

Lecture Notes

On

# **FUEL, FURNACE AND REFRACTORIES**

(3rd semester Metallurgy Branch)

By

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FR  
Fuels

3rd Sem (Metl.)

## Define fuel

A substance which produces heat is called a "fuel". The heat may be produced either by combustion or by nuclear fission ~~or~~ fusion.

~~Fuels~~ produces heat by combustion → simply called as fuels.

↳ produces heat by fission or fusion → nuclear fuels.

## Types of fuels

Mainly of four classes as — fossil, by-product, chemical & nuclear fuels.

Fossil fuels — released heat by combustion.

Nuclear fuel — " " " fission or fusion by converting mass into energy

Fossil fuels → ex — coal, petroleum, natural gas etc.

By-product fuels → <sup>are</sup> the co-product of some regular manufacturing process

ex — coke oven gas, blast furnace gas etc.

Chemical fuels → are of an exotic nature.

ex — hydrazine (rocket fuel), ammonium nitrate, fluorine etc.

Nuclear fuels → releases heat by fission.

ex — Uranium, ~~plu~~ Plutonium etc.

Depending upon the state of occurrence → fuels are classified as solid, liquid & gaseous fuels.



	Natural	Manufactured	Byproduct
Solid Fuels →	Wood coal	Coke Semi coke charcoal etc.	charcoal Wood refuse coke breeze etc.
Liquid Fuels →	Petroleum	Petrol Kerosene Alcohol Naptha Veg. oil etc.	Tar Pitch Paper pulp mill waste etc.
Gaseous Fuels →	Natural gas	Producer gas water gas coal gas Butane propane LPG etc.	Blast furnace gas Coke oven gas Oil refinery gas etc.

Liquid Fuels → - store more compactly than solid fuels.

- handled easily
- It has no ash & clinking problems.
- combustion can be easily regulated.
- It can be used in I.C. engine.
- Low sulphur oils are next to gaseous in cleanliness & controllability.

Gaseous Fuels → - It has no ash or clinking troubles.

- It requires least amount of excess air for complete combustion, so gives high thermal efficiency.
- It can be used in I.C. engines.
- It is easier to maintain oxidising or reducing atmosphere inside the furnace.
- Sulphur compounds from gases can be removed easily.

### Important of Solid, Liquid & Gaseous Fuels →

- Solid →
- No special provision need be made for storage.
  - It is cheap, occurs widely & is easy to handle.
  - It can be pulverised with flexibility of liquid fuels.
  - Sulphur content of solid fuels is very less resulting less atmospheric pollution & corrosion of equipments.
  - Because of low hydrogen content, greater proportion of gross calorific value of solid fuels are utilized.



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## Chapter 10 (3rd Sem. Mett.) Solid Fuels

### Origin of coal

Coal is a complex mixture of plant substances altered in varying degree by physical & chemical processes. These processes changed plant substances into coal & has been accomplished by bacteria, heat & pr. inside the earth crust in millions of years.

Two theories are used regarding the mechanism of formation of coal from plant substances → insitu & drift theories.

Insitu theory → In this coal seam occupies the same place where original plants grew and where their remains accumulated several millions years ago to produce coal under the action of heat, pr & bacteria.

Drift theory → In this, the plants, trees etc. were uprooted & transported by rivers to lakes & get deposited to form coal & there during the course of time after they under-ground.

If sea water is the carrying agent or if the deposit is covered by marine inorganic sediments, then coal formed are rich in hydrogen & having coking properties.

### Stages in the formation of coal →

plant debris (wood)

↓  
peat

↓  
Lignite

↓  
brown coal

↓  
sub-bituminous coal

↓  
bituminous coal → semi anthracite coal

graphite

↑  
anthracite coal

↑

Most coal founds in the world are 'insitu' origin & very little are of 'drift' origin.



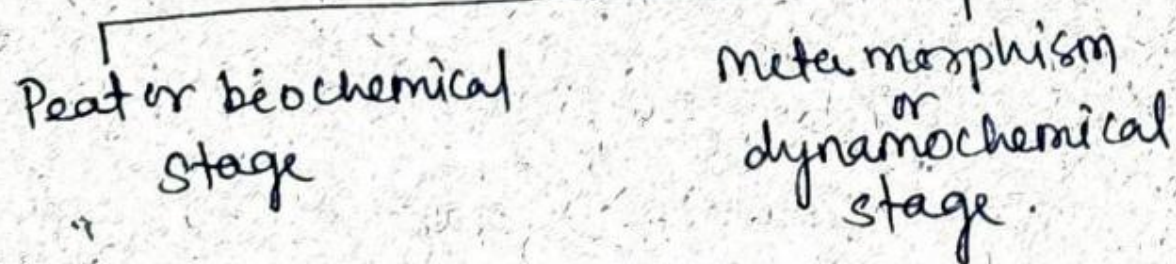
This process of coal formation may be completed or stopped at any stage giving rise to coal of varying grade term as "rank" of the coal.

In this, from peat to anthracite, each coal is more mature or of higher 'rank' than the one which precedes in the series. Thus anthracite coal is of higher rank than bituminous coal. Bituminous coal is of higher rank than lignite.

With the progress of coal forming rxn, moisture & oxygen content reduces & % of carbon increases. Also C.V. increases from 4500 kcal/kg for lignite to 8500 kcal/kg for bituminous coal. There is a little fall in the C.V. of anthracite coal because of removal of hydrogen.

When plant accumulated under water, at a latter stage some mineral got mixed with the coal as it formed. The initial transformation of wood is due to bacterial action causing degradation of organic matter & removal of oxygen. The bacterial act<sup>n</sup> produce acid which if gathered prevent further act<sup>n</sup> & coal formation couldn't proceed. In some cases, the soil is alkaline which neutralised the acid & bacterial act<sup>n</sup> continued to take place bringing further degradation of vegetable matter. Bacterial act<sup>n</sup> takes place & break up organic matter into simpler molecules. The degraded organic matters, as time passed, gave rise to peat. Beyond this stage, heat, pr & time became the chief factors for conversion of peat into different grade of coals.

Stages in formation of coal → 2-stages



In peat stage, the plant material underwent decay under moist conditions by bacterial attack. This happens either by rapid burial of peat deposits under inorganic sediments or by complete flooding by stagnant water followed by covering of sedimentary earth.

In metamorphism ~~stage~~ stage, due to pr. of overburden, tectonic pr. caused by earth movements, regional temp. ↑ by 3-5°C for every 100m ↑ in depth & contact with molten rock & lava. These were operative for a very long time. Thus result<sup>g</sup> in coals of different rank of coal.

Normal age of coal deposits

Geological system era	Mean age (x10 <sup>6</sup> yrs)	Rank of coal formed
Paleozoic	300-245	Anthracite Sem-Anthracite Bituminous
Mesozoic	200-120	Bituminous & Sub-bituminous
Tertiary	60-20	Bituminous & Lignite
Quaternary	<1	Peat

→ With ↑ in vertical depth, the carbon content of the coal ↑ & the volatile matter ↓. The coalificat<sup>n</sup> or metamorphism may be complete or may be stopped at any stage thus giving rise to coals of varying rank of coal.



(2)

FR 300 (Mett.)  
Solid FuelsComposition of Coal

It is expressed in terms of its proximate analysis & ultimate analysis  
composition change from wood to Anthracite

Fuels	% composition on dry ash free basis C-H-N-O	C.V. Kcal/kg	Moisture at 60% RH & 40°C, %
Wood	50-6-0.5-43.5	4990	25
Peat	57-5.7-2-35.3	5490	25
Lignite	67-5-1.5-26.5	6495	18
Sub-bituminous coal	77-5-1.8-16.2	7210	11
Bituminous coal	83-5-2-10	8595	4
Semi-Anthracite coal	90-4.5-1.5-4	8690	1
Anthracite coal	93-3-0.7-3	8500	1.5

Characteristics of Different coalsPeat

It is the first stage product in the formation of coal from wood under the action of temp. & bacteria.

It contains large amount of water upto 90% & its CV is 4500 kcal/kg.

Near the surface of the deposit — it is light brown in colour & highly fibrous in nature.



With 1m depth  $\rightarrow$  colour is darker & finally black.

Before use it is dried for ~~40-50 days~~ 40-50 days.  
The lower layer have higher ash than the upper layers.

Uses - domestic fuel, steam boilers, power stations,  
for making fertiliser.  
Mostly use for heat generation.

Composition Ash - 3-10, moisture - 15-25, Fixed Carbon - 25-30,  
volatile matter - 50-55  
Carbon - 55-60, Hydrogen - 6-6.5, Oxygen - 30-35,  
Nitrogen - 1.5-2 & Sulphur - 0.6-1

Lignite - It is the second stage product. It occurs  
in upto 30mt. thickness near the earth's surface.  
moisture - upto 60%, CV - 5000 kcal/kg on 10%  
moisture basis.

On exposure to the atmosphere, the brown colour  
changes to darkens & the moisture content reduces to  
10 to 20%. On drying it shrinks & breaks up in an  
irregular manner. Hence it can't be moved far from  
the mine. It ignites spontaneously as it absorbs  
oxygen readily & so must n't be stored in open  
without care.

Composition moisture - 10-30, Ash - 3.5-7.5, vol. matter - 40-45  
Fixed Carbon - 30-35.  
Carbon - 70-73, Hydrogen - 4.6-5.5, Oxygen - 22-26,  
Nitrogen - 0.6-1.0, & Sulphur - 0.6-1.5  
C.V - 4000-5,500 kcal/kg (Neyveli)  
lignite

Due to high moisture it is an inferior fuel having low C.V,  
small size & bad weathering properties.

Uses - gas production, power generation, raw material  
for synthetic petrol.

It is also gasified into synthesis gas for ammonia  
production.

### Sub-bituminous Coal

It is a black, homogeneous & smooth mass  
having high moisture & volatile matter content which  
breaks into smaller pieces on exposure to air.  
Carbon content - 70-80% & Oxygen - 10-20%.  
It is a non-coking coal having C.V. - 7000 kcal/kg.  
On exposure to atmosphere it disintegrates & is so  
difficult to transport.

It ignites easily & is used in raising steam & for  
making gaseous fuel also if low in ~~low~~ sulphur.

### Bituminous Coal

most common variety known as "koela" in Hindi.  
Black & brittle which burns & ignites readily with  
yellow smoky flame.

Moisture content - < 10% Vol. matter - 20-45%.  
Carbon " - 75-90%.

Depending upon vol. matter - it is divided into low,  
medium & high volatile coal.

C.V - upto 9000 kcal/kg on mineral free basis.

Most of the coking coal are of this type coal.

The coal breaks along vertical joints (cleats) into  
rectangular or cubical pieces. The lustre varies  
from bright to dull.

It is denser & harder than lignite & sub-bituminous coal  
& doesn't disintegrate into slacks on exposure to the  
atmosphere.



Uses — combust<sup>n</sup> in domestic ovens, industrial furnaces, boilers, railways locomotives, thermal power plants.  
Also uses in ~~car~~ carbonizati<sup>n</sup> & gasification whereby coal is converted into solid fuels (e.g. coke & semicoke).

Semi-anthracite coal — It is harder than bituminous coal & ignites more easily than anthracite to give a short flame changing from yellow to blue.

Moisture content — 1-2%, vol. matter — 10-15%.

c.v — 8,500 to 8,800 kcal/kg. It is a ~~non-coke~~ non-coke type.

Not found in India.

Anthracite coal — Most matured one of highest rank.

Carbon content — 85-95%, low volatile matter ( $< 10\%$ ) coal is hard, non-coke & burns without smoke with a short non-luminous flame imparting intense localised heat. Due to low vol. matter  $\rightarrow$  ignition is difficult.

c.v — 8000 — 8500 kcal/kg.

It doesn't soil the hand. These coals are non-caking. It has sub-metallic lustre, sometimes even a graphitic appearance. ~~It doesn't found in~~ ~~occurs in~~ India.

Uses — in boilers, domestic ovens, metallurgical furnaces. Also uses in small amount as a component of coke oven charges.



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~~Ques~~

Mett. (3rd Sem)

## Significance of various constituents of coal

Moisture → In general high moisture content is undesirable because it reduces C.V., increase the coal consumption for heat purposes, it lengthens the time of heating.

But in some cases moisture is added to check dust nuisance while loading & unloading. Sometimes, moisture is added on the coal in the coke oven. (This is done to protect the methane & other gas hydrocarbons present in the coke oven gas from cracking in presence of hot coke & hot oven wall).

Generally, the quantity of moisture held by coal at an approximate saturated atmosphere (96-99% relative humidity) is called bed moisture. This can help in to determine the rank of coal.

Always coal is associated with moisture & can be ~~removed~~ removed only on heating above  $100^{\circ}\text{C}$ .

Volatile matter → It is not a constituent of coal. VM is the loss of wt. of coal when heated in absence of air for standard time at standard temperature.

Coal with high VM content → ignites easily, burns with long smoky yellow flame, has low CV, require larger furnace volume for its combustion etc.

Volatile matter doesn't include the moisture of coal.

The high the VM the low is the fixed carbon. With ↑ in the rank there is a ↓ in VM.

The physical nature of the residue left after the VM test is noted as an approximate measure of the caking properties of coal.



### Mineral matter & Ash

Ash is the combustion product of mineral matters present in the coal. It comprises mainly of silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ) & ferric oxide with varying amount of other oxides such as  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$  etc.

High ash content in coal is undesirable because—

- it is harder
- has low C.V.
- produce more slag

The ash content of the coal is reduced by crushing of coal. Coal contains inorganic mineral substances which are converted into ash by chemical reactions during the combustion of coal. Ash & mineral matter of coal are so not same.

Mineral matters in coal consists silicate of ~~aluminium~~ alumina + basic oxide like lime ( $\text{CaO}$ ), magnesia ( $\text{MgO}$ ), & iron ( $\text{Fe}_2\text{O}_3$ )

The mineral matter in coals is either inherent or extraneous.

inherent mineral matter → The inorganic material of organic vegetable substances is responsible.

extraneous mineral matter → due to decaying vegetable during its conversion into coal.

The coal ash consists of silica, alumina, iron oxide & lime. When heated, coal ash doesn't melt sharply at any temp. but begins to soften at much lower temp. than that at which it becomes molten & flows. Higher alumina resulting the ash refractory & while lime, magnesia & iron oxide have fluxing effect & lower the ash fusion temp.

Indian coal — ash is of refractory in nature & the fusion range is above  $1400^\circ\text{C}$ .

→ 1% rise in coal ash is equivalent to 0.3-0.4% fall in boiler efficiency. High ash is so undesirable & harmful. But the coal ash may be used for extracting valuable rare element like germanium. The ash of coal is directly determined in the laboratory by completely burning the coal.

Parr formula is used for calculating the mineral matter content from the ash.

Parr formula →  $\text{MM} = 1.08A + 0.55S$

For Indian coal →  $\text{MM} = 1.1A$ , as Indian coals are low in Sulphur.

Total Carbon → It ~~means~~ means the fixed carbon + carbon present in V.M. e.g.  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{CH}_4$ , hydrocarbons etc.

Total carbon is always more than fixed carbon in any coal. More the total carbon high will be the C.V.



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## Liquid Fuels (FR) (3rd Metl.)

Petroleum (or rock oil) is a naturally occurring, brown to black oil comprising of hydrocarbons found under the crust of the earth on shore or off shore.

It obtained  $\rightarrow$  either by natural seepage or by drilling wells to various depths.

Petroleum oil flows out itself due to underground gas pressure or these are mechanically pumped out.

### Origin of Petroleum

Mainly 3-theories put forward to explain the origin of petroleum.

a) Carbide theory — Accordg to this, hydrocarbons present in petroleum are formed by the act<sup>n</sup> of water on inorganic carbides. Inorganic carbides, in turn are formed by the reaction of metal & carbon under high temp. & pr. conditions inside the earth. These lower hydrocarbons then undergo hydrogenation & polymerization to give ~~various types~~ paraffins, aromatic & cycloparaffins.

b) Engler theory — Accordg to this, petroleum is of animal origin. Petroleum is formed by the decay & decomposition of marine animals under high pr. & temp.

c) Modern theory — Accordg to this, petroleum is believed to be formed by the decay & decomposition of marine animals & vegetable organism of the pre-historic forests.

Due to prolonged action of high temp. & pr. in the interior of the earth for ages, the biological matter decomposed into petroleum.

### Composition of petroleum

C - 84-87%, H - 11-15%, S - 0.1-3%, N - 0.1-1.5%,  
& O - 0.3-1.8%.



## Constituents & Properties of Petroleum Products

### Constituents of Petroleum →

Constituents of petroleum are found by its refining which has got different boiling ranges.

The lighter products (have low boil pt. & mol. wt.) are separated from top of the distillation column whereas the heavier products (have high boil pt. & mol. wt.) are separated at the bottom.

(Distillation column → A pipe in a furnace & its vapours are passed through a tall cylindrical fractionating column which has a no. of plates inside it.)

Petroleum → Distillation → (i) LPG (mainly propane & butane (-160°C to -40°C))

(ii) Gasoline or Petrol (30°-200°C)

(iii) Naptha (120°-200°C)

(iv) Solvent spirit (120°-250°C) or Jet fuel (130°-260°C)

(v) Kerosene (140°-290°C)

(vi) Diesel (140°-300°C)

(vii) Gas oil (180°-350°C)

(viii) Lub. oil (200°-350°C)

(ix) Petroleum (220°-350°C)

(x) Light fuel oil (> 200°C)

(xi) Heavy fuel oil (> 250°C)

(xii) Road make bitumen or tar

(xiii) Wax / asphalt

(xiv) residue pitch / coke

## Properties of Petroleum Products

— Sp. gravity (it determines the max. power/unit of wt./volume.)

— Mol. weight (it is given by (for  $\phi < 0.92$ )  

$$\text{Mol. wt.} = \frac{14.29 \times \phi}{1.03 - \phi} \quad (\phi = \text{sp. gravity at } 15.5^\circ\text{C})$$

— Vapour pressure

— Viscosity

— Viscosity Index (change in viscosity with change in temp. is expressed by Viscosity Index)

$$V.I. = \frac{L-U}{L-H} \times 100 \quad ; \quad U = \text{viscosity of oil sample at } 100^\circ\text{F}$$

$H = \text{viscosity of a std. oil of } V.I. = 100 \text{ at } 210^\circ\text{F}$

$L = \text{viscosity of a std. oil of } V.I. = 0, \text{ at } 210^\circ\text{F}$

(std. oils are taken as — Paraffinic oil has  $V.I. = 100$  & naphthenic oil has  $V.I. = 0$ )

— Viscosity Gravity Const. (VGC) →

$$VGC = \frac{10G - 1.0752 \log(V-38)}{10 - \log(V-38)}$$

( $G = \text{sp. gravity at } 15.5^\circ\text{C}$   
 $V = \text{Saybolt viscosity at } 37.8^\circ\text{C}$ )

— Viscosity Index Extension (VIE) →

$$VIE = 100 + \frac{(\text{antilog } N) - 1}{0.0075} \quad ; \quad N = \frac{\log H - \log U}{KV_{120}}$$

( $H > U$ )  
 $(KV_{120} = \text{Kinematic viscosity of oil samples at } 210^\circ\text{F})$



- Flash point
- Fire point
- Cloud pt., pour pt. & Freezing pt.
- Smoke pt. & char value (for kerosene)
- Carbon residue
- Aniline pt.
- Diesel Index
- Octane no.
- Performance no.
- Cetane no.
- Emulsibility
- Oxidat<sup>n</sup> stability
- Acid no.
- Sulphur Content
- Moisture
- Colour & fluorescence
- Distillat<sup>n</sup> range
- C.V.
- Sediments in liquid fuels
- Ash in Petroleum products
- Settl<sup>n</sup> pt. & melt<sup>n</sup> pt. of wax
- Gum Content of petrofuels
- Reactive index of petrofuels etc.



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~~Ch 03~~ FR (3rd Mtl)

## Liquid Fuels

### Definitions

#### → Flash Point

It is the min. temp. at which an oil gives sufficient vapour to form an inflammable mixture with air & catches fire momentarily (i.e. flashes, when flame is applied.)

It gives an idea about —

- nature of ~~oil~~ boiling pt. diagram of the system
- amount of low boiling fraction present in the liquid fuel.
- explosion hazards during storage & handling.
- volatility of the liquid fuel.

#### Cloud point

When oil is cooled at a specific rate, the temp. at which it becomes cloudy is called the "cloud point" of oil. This is due to the separation of the crystals of wax or increase of viscosity at low temp.

Cloud pt. is important for fuel oils which have to pass through unheated filters of fine mesh.

ex- a jet plane may be exposed to  $-60^{\circ}\text{C}$  & if solid wax separates from fuel oil, the carburettor may be blocked up.

#### Pour point

The temp. at which the oil just ceases to flow is called the "pour point". It determines the temp. below which, an oil can not be used as a lubricant as well as the waxy nature of oil. Increasing lighter hydrocarbons reduces the pour point.



### Aniline Point

It is the lowest temp. at which an oil is completely miscible with an equal volume of aniline. It is the measure of aromatic content of the oil, hence is a characteristic property of diesel.

Aniline point of an oil gives an indication of the possible deterioration of rubber sealing, packing etc.

Higher the aniline pt., better the diesel fuel & the lubricant.

### Octane no.

This is the property of gasoline which is used in a S.I. engine for determining & expresses its knocking characteristics.

(Knocking — When an SI engine operates at high load & low speed, a rattling sound may develop inside the combustion chamber resulting from unsteady & uncontrolled combustion. This noise is called as "knocking or detonation".)

### Cetane no.

It is a characteristic ~~poor~~ property of diesel & is used to indicate its quality & performance in C.I. engine.

A oil of high cetane no. has a low octane no. & vice versa.

High cetane no. will facilitate easy start of engine in cold weather, fast engine warmup & ↑ in  $\eta_{\text{engine}}$  with less exhaust smoke.

### Sp. gravity

It is the ratio of wt. of any vol. of the liquid to the wt. of same vol. of water.

$$\text{Sp. gravity} = \frac{\text{Wt. of any vol. of liquid}}{\text{Wt. of same vol. of water}}$$

### Viscosity

It is the property of a fluid by virtue of which the fluid offers resistance to shear or to angular deformation.

Greater this resistance, greater is the viscosity.

Fire Point — <sup>Not in the syllabus</sup> It is the lowest temp. at which vapours given off by oil ignites & continues to burn for at least 5 sec. It is 5-40°C higher than flash point. It gives an idea of fire hazards during the storage & use of oil.

Freezing Point — It is the temp. at which the fuel oil freezes completely & cannot flow at all. This is imp. in case of aviation ~~gasoline~~ gasoline because at high altitudes where temp. are encountered, the fuel supply from fuel tank to engine may be impeded due to clogging of pipe-line if the freezing point of the fuel oil is not sufficiently low. Aviation gasoline has freeze pt. of below 60°C.

Smoke point → This is the max. ht. of flame in mm. without smoke formation when kerosene is burned in a std. lamp under closely controlled ~~control~~ cond's. Smoke is due to presence of aromatic hydrocarbons.

Char value — It is the amount of charred oil deposit on the wick obtained from kerosene after burning in a std. wick lamp at a std. rate of 24 hrs. The wt. of char



## Process of Crude oil distillation

Distillation of crude oil is done to separate the crude oil into motor gasoline, kerosene, gas oil & fuel oil. Fraction of crude oil is identified by its boiling range.

The crude oil is first pumped from tankers to the crude oil tanks where it is allowed to settle to separate the water & then water is drain off.

The crude oil is pumped from the tanks to the primary column of the distillation unit by centrifugal pump with high pressure. This is done because before entering to the column the crude oil has to pass through pre heat exchanger & a preheat furnace.

The crude oil, partly vaporized, enters the primary tower which is a conventional distillation column with a no. of plates. Gasoline & gas rise to the top and are condensed in the overhead condenser & flow into an accumulator. The heavier components (gas oil & residue) fall to the bottom of the column. In order to provide sufficient liquid flow down the column, to affect fractionation, a part of the condensed liquid from the overhead ~~column~~ accumulator is pumped back to the column as reflux. Within certain limits, greater the reflux, better is the quality of overhead products.

The primary tower is operated under pressure to retain & dissolve substances like butane which improve the ~~antiknock value of gasoline~~ antiknock value of gasoline.

The straight-run gasoline from the primary tower contains certain very low boiling compounds which render it unsuitable for storage under atmospheric conditions.



The max. temp. upto which crude oil can be heated without cracking is  $400^{\circ}\text{C}$ , which sets the limit of the max. amount of distillate that can be collected by atmospheric distillation.

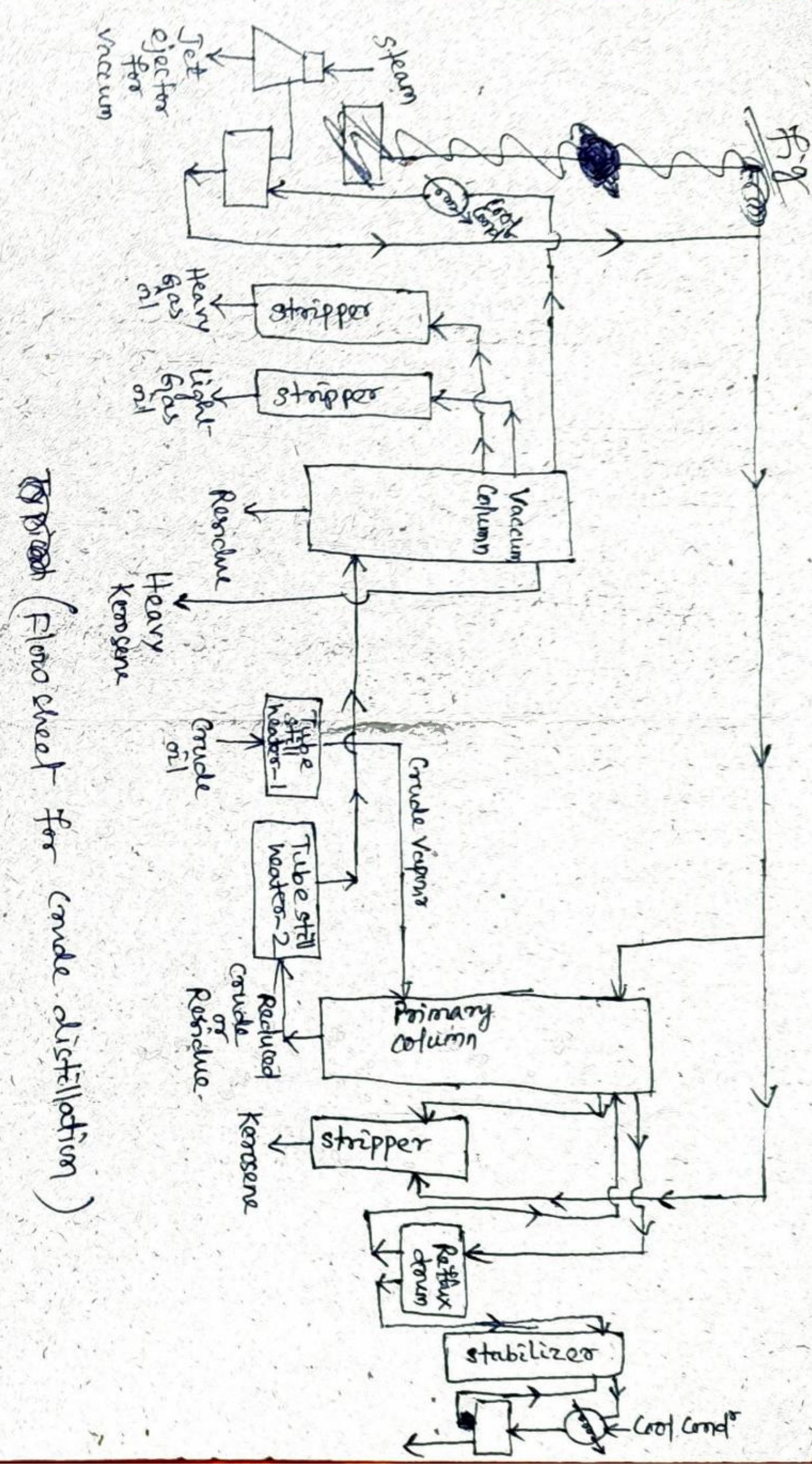
The reduced crude at the bottom of the primary tower consists of kerosene, gas oils & residue. It is then pumped through a furnace into the secondary tower. The components of reduced crude are all high boiling materials & would require very high temp. to vaporise them. High temp. will destroy the quality of oil by cracking it & will prove very corrosive to the material of the tower itself. The boiling pts. are hence lowered by applying a vacuum to the tower by the use of steam jet ~~condenser~~ ejectors. Operation at a absolute pr. of 30 mm. Hg lowers boiling points well enough to vaporise all the oils with a heater o/l temp. of  $320^{\circ}\text{C}$ .

Kerosene & light & heavy gas oils are drawn off as side streams. The last two liquids still contain some low boiling material which lower the flash point & render them unsafe for storage. Then they are fed into columns called strippers where steam or oil heat is applied to drive away the light material. steam reduces the partial pressure of oil vapour & causes the low boiling components to be driven off.

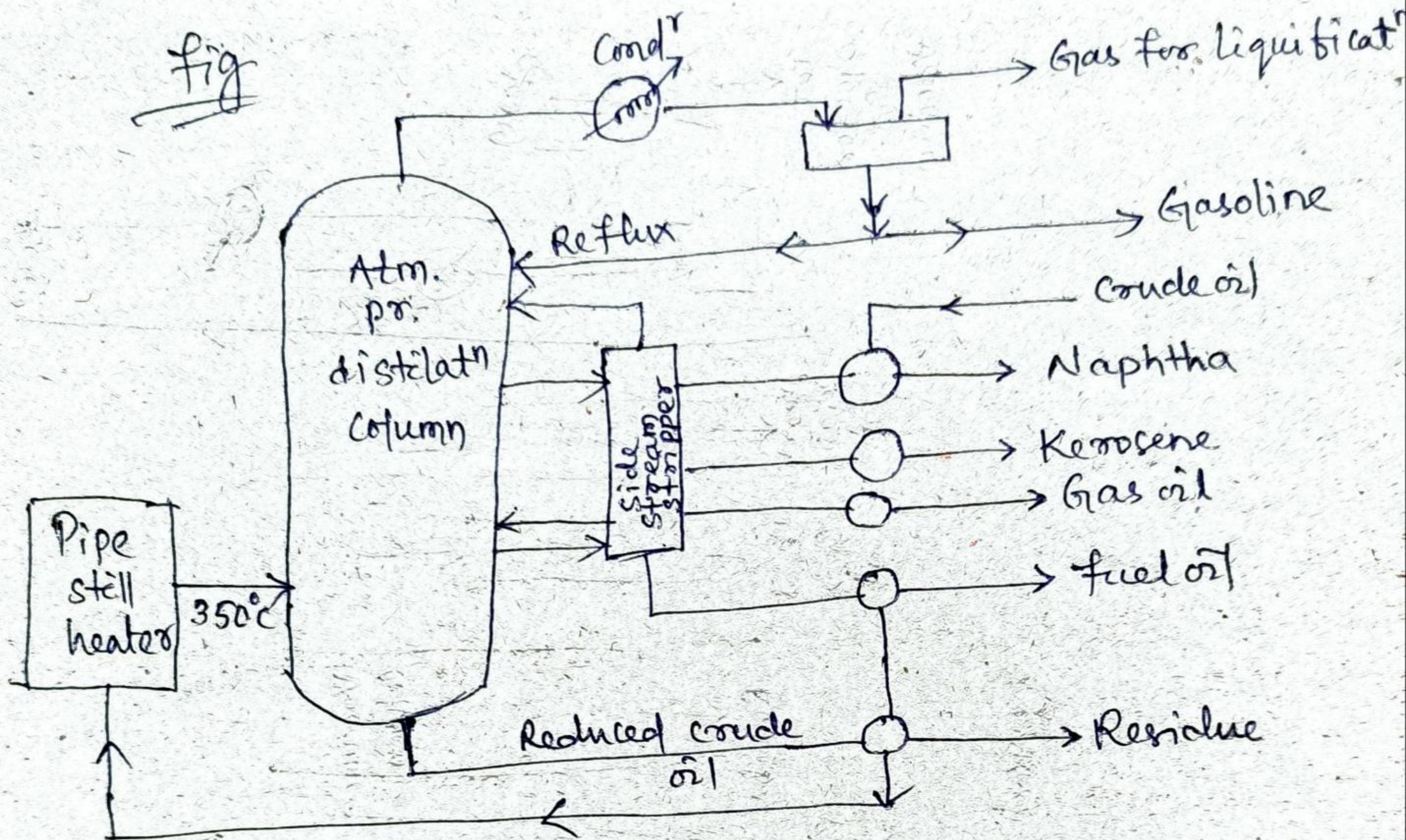
The residue from the secondary tower is pumped away to storage or feed unit where it is split into asphalt for bitumen manufacture & waxy distillate for catalytic cracker feed.

### Various Crude oil distillation systems

- a) shell still distillation (obsolete)
- b) single stage " Unit (Atmospheric pr.)
- c) Two stage " " (Atmospheric & High pr. units)
- d) Three " " (High pr., Atm. pr. & Vacuum units)







(Single stage Crude-refining process)



(A)

Ch-04 FR (3rd Sem Mett.)  
Gaseous Fuels

Methane Gas

During coalification process coal absorbs methane formed, so it is associated with coal & is obtained from coal mines. During coal mining, methane gradually desorbed. Methane gas from mines recovered by a system of boreholes & is used as a fuel. The composition of methane gas from coal mines is variable but is essentially a high concentration methane. In India, methane is not being recovered.

Natural Gas

It is a mixture of paraffinic hydrocarbons in which methane is present. It occurs in gas field & with crude petroleum in oil fields. After delivery from wells, natural gas is proceeds to remove the solids. It is then treated for recovery of gasoline & LNG. The natural gasoline recovery from gas is done by compressing & cooling or adsorption on a porous solid. When natural gas contains very less recoverable condensate  $< 15 \text{ gm/m}^3$ , it is called as dry natural gas & when contains more than  $> 50 \text{ gm/m}^3$  it is known as wet natural gas. Natural gas contains large quantity of  $\text{N}_2$  &  $\text{CO}$  with recoverable amount of helium. Some time  $\text{H}_2\text{S}$  are also present.  $\text{H}_2\text{S}$  free gas is called Sweet gas.

Uses

- Used as a fuel for cooking, heating for process furnace & boilers.
- Gas turbine also use natural gas as a fuel.
- Making water gas (Methane in natural gas reacted with steam for this purposes).



Producer Gas  $\rightarrow$  It consists of  $\text{CO}$  &  $\text{N}_2$  & is produced (for fig. see book) in a furnace called producer by blowing air or mixture of air & steam through hot bed of solid fuels like coke or coal.

In the simple gas producer, dry air is blown through a bed of coal or coke of sufficient depth & at a sufficiently high temperature. Gas obtained is  $\text{CO}$  &  $\text{N}_2$  in the ratio 1:2 by volume, with traces of  $\text{CO}_2$  &  $\text{H}_2$ . If coal is used under similar conditions, the gas contains additional hydrogen & methane. Above method was modified due to highly more temperature of fuel bed & much of the potential heat of the fuel leaves the producer gas as sensible heat of the gas.

The common type of producer used is vertical cylindrical chamber type into which the fuel is fed continuously from top. Air is blown through a grate at the base & the gas exit at the top. Ash & 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.

Producer gas composition (by volume %)

$\text{CO}_2$  - 4-6,  $\text{CO}$  - 20-30,  $\text{H}_2$  - 11-20,  $\text{CH}_4$  - 0-3,  
&  $\text{N}_2$  - 46-55

C.V. - 1250-1550 kcal/ $\text{Nm}^3$

Sp. gravity - 0.85-0.90 (Air=1).

Also producer gas contains steam, sulphur compound, tarry vapours,  $\text{NH}_3$  in very low quantity.

Uses — i) Used for firing in glass melting & open hearth furnaces.

ii) Used in I.C. engine.



(B)

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FR (mett. Diploma)

### Gaseous Fuels

Water gas → It is a medium c.v. gas about  $2500 \text{ kcal/Nm}^3$  comprising mainly of  $\text{CO}$  &  $\text{H}_2$ . It is prepared by action of superheated steam on a bed of hot coke or coal at about  $1000^\circ\text{C}$  as per the reaction  
 $\text{C} + \text{H}_2\text{O} = \text{CO} + \text{H}_2$ ,  $\Delta H = +28 \text{ kcal/kmol}$   
(endothermic reaction)

As the above reaction is endothermic, the coal cools down after few minutes & then  $\text{CO}_2$  &  $\text{H}$  are formed instead of water gas. In order to avoid this, the current of steam is intermittently replaced by a blast of air. Thus due to exothermic reaction the temp. of carbon again rises & when the temp. increases to  $1000^\circ\text{C}$  air entry is stopped & steam is then allowed to pass. The period of steam blow (cold blow) is for 4-min. while the period of air blow (hot blow) is for about 1-2 min. This process is adjusted in such a way that the maximum yield of water gas is obtained.

A water gas generator is a cylindrical vessel made of steel of 4-5 mt. in height & 2-3 mt. in dia. A hopper is provided at the top for coke adding & water gas outlet is provided near the top. There also provision for inlet of steam & air to the generator. At bottom an arrangement is there for taking out ash formed during the process. During steam blow water gas is produced & is taken out through the gas outlet of the generator. Some nitrogen,  $\text{CO}_2$  &  $\text{CO}$  are also generated during the air blow. These are allowed to escape to the atmosphere, so the manufacture of water gas is intermittent.

Composition —  $\text{H}_2$  — 48-51%,  $\text{CO}$  — 40-42%,  
 $\text{CH}_4$  — 0.1-0.5%,  $\text{CO}_2$  — 3-5%,  $\text{N}_2$  — 3-6%.

Fuel used — hard coke & anthracite coal.

c.v. — 2500 — 2800  $\text{kcal/Nm}^3$ , sp. gravity — 0.5-0.55 (Air=1)

It is also called as blue gas.

Uses → Fuel in furnace, Use as a source of hydrogen for Ammonia synthesis in fertilizer plant.

(for fig see book)



## Carburised Water gas

Water gas enriched to make carburised water gas by mixing with hydrocarbon oil vapour having high c.v. of 10000-13000 kcal/Nm<sup>3</sup>. Process of making this gas involves both gasification of coal as well as oil & then mixing oil gas & coal gas. Carburised water gas is a mixture of water gas & oil gas.

Carburised water gas is made by passing water gas through a hot chamber i.e. carburiser into which hydrocarbon oil is sprayed. The oil cracks & produces methane, ethane, ethylene, propane & other unsaturated hydrocarbons with high c.v. The resultant gas mixture is the carburised water gas with a c.v. of 4300 kcal/Nm<sup>3</sup>.

### Composition

$\text{CO}_2 = 5.6\%$ ,  $\text{CmH}_n = 7\%$ ,  $\text{O}_2 = 0.4\%$ ,  $\text{CO} = 30.5\%$ ,  
 $\text{H}_2 = 37.0\%$ ,  $\text{CH}_4 = 14\%$ ,  $\text{N}_2 = 5.5\%$ , Gross c.v. = 4770 kcal/Nm<sup>3</sup>,  
 Sp. gravity (Air=1) = 0.63

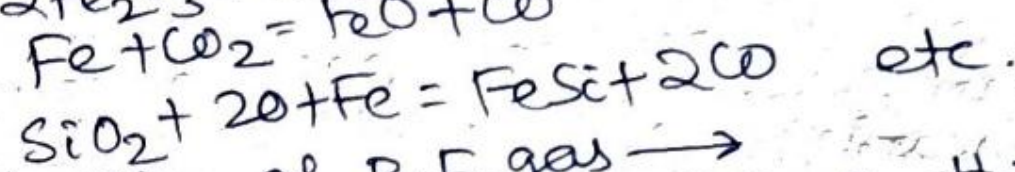
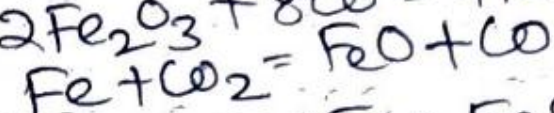
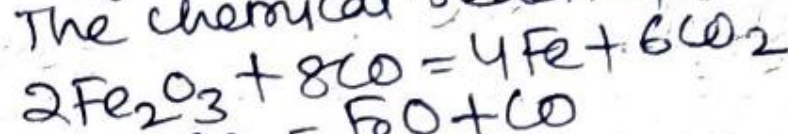
This plant involves unit of carburiser & superheater with a water gas generator. The oil used in carburising is a light petroleum fraction comprising of paraffins. Carburiser & SH are filled with chequered bricks. The gas produced during blow period is burned in the carburiser & then the combustion is completed in the superheater. During the run period oil is sprayed into the carburiser & the water gas is passed through the chamber. Endothermic oil cracking process is completed in the SH which results to fall in brickwork temperature which are again heated up during the blow period. The cyclic process of carburising water gas is synchronised with the water gas & the resultant gas is passed out of the plant through a wash box. Production of 1Nm<sup>3</sup> of carburised water gas requires steam - 0.65 kg, coke - 0.45 kg, oil - 0.3 kg & air - 1.5 Nm<sup>3</sup>.  
 Uses - used as an ingredient of town gas & as substitute of coal gas to meet peak loads of gas supply.

(For fig see book)

## 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 iron blast furnace. During the manufacture of pig iron, when the air enters the tuyers its oxygen reacts with coke. The resulting gas passes up through the shaft of the furnace which has been charged with the coke, iron ore, manganese, quartz, limestone, dolomite etc. & after a number of chemical reactions a heated dust laden lean combustible gas is generated.

The chemical reaction responsible for B.F. gas is



Composition of B.F. gas →  
 By volume % is —  $\text{CO} = 21-23$ ,  $\text{H}_2 = 4-5$ ,  $\text{CO}_2 = 18-20$ ,  
 $\text{N}_2 = 53-55$ ,  $\text{O}_2 = 0.2-0.5$

B.F. may be regarded as gas producer in which a few other reactions takes place in addition to the usual producer reactions. The resultant gas has a high  $\text{CO}_2$  content & low  $\text{H}_2$  content.  
 The c.v. of B.F. gas is very low as 800-850 kcal/Nm<sup>3</sup>.  
 B.F. gas produced in steel plant in a very large amount.

### Uses

- Hot dip galvanising line furnace
- B.F. stoves
- Soaking pit
- Reheating furnace
- Billet heating
- Foundry ovens
- Annealing furnaces
- Boilers

— Coke oven underfiring.  
 Mostly B.F. gas is mixed with coke oven gas & is used in various steel plants.



## Coke oven Gas

It is produced during high temperature carbonisation of coking coal. It is the most important fuel in a steel plant. Yield of coke oven gas is 290-300  $\text{Nm}^3$  of gas/ton of dry coal carbonised.

### Composition (by volume %)

$\text{CO}$  - 7-8,  $\text{H}_2$  - 58-60,  $\text{CH}_4$  - 23-25,  $\text{N}_2$  - 2-3,

$\text{CO}_2$  - 2-4,  $\text{O}_2$  - 0.5-0.8,  $\text{CmHm}$  - 2-3

About 20% of Sulphur in coal is evolved with the distillation products. Much of this remains in the coke oven gas as  $\text{H}_2\text{S}$ . Gases high in Sulphur content are undesirable for metallurgical use as they cause brittleness of surface while rolling the steel after hot starting the slabs of steel.

### Uses

- Coke oven heating
- B.F. stoves heating
- Boilers of captive T.P. plant
- Soaking pits, annealing furnace
- Foundry oven, Forge furnaces
- B.F. runner & ladle drying
- Calcination & kilns etc.

Coke oven gas produced in low temperature coal carbonisation plant has a higher C.V. of 6000-6500  $\text{kcal/Nm}^3$ .

It is used as an ingredient of town gas supply system. It is also suitable for synthesis gas.



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## Gaseous Fuels

### Mixed Gas

It is a mixture of B.F. gas & coke oven gas in different ratios to have a gaseous fuel of desired C.V. & combustion characteristics. In some applications neither B.F. gas nor coke oven gas were used alone. By mixing these two gases of great variance in characteristics, a more ideal gas can be obtained for specific applications with specific properties. The C.V. & speed of combustion is very high for coke oven gas & very low for B.F. gas. So by proper mixing & proportioning of the two gas mix gas is ~~used~~ generated for attaining the desired speed & C.V. There may be a common gas mixing station for the mixed gas of a fixed C.V. to be supplied to the entire furnaces of the steel plant or the ~~individual~~ individual gas mixing stations to mix the two gases in different proportions suitable for different applications.

Uses — Used in integrated steel & iron plant.



Combustion

All Fuels (Fossil) contains basically C, H & S which when burnt - react with oxygen of air form  $\text{CO}_2$ , CO & water vapour and also sulphur dioxide.

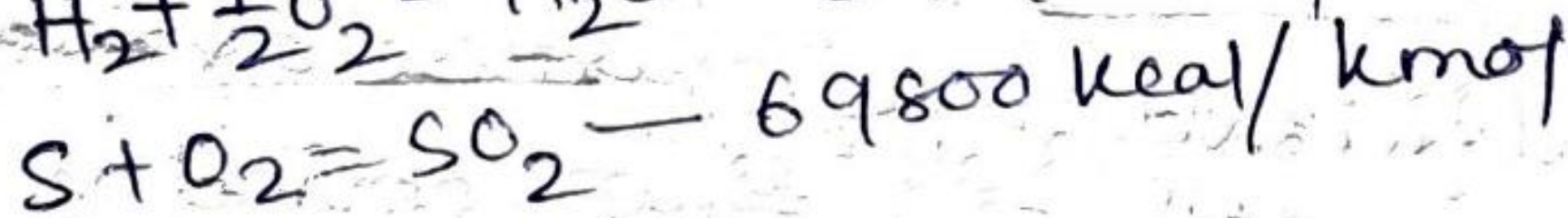
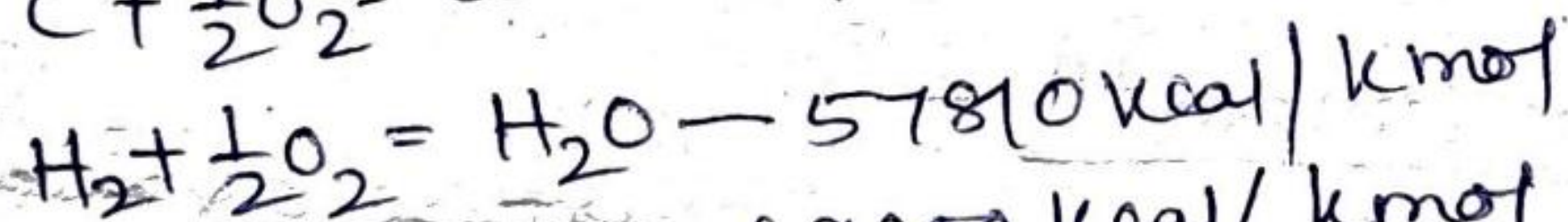
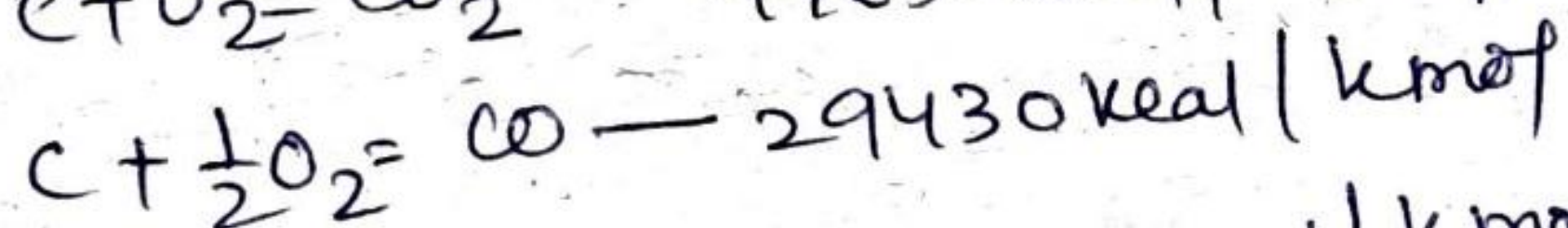
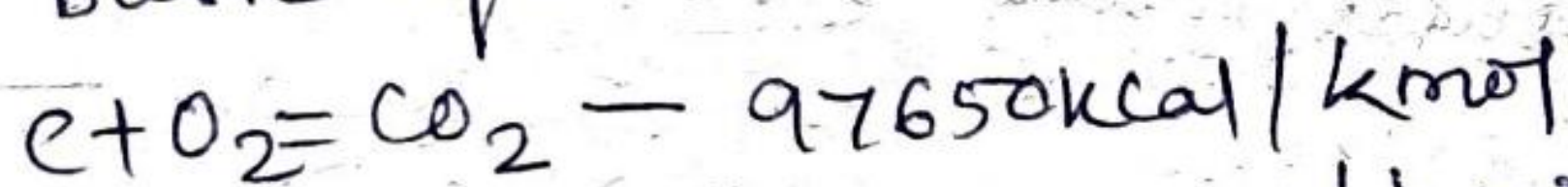
Solid Fuels - burned in lumps or in pulverised form suspended in the air stream

Liquid Fuels - burned either by vaporising & mixing with air before ignition (gaseous fuels) or in the form of fine droplets which get evaporated while mixing with air stream during burning.

Gaseous Fuels - burned either in burner where fuel air both are premixed or they flow separately into furnace & mix together where as combustion proceeds.

Chemical equation for Combustion of Fuel

The basic eqns are —



Combustibles present in gaseous fuels are CO,  $\text{H}_2$ ,  $\text{CH}_4$ , proaffins etc.

Combustion Process

In Combustion process the rapid chemical combination of oxygen with combustible portion of the fuel results in heat release. The most common fuel contain C & H either as elements or as parts of compounds. These combustible elements & compounds react with oxygen to form  $\text{CO}_2$  &  $\text{H}_2\text{O}$  (water vapour). CO can also be formed. Usually S is present in some



Fuels & its combustion products can cause corrosion & environment pollution. Combustion of fuel produces ~~these~~ flue gases also called as exhaust or chimney gas.

### Requirements of Combustion

- Fuel — Commonly used fuels are solid, oil, gas coal & lignite. Fuel is one of the comp. requirement for combustion.

- Oxygen — The normal source of  $O_2$  is air for combustion. Air is a mixture of Nitrogen,  $O_2$  &  $H_2O$  with very small amount of inert gases. By vol. air contains 79% Nitrogen & 21%  $O_2$ . Nitrogen doesn't enter into the combustion, so 79% of the air supplied to combustion process doesn't take part in the reaction but has to be heated along with oxygen to sustain the burning process losing efficiency. Hence a large mass of air must be reqd. for combustion process to get max. of oxygen. The dilution effect of the nitrogen causes many problems in terms of lost efficiency.

### The 3T's for Combustion

Time — Sufficient time must be available for completion of combustion. This time period is important b/c of the dilution effect of nitrogen in the air.

Temperature — ~~For oxidation acceleration~~ when fuel reaches its ignition temp., oxidation is greatly accelerated. The air-fuel mixture must be heated to ignition temp. to promote combustion.

### Ignition temp. of Common Fuel

oil —  $260^\circ C$ , wood —  $290^\circ C$ , Bituminous coal —  $400^\circ C$   
 $CH_4$  —  $705^\circ C$ ,  $H_2$  —  $565^\circ C$  etc.

Turbulence — It is vital that air & fuel are thoroughly mixed otherwise complete combustion can't take place. So turbulent mixing is the best to this problem.

Perfect combustion occurs when enough air has been supplied to burn all the fuels. To ensure this, all fuel has been consumed, additional air is supplied. This extra air is called excess air.

### Hess's Law

For any chemical reaction at std. condition, the std. enthalpy is the sum of the std. molar enthalpies of formation of the products (each multiplied by its coefficient in the balanced chemical equation) minus the corresponding sum for the reactants.

$$\Delta H_{rxn}^\circ = \sum \eta \Delta H_f^\circ \text{ products} - \sum \eta \Delta H_f^\circ \text{ reactants}$$

(where,  $\eta$  = ~~stoichiometric~~ stoichiometric coefficients)

example  $CH_4$  Combusting into  $CO_2$  &  $H_2O$  →  
 $CH_4 + 2O_2(g) \rightarrow CO_2 + 2H_2O(g)$

### Kirchhoff's law

It describes the enthalpy of a reaction varies with temp. changes. The overall enthalpy of the reaction will change if the difference in the enthalpy of products & reactants is different.



Enthalpy — It is a thermodynamic property.  
It is the sum of the internal energy added to the  
product of the pr. & vol. of the system.

It is denoted by  $H$ .

Sp. enthalpy is  $h$ .