fuel
- Oxygen
- The 3T → (a) Time (b) Temperature (c) Turbulence

***Fuel*:** The most commonly used fuels are oil, gas, coal etc.
Oxygen: The normal source of oxygen for combustion is air.
Time: Sufficient time must be available for complete combustion to occur. This time period is significant because of the dilution effect of the nitrogen in the air.