Module-2

Solid Fuel

Coal is a fossile fuel that forms when dead plant matter is converted into peat, which in turn is converted ito lignite, then subbituminous coal, after that bituminous coal & lastly anthracite. This involves biological & geological processes.

lignite Coal → Brown or black color woody substances with high moisture contents.

There are two theories propased for the mode of accumulation of the plant materials to transform into coal.

1) In-situ theory :- The coal seems are observed where once forest grew. As the land was sinking slowly, the accumulated vegetation matters went under water slowly & did not decompose & destoyed. In the course of time, the rate of sinking of land was increased & coal forest was submerged under water. Again, land along with the coal forest emerged out of water after sufficient time & this cycle went on again & again, which is responsible of formation of coal strata & seams. The evidence of this phenomenon is observed in the coal that the stem of fossil trees is found standing erect with their roots protruding into the under lays. The uniformity in thickness & composition of coal seam over wide area suggests that the deposition of plant material took place in still water.

2) Drift theory → The plant material was transported with the stream of water from one place to another & finally get deposited in a place of swamp having suitable condition like sediments. The coal seams of India are of drift origin. The evidence of drift theory that the rocks associated with the coal seams are of distintly sedimentary. The coal seams itself behaves like a sedimentary bed & they are observed to branch out.

Peat transforms into coal by the sequence, as shown in fig.

Peat → lignite → sub-bituminous → Bituminous → Anthracite

Although samples of each rank of coal have distinct physical & chemical characteristics, the border line b/w two consecutive ranks of coal is difficult to determine. The first four samples in the series have a nearly continuous gradation of a given physical & chemical properties, such as moisture content, carbon content, heat content etc.

The major coal fields in India are Gondwana coal field & Tertiary coal field. Gondwana coal field covers the areas of WB, Bihar, Orissa, MP, MH, Andhra pradesh etc. Tertiary coal field covers Northeast India, TN, RJ, J&K, Gujrat etc. more than 98% coal is obtained from Gondwana coal field. Vast reserves of bituminous coal are found in Raniganj & Bokaro-Ramgarh-Karanpura deposits in Gondwana coal field. Raniganj coal measures are high in moisture (3-10%) & high in volatile matter (30-36%). The coals of Gondwana basins are mainly of sub-bituminous.

Classification of solid fuels: — It can be classified into natural & manufactured fuels (artificial).

Natural
- Wood
- Peat
- lignite
- hard coal
  - Bituminous
  - Anthracite

often peat & lignite are considered vegetable coal, while bituminous & anthracite coal are considered mineral coal.

Manufactured solid fuels –

✓Wood charcoal
✓Peat charcoal
✓lignite coke
✓Coal briquettes

✓Coke (from coal) → low temp, high temp, medium temp.

Seyler's classification –

Rank	C%	H_2%.	Volatile matter%.	C V (MJ/kg)	B.S. swelling index
Anthracite	>90	3-3.8	5-10	32.9	1
Bituminous	80-90	4-5	20-36	30.5	9
lignitous	75-80	5-6	36-50	29	2
lignite	<75	5-6	50-60	25	1

Type & composition of coals: –

Type of coal	Carbon% mass	H_2% mass	Age (year*10^6)
1) Anthracite	93-95	3.8-2.8	210-250
2) Carbonaceous	91-93	4.25-3.8	,,
3) Bituminous	80-91	5.6-4.35	150-180
4) Sub-bituminous	75-80	56 - 5.1	60-100
5) lignitous	60-75	5.7-5	20-60
6) Peat	50-60	6.1-5.8	1
7) Wood	46-51	6.2-5.9	0

Analysis of Solid fuels: — composition is characterized by two types of analysis.

1) Ultimate analysis → Mass fraction of the elements present like :. C, H, O, N, S & ashes.

2) Proximate analysis → mass fraction according to the decomposition.

a) Moisture (determined at 110°C)
b) Volatile matter (gas released by heating to 950°C)
c) Fixed Carbon (calculated from the difference to rema[illegible]g Values)
d) Ash (residue obtained when fuel is burned in air)

Properties — ~~Physical~~ : — Apparent density - 1.2-1.8×10^3 kg/m³
Internal area ~ 100m²/gm

Measurement of Moisture → It is carried out by placing a sample of powdered raw coal of size 200 μm size in a uncovered crucible & it is placed in the oven kept at 108±2°C along with the lid. Then the sample is cooled to room temperature & weighed again. The loss in weight represents Moisture.

Measurement of Volatile Matter — fresh sample of crushed coal is weighed, placed in a covered cruicible, & heated in a furnace at 900±15°C. The sample is cooled & weighed. Loss of weight represents moisture & Volatile matter. The remainder is coke (fixed Carbon & Ash).

Measurement of Carbon & Ash → The cover from the crucible used in the last test (volatile matter) is removed & the crucible is heated over the Bunsen burner until all carbon is burned. The residue is weighed, which is the incombustible ash. The difference in weight from the previous weighing is the fixed Carbon. In actual fixed carbon derived by substracting from 100 the value of moisture, Volatile matter & ash.

Heating Value: — Calorific Value → "It is defined as the total amount of heat liberated when a unit mass of fuel is burnt completely" Two type of Calorific Values.

High or Gross Calorific Value → It is defined as the total amount of heat liberated, when a unit mass of fuel is burn completely.

lower or Net Calorific value — It is defined as the net heat produced, when a unit quantity of the fuel is completely burnt.

Calculation of NCV →

Net Calorific Value = gross Calorific value − latent heat of water vap.

NCV = GCV − weight of $H_2 * 9 *$ latent heat of water vapors.

latent heat of water vapors → 587 Kcal/kg.

H_2 in the fuel reacts with O_2 to give water

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

2 Parts — 16 Parts — 18 Parts.

1 Parts — 8 Parts — 9 Parts.

Thus

$$NCV = GCV - 0.09\,H * 587$$

where H → % of H_2 in the fuel.

Theoretical Calculation of Calorific Value — Dulong's Formula —

If both H_2 & O_2 are present, it may be assumed that all the O_2 are already combined with $\frac{1}{8}$ of its weight of H_2 to form H_2O.

Thus for a fuel containing C, H, O & S, the Calorific Value of the fuel is given by Dulong formula.

$$\text{Calorific value} = \frac{\left[8080C + 34500\left\{H - \frac{O}{8}\right\} + 2240S\right]}{100}\ \text{Kcal/kg}$$

C, H, O, S are to % ~~of fi~~ Present in fuels.

Relationship b/w Ultimate analysis & Proximate analysis —

$$\% C = 0.97C + 0.7(VM - 0.1A) - M(0.6 - 0.01M)$$

$$\% H = 0.036C + 0.086(VM - 0.1A) - 0.0035M^2(1 - 0.02M)$$

$$\% N = 2.1 - 0.02\,VM$$

where C → % of fixed carbon A → % of Ash
VM → % of Volatile matter M → % of moisture.

Q Calculate % of C, H, N if given. C → 68% , M - 3% , A - 5% & VM - 13%.

~~Preparation of Coal~~ →

Caking Index → Caking index for coal is determined by a taking sample of the Uniform mixture say sand & Coal at ~~total~~ 25gm in different weight ratios. Then the crucibles are removed & allow to cool. The lump or cake is observed to form the mixture. The cakes are taken out carefully & 500g weight is placed on the cakes. The percentage of loose particles comes out from the cakes are determined separately for each cake which gives a measure of the binding property of the coal sample. The maximum whole number ratio of sand to coal in the 25gm mixture which produces a cake after heating that can withstand a weight of 500g without producing 5% loose grain is the caking index.

Swelling Index :— It is one of the important properties of Coal. Coal is heated under specified condition on flame in a crucible. The swollen mass is cooled & compared with a standard chart where profiles with number are given. The numbers are increasing order from 0 to 9 with a 0.5 increment. The higher the number better is the caking & swelling characteristics.

Coal Mining : "It is the term that encompasses the physical extraction or removal of coal from earth's surface." → Classification of coal mining are given as

1) surface mining method :-
   - * Strip mining
   - * Slice mining
   - * Horizon mining
2) Underground mining method.
   - Bord & piller
     - Shortwall method
   - longwall method
     - Advancing
     - Retreating

Coal can be mined by both surface & underground mining method. Surface mining is a form of mining in which the soil & rock covering the mineral deposits are removed. surface mining carried out when the deposits are found closer to the surface. Underground mining is carried out when minerals deposits are located at a distance far beneath the ground to be extracted with surface mining.

Mining process : — Underground.

Drilling	Coal drill
↓	↓
Blasting	Permitted explosives
↓	↓
Loading	Manual / Scraper
↓	↓
Hauling	Manual / Scraper
↓	↓
Transporting	Tubs, conveyors et
↓	↓
Processing / washing	Coal washeries.

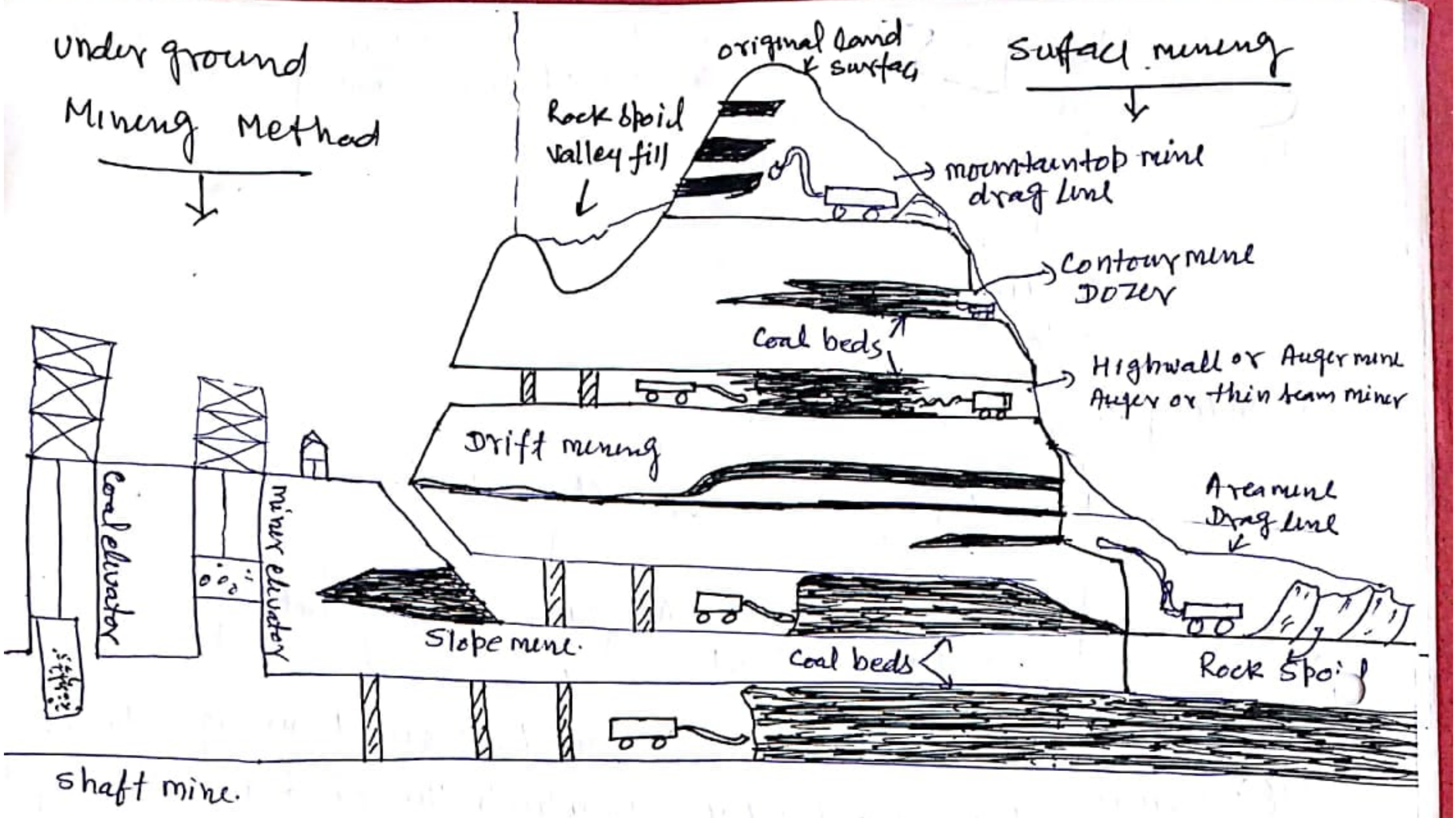


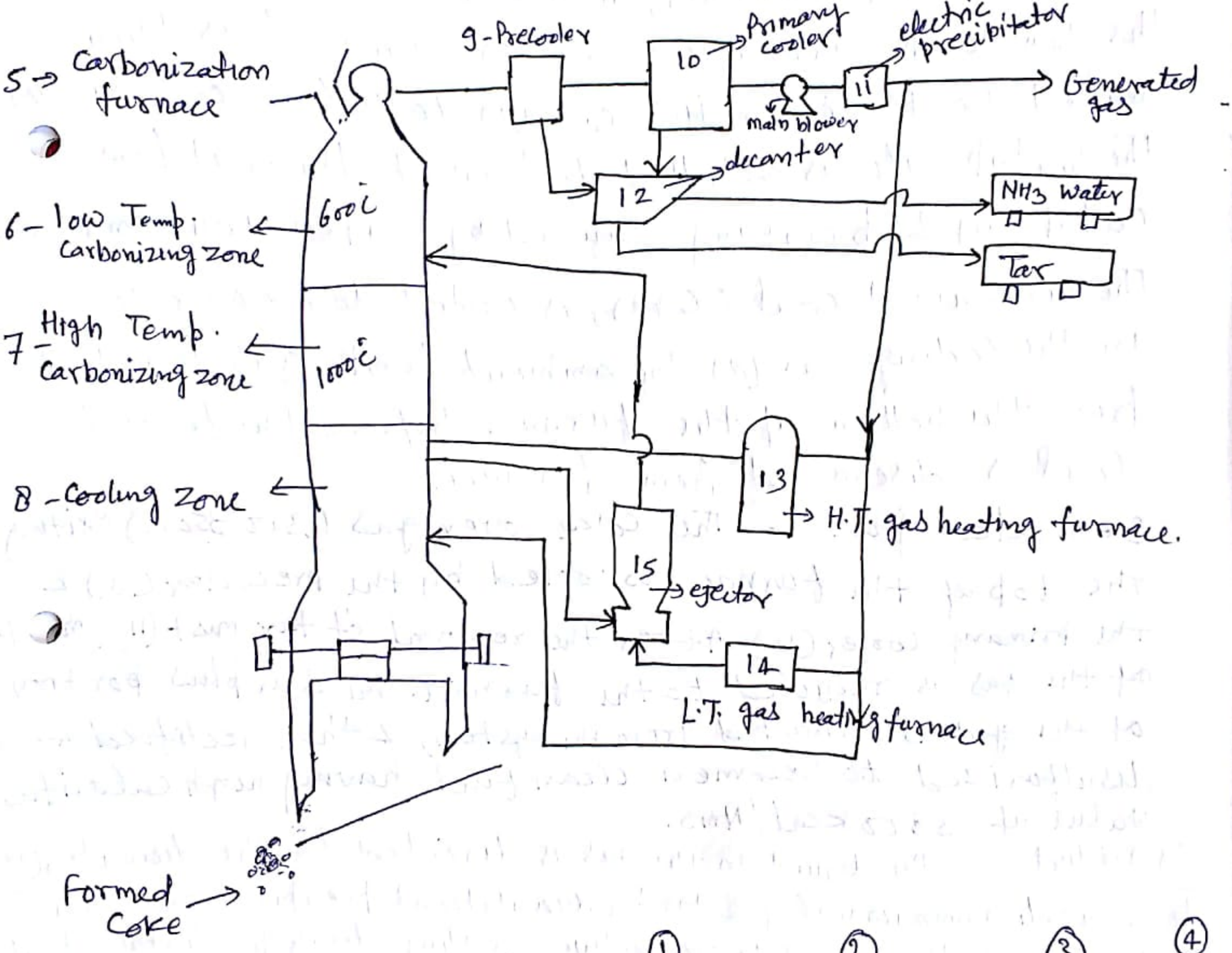
Fig. Mining process digram.

Exploration	→ Finding high quality ore
Drilling & blasting	→ Getting ore out of the ground
Crushing & milling	→ Getting the mineral out of the ore
Separation	→ Separation the mineral from the waste rock
Refining	→ cleaning the mineral or metal
Distribution	→ Distributing the minerals & metals to where they are needed.

Carbonization: —

Characteristics ✓	H.T. Carbonization	L.T. Carbonization
1- Heating Temp	500-700°c	900-1200°c
2- Yeild of Coke	75-80%	65-75%
3- Volatile Matter	5-15%	1-3%
4- Mechanical strength	Poor	Good
5- calorific value	6500-9500 Kcal/m3	5400-6000 Kcal/m3
6- quantity of by product gases	130-150 m3/tone	300-390 m3/tone.
7- Coke produced	Soft	Hard
8- Uses	Domestic	Metallurgy.

Coke Process:- A series of steps are employed in formed Coke process (FCP) ~~("utilize noncaking Coal as the main raw material")~~, including raw material processing, shaping, Carbonizing the formed coal & Cooling the Carbonized coke. In particular, the carbonizing & cooling steps are conducted in a vertical furnace within an enclosed system, providing many superior features in terms of work environment, work productivity, ease of system starts & stops.



Noncaking coal, Caking Coal → ① Drying → ② Pulverizing → ③ Kneading → ④ Forming

Pulverizing ↓ small particle

Kneading ↓ mixing

Forming ↓ Carbonizing

Forming stage: — Noncaking coal is the main raw material (60-80%). The coal is dried to a water content of 2-3%.(1) The dried coal is next pulverized(2). After a binder is added to the pulverized coal, the mixture is kneaded(3) & formed (4), thus producing formed coal.

Carbonizing : — The formed coal is fed to the carbonization furnace(5), where the coal passes through the Low temp. carbonizing zone(6). The coal is then heated to 1000°C in H.T.C.Z (7) to undergo carbonization. The heatup rate is controlled to prevent the coal from collapsing & breaking caused by expansion & contraction. The carbonized coal (coke), is cooled to 100°C or cooler in the cooling zone (8) by ambient temp. gas injected from the bottom of the furnace before the formed coal is discharged from furnace.

Generated gas: — The coke oven gas (300-350°C) exiting the top of the furnace is cooled by the precooler (9) & the primary cooler (10). After the removal of tar mist (11), Most of the gas is recycled to the furnace. The surplus portion of the gas is extracted from the system, & then rectified & desulforized to become a clean fuel having high calorific value of 3800 kcal/Nm3.

By Product: — The liquid in the gas is directed to the decanter(12) to separate ammonia water & tar by decantation & precipitation. Each of these by products is sent to respective existing plants for further treatment. After treated, the tar is reused as the binder for the formed coke.

Gas Recycling → After the tar mist has been removed in the electric precipitator, the gas is heated to approximately 1000°C in the H.T. gas heating furnace (13). It is then injected into H.T.C.Z. (7). The gas, heated to 450°C in the L.T. heating furnace (14) drives the ejector (15). The ejector draws in the H.T. gas that was used to cool the coke. Next, the gas is fed to the low. T. C. Zone (6) at a temp. of approximately 600°C.

Coal liquefaction

— It is process where coal is converted into liquid fuels, mainly to provide substitutes for petroleum products, which may be either used directly as fuel or converted into chemicals or other liquid fuels. Coal liquefaction processes were first developed in the early 20th century. The crude petroleum rich countries may not need this process for fulfilling their reeruitment af liquid fuel but the countries which are lacking of crude but have good reserve of solid fuel like coal, a large scale applications of coal liquefaction process is entertained.

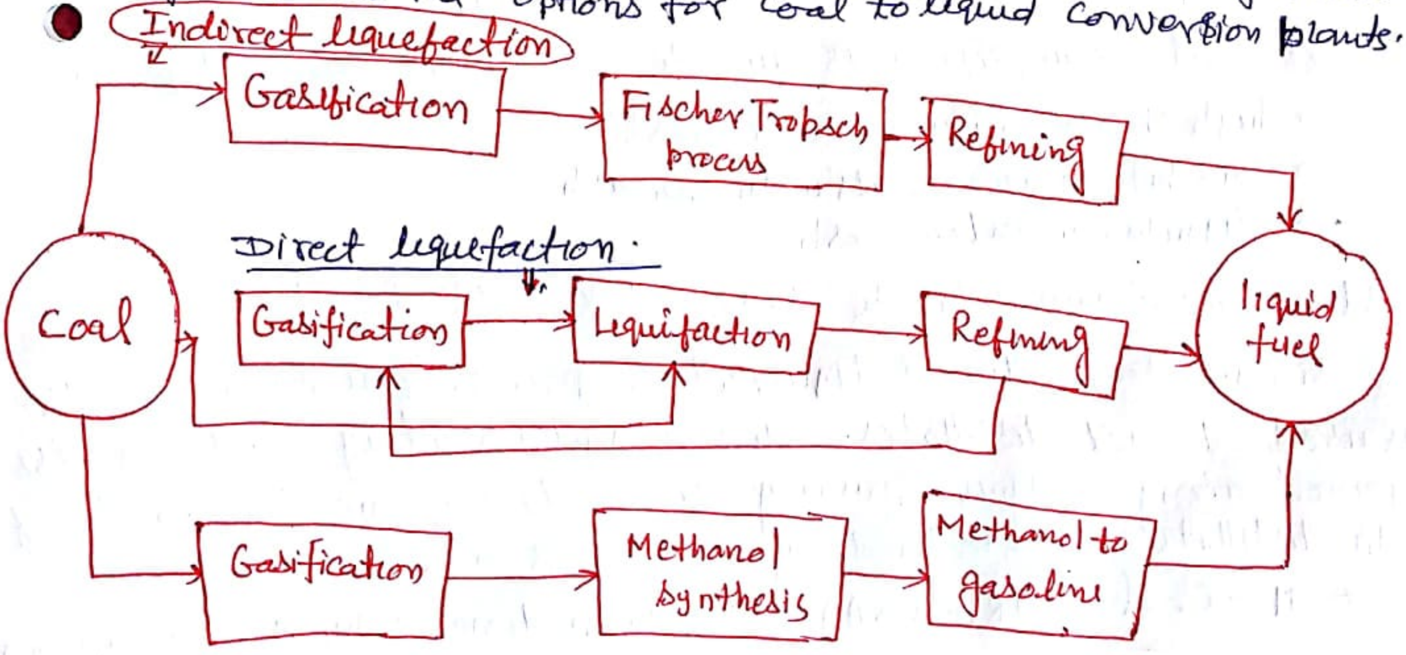
Hydrocarbon type liquid fuels are obtained from solid fuel like coal by the following routes mainly:

a) Hydrogenation of coal

b) Solvent extraction of coal & hydrogenation of coal extracts.

c) Refining of tar & oil obtained from carbonization af various solid fuels & oil shales.

d) Gasification of solid fuels into synthesis gas & conversion of the gas into liquid fuels & chemicals. The following block diagram shows the options for coal to liquid conversion plants.



Different routes of coal liquefaction

Coal liquefaction can be achieved either by direct or indirect process. The difference b/w these two processes lies in that, the indirect liquefaction process needs to go through gasification first, while, direct liquefaction process involves producing partially refined synthetic oil from coal. It is said by the technologists that, indirect liquefaction is more efficient than direct coal liquefaction ~~technologies~~ techniques which are currently available.

Direct liquefaction:- The coal is ground so that it can be mixed into coal derived heavy oil recycled from the process to form a coal-oil slurry feed. The slurry containing 30-50% coal is then heated in a reactor to about 450°c in a hydrogen atmosphere 14-22 MPa pressures for about one hr. Different catalyst used are tungsten or Molybednum sulfides, tin or nickel oleate. The reaction produces heavy oil, Middle oil, gasoline & gases.

The liquids produced have molecular structures similar to those found in aromatic compounds & need further upgrading to produce specification fuels such as gasoline & fuel oil.

Direct coal liquefaction is suitable for a wide range of feeds.

* high volatile bituminous coals.
* sub-bituminous coals with low ash
* lignites with low ash.

It is two types, single stage & two stage processes.

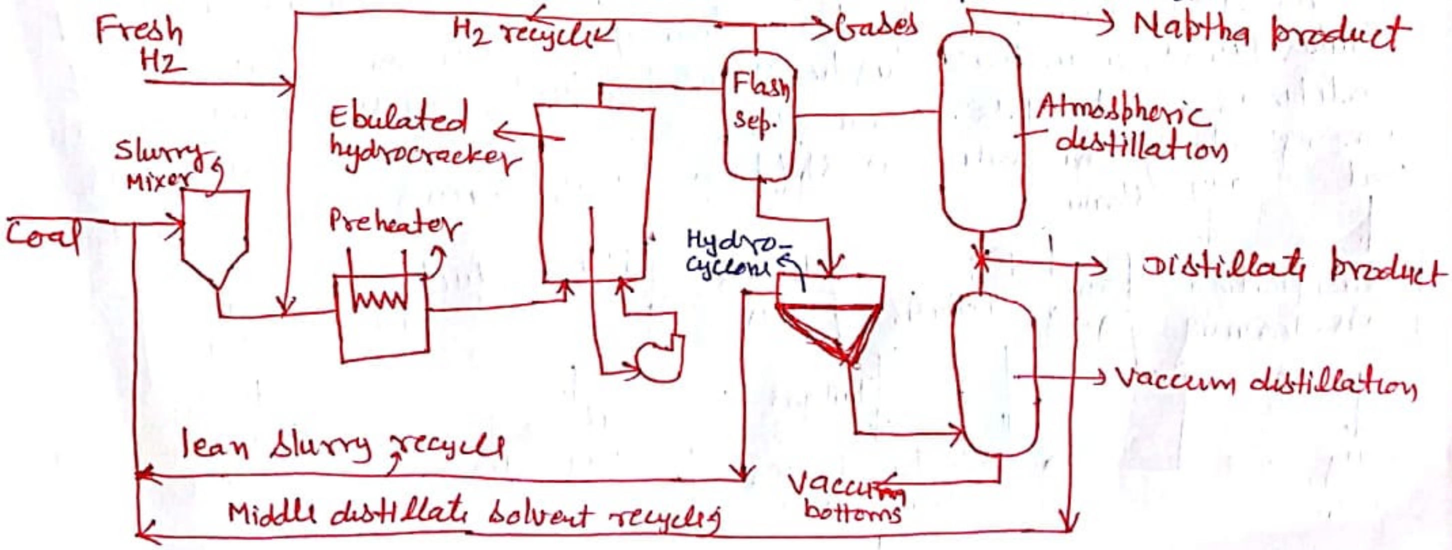
In single stage direct liquefaction process, one primary reactor is used to get distillates. Here a hydrotreating reactor is also joined along with the primary reactor to improve the quality of the distillate. The technology developers are

* H-Coal (HRI-USA) * Exxon donor solvent (Exxon, USA)

Two reactors in series are used in two-stage direct liquefaction process. In the first stage, Coal dissolution is done where the process is operated either without a catalyst or with a low-activity disposable catalyst. The heavy coal liquids produced in the first reactor are hydrotreated in the second stage in the presence of a high activity catalyst to produce desired distillate. The process & technology developers include.

- Catalytic two stage liquefaction
- liquid solvent extraction
- Brown coal liquefaction

H-Coal Process: — In this process, coal slurry is prepared with recycle solvent that consists of a mixture of heavy & middle distillates obtained by product fractionation & solids containing hydrocracker product. Hydrogen is added to the slurry, the mixture is preheated & fed to an ebullated bed hydrocracker, which is distinguishing feature of the process. The reaction condition are: Temp – 425–455°C & Hydrogen pressure 2900 Psig. The catalyst used is either Ni–Mo or Co–Mo supported on alumina. The catalyst is fluidised by hydrogen & a pumped internal cycle stream. This recycle stream contains unreacted coal solids. H-coal process have advantages of ebullated bed reactor over fixed bed reactors are that, the reactor contents are well mixed & temp. can be monitored & controlled in better way in the previous one.



Indirect liquefaction (ICL) — It is the process for production of fuels with an intermediate step of production of synthesis gas (syn gas) by gasification of coal. The principal constituents of syngas are CO & H_2, which can be processed chemically in further steps to produce a variety of different chemicals & fuels. chemicals & fuels that can be made by ICL include methanol (CH_3OH), dimethyl ether (CH_3OCH_3) & Fischer-Tropsch diesel or gasoline like fuels, & H_2.

The Process of ICL involves two steps. The first step is the complete breakdown of coal structure by gasification process to produce mainly syn gas. Sulfur bearing compounds are removed at this step. gasification products are reacted in the presence of a catalyst at a definite temperature & pressure. The synthetic liquid products include paraffins, olefins, & alcohol, mainly methanol depending on the catalyst selected & the rxn conditions utd.

Fischer-Tropsch process: — In the FT Process, CO & H_2 in syngas react catalytically to convert into hydrocarbons of a series of molecular weights according to the following rxn.

low Tem — 150-350°C Catalyst: cobalt based. High Tem — 300-350°C Catalyst: Fe based

$$(2n+1)\,H_2 + n\,CO \longrightarrow C_nH_{(2n+2)} + n\,H_2O$$

where n → integer, when n = 1, the rxn represents the formation of CH_4, which is considered an undesirable by product. The main aim of FT process is to maximize the formation of hydrocarbons in the range of liquid fuels, which are higher value products, by using suitable rxn conditions & catalysts. Some other side rxn occur in this process, among which the water gas shift rxn is the main → $CO + H_2O \rightarrow H_2 + CO_2$