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Course Title: Fuel Chemistry
Credits: 2+1+0
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Total Marks: 50 (Theory: 50)
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Unit 3: Petroleum, petrochemical industry and lubricants
Composition of crude petroleum, refining and different types of petroleum products and their applications.
Fractional Distillation (Principle and process), Cracking (Thermal and catalytic cracking), reforming petroleum and non-petroleum fuels (LPG, CNG, LNG, biogas, fuels derived from biomass), fuel from waste, synthetic fuels (gaseous and liquids), clean fuels.
Petrochemicals: Vinyl acetate, Propylene oxide, Isoprene, Butadiene, Toluene and its derivatives Xylene.
Classification of lubricants, lubricating oils (conducting and non-conducting) Solid and semisolid lubricants, synthetic lubricants. Properties of lubricants (viscosity index, cloud point, pour point) and their determination.

1. <u>Composition of crude petroleum:</u>

Petroleum i.e. crude oil is a naturally occurring liquid that is refined to prepare products like gasoline i.e. petrol, diesel fuel, jet fuel, home heating oil, lubricating oil, wax, asphalt, and many other useful products. **The word petroleum originates from Latin, where "petra" means rock and "oleum" means oil**. Petroleum also includes natural gas which has similar chemistry to crude oil. Transportation and power generation are the two major uses of petroleum. Chemicals obtained from the refining of crude oil and the processing of natural gas are used by the petrochemical industry to produce petrochemicals like synthetic rubber, fertilizers, plastic, latex paints, drugs, synthetic fibres, and explosives.

Crude oil is a mixture of comparatively volatile liquid hydrocarbons (compounds composed mainly of hydrogen and carbon), though it also contains some nitrogen, sulfur, and oxygen. Those elements form a large variety of complex molecular structures, some of which cannot be readily identified. Regardless of variations, however, almost all crude oil ranges from 82 to 87 percent carbon by weight and 12 to 15 percent hydrogen by weight.

Petroleum majorly contains alkanes and also cyclohexanes, aromatic hydrocarbons and more complex hydrocarbons such as asphaltenes. Carbon and hydrogen are the two basic constituent elements of petroleum. Crude oils vary greatly in their chemical composition due to the combination of the above elements in various complex ways.

The Basic Chemical Composition of Petroleum

Carbon	84-87%
Hydrogen	11-14%
Sulphur	0.06-2%
Nitrogen	0.1-2%
Oxygen	0.1-0.2%
Metals	0-0.14%

2. **<u>Refining of Petroleum</u>:**

Petroleum refineries are very large industrial complexes involving a great many processing units and auxiliary installations such as utility units and storage tanks. That refinery has its own specific arrangement and combination of processes for refining largely dictated by the location of the refinery, the target products and the economic considerations.

An oil refinery or petroleum refining is an industrial manufacturing facility where crude oil is extracted and converted into more valuable goods, such as petroleum naphtha, gasoline, jet fuel, asphalt foundation, heating oil, petroleum kerosene, and liquefied gas.

Oil refineries are usually huge, vast industrial facilities with extensive pipelines running throughout, holding fluid streams in between.

Petroleum is a mixture of many substances such as gas, petrol, diesel, kerosene, lubricating oil, paraffin wax, etc. As these constituents serve different purposes, it is important to separate them, or in other words, refine the crude oil. This process of separation of various constituents of petroleum is called petroleum refining.

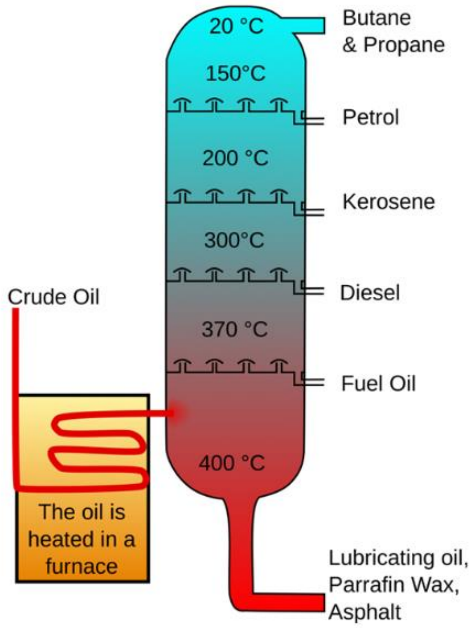
This is done in oil refineries. It is a three-step process.

- The first step is **separation** where the crude oil is separated into various components through the distillation process. The heavier constituents remain settled at the bottom whereas lighter constituents rise up as vapour, or remain liquid.
- Next, these constituents, which are still quite heavy, are converted into gas, gasoline, and diesel. Thus, the next step is **conversion**.
- These have certain impurities, so the last step is **treating,** where they are treated to obtain pure forms of various products.

The oldest and most common way of separating things into different components (called fractions) is to do it using the boiling temperature differences. That process is known as fractional distillation. You essentially heat up crude oil, let it spray, then condense the vapour.

New methods, in a method called conversion, use Chemical processing on certain fractions to produce others. For example, chemical processing may split lengthier chains into shorter chains. This allows a refinery to convert diesel fuel into gasoline, depending on the gasoline demand.

In industry, the refining process is generally called the “downstream” sector, while the “upstream” sector is known as the raw crude oil output. The word downstream is synonymous with the idea of sending oil down the supply chain of a commodity to an oil refinery to be refined into petrol. The downstream phase also includes the actual sale of petroleum products to other companies, governments or private individuals.



3. Different types of petroleum products and their applications.

Examples of petroleum products obtained from petroleum:-

Fuels: Gasoline, Kerosene, Liquefied natural gas, Liquefied petroleum gas, Butane, Diesel fuel, Fuel oil, Propane

Other Products: Paraffin wax, Petroleum jelly, Petroleum wax, Microcrystalline wax, Napalm, Naphtha, Naphthalene, Refined asphalt, Refined bitumen

Some Petroleum Products and their Uses:

1. Gases: Gaseous products obtained from the refinery are hydrogen, fuel gas, ethane, propane, and butane. Propane and butane are collectively known as liquefied petroleum gas (LPG), which is a portable and suitable fuel for light industrial use and domestic heating (cooking).

2. Gasoline: Gasoline uses include application in internal combustion engines, commonly used in private and commercial vehicles.

3. Diesel: It is commonly used in trucks, buses and public transport, locomotives, farm and heavy equipment. Diesel has greater energy and power density than gasoline.

4. Kerosene: It is used extensively globally in cooking and space heating. It is also the basic fuel for modern jet engines.

5. Fuel oil: It can be used as a power source of lamps, heaters, stoves, engines and lanterns typically at home in furnaces and boilers. The machinery of farming, mining or quarrying machinery or even bunkering ships uses fuel oil.

6. Other Petroleum Products:

i. Naphtha is used to manufacture solvents for paints, cosmetics, commercial dry cleaning etc. Paper manufacture and foodstuffs use wax.

ii. Asphaltic bitumen is employed in the construction of roads and airfields and the manufacture of roofing felts, waterproof papers, pipeline coatings, and electrical insulation.

iii. Decomposing liquid hydrocarbon fractions make carbon black which is compounded with rubber in tire manufacture and used in printing inks and lacquers.

4. Fractional Distillation (Principle and process)

Fractional Distillation:

Fractional distillation is the process of separating the various components of a mixture by heating. If the boiling points of the two liquids are very close to one another, the separation cannot be achieved by a simple distillation method. It is because, with the boiling point of the more volatile liquid of the mixture, there will also be sufficient vapours of the less volatile liquid. As a result, both the liquids will distil together, and the separation will not be completed. The separation of such liquid mixture into individual components can be achieved by a process called fractional distillation, which involves repeated distillations and condensations. It is used in processes like oil refining, perfume manufacturing and separation of crude oil in the industry.

- **Principle of Fractional Distillation**

Normally, the vapour composition of any liquid mixture does not remain equal to the liquid composition. When the mixture is heated, the liquid with the lower boiling point boils and converts to vapours.

The more volatile component remains in a vapour state longer than the liquid component. Repeated distillations and condensations are used in the process, and the mixture is usually separated into component parts.

The more volatile components increase in a vapour state after heating, and when this vapour is liquefied, the more volatile components increase in a liquid state.

Distillation refers to the process of vaporisation followed by condensation (liquefaction). When this distillation process is repeated, a more volatile component will remain in a pure state in the liquid state. By using the fractional distillation method, components of the liquid-liquid mixture can be separated as a pure substance.

The basic principle of this type of distillation is that different liquids boil and evaporate at different temperatures. So when the mixture is heated, the substance with lower boiling point starts to boil first and convert into vapours.

- **Process of Fractional Distillation**

Given below are the steps for the fractional distillation of crude oil:

Step 1:- In this step, crude oil is heated, and after heating, it is passed into the fractionating column.

Step 2:- The oil gets converted into vapours, and the various components of the oil are evaporated at different temperatures.

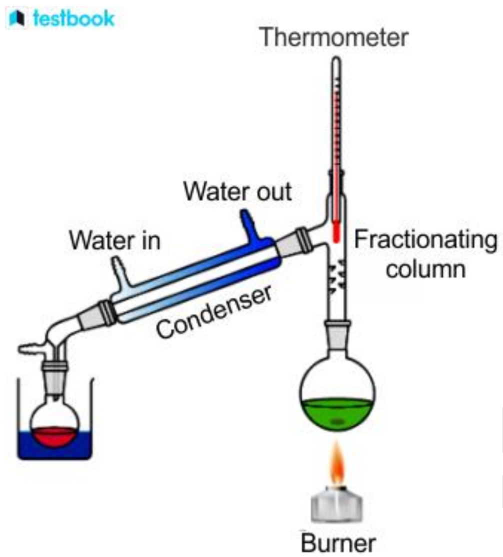
Step 3:- These vapours rise through the column and get condensed as it cools down and the temperature drops.

Step 4:- Small chain hydrocarbon molecules are collected at the top of the fractionating column because of their low boiling point and fewer intermolecular forces.

Step 5:- Long-chain hydrocarbon molecules are collected at the bottom because of their high boiling point and more intermolecular forces.

The boiling point of separated fractions in the fractionating column increases from top to bottom.

The below diagram explains this process:



Fractional Distillation

5. <u>Cracking (Thermal and catalytic cracking)</u>

Cracking defines the breakdown of complex long chain molecules like hydrocarbons into simple molecules by breaking their carbon-carbon bonds. It is the most important step for the commercial production of petroleum and other petroleum products. Usually, cracking is done either under high temperature and pressure conditions or under the influence of catalysts. When catalysts are used, the requirement of high temperature conditions can be minimised and hence it is a way of saving energy.

- Thermal Cracking: Thermal cracking is the breakdown of complex long-chain hydrocarbons into lighter particles by using high temperature conditions. The major products of thermal cracking are olefins. Depending on the product range, two types of thermal cracking are known. The first one is steam cracking or pyrolysis which is carried under high temperature conditions ~750 to 900 $^{\circ}$C in the absence of oxygen, which produces ethylene and other feedstocks valuable in petrochemical industries.The second type of temperature cracking is known as delayed coking which is carried out under a relatively lower temperature range ~500 ℃. The product of delayed coking is a highly crystalline petroleum coke called needle coke which is used in the production of electrodes in steel and aluminium industries. Modern high pressure thermal cracking operates at 7,000 kPa.

- Catalytic Cracking: Modern cracking uses zeolites as the catalyst. These are complex aluminosilicates, and are large lattices of aluminium, silicon and oxygen atoms carrying a negative charge. They are, of course, associated with positive ions such as sodium ions. You may have come across a zeolite if you know about ion exchange resins used in water softeners. The alkane is brought into contact with the catalyst at a temperature of about 500°C and moderately low pressures. The zeolites used in catalytic cracking are chosen to give high percentages of hydrocarbons with between 5 and 10 carbon atoms - particularly useful for petrol (gasoline). It also produces high proportions of branched alkanes and aromatic hydrocarbons like benzene. The zeolite catalyst has sites which can remove a hydrogen from an alkane together with the two electrons which bound it to the carbon. That leaves the carbon atom with a positive charge. Ions like this are called carbonium ions (or carbocations). Reorganization of these leads to the various products of the reaction.

Difference Between Thermal Cracking and Catalytic Cracking

Thermal Cracking	Catalytic Cracking
In this chemical process, no catalyst is used. Only heat is used in the process.	As the name suggests, a catalyst is used in the process. The most common catalyst used is zeolite.
The process requires a high temperature that is 500 degrees celsius- 1000 degrees celsius.	The process requires a moderate amount of temperature that is 450 degrees celsius- 500 degrees celsius.
The amount of waste (coke) generated is high.	The amount of waste(coke) generated is low.
The amount of pressure required in this process is high.	The process requires a low amount of pressure.
Quantity of product disposed of is higher.	Quantity of product disposed of is lower.
Yield of gasoline is less.	Yield of gasoline is more.

6. Reforming petroleum and non-petroleum fuels (LPG, CNG, LNG, biogas, fuels derived from biomass)

Definition of Reforming: **The conversion of straight chain hydrocarbon into branched chain hydrocarbon is called reforming of petroleum**. By the process of reforming, the octane number of a gasoline is improved. The process of reforming is carried out in the presence of catalyst n-alkanes burn in internal combustion engine with explosion and produce knocking but branched chain hydrocarbons burn smoothly. Reforming is a process similar to cracking, which converts n-alkanes into branched alkanes. The octane number of gasoline may also be improved by adding tetraethyl lead (TEL) $Pb(C_2H_5)_4$ which is a knock inhibitor.

- *Octane number is a standard which determines the knocking ability and quality of gasoline. Higher is the octane number of a gasoline, lower is the knocking it* *produces. Octane number can be increased by the following two methods: Reforming By adding TEL (tetraethyl lead)*

- *Knocking is a sharp metallic sound produced in the internal combustion engine. Knocking is caused by the low octane number of gasoline.*

7. Fuel from waste:

Many fuels can be derived from waste, refuse can be combusted directly in an incinerator to provide power, methane produced at landfill can be collected and combusted, even chicken litter can be dried and combusted.

There are a number of ways of producing fuel from waste, including:

i. Anaerobic Digestion, the use of bacteria to decompose organic matter in the absence of oxygen to produce gases. These gases are produced from organic wastes such as livestock manure or food processing waste. The end product is a medium heating value biogas mixture (usually 60% methane, 40% carbon dioxide) and a mixture of solid and liquid fertiliser. Because anaerobic digestion does not produce any more carbon dioxide than would normally be produced from the wastes natural decomposition, it is said to be 'carbon neutral'.

ii. Gasification involves heating organic waste with a reduced amount of oxygen and/or steam. It produces a synthetic gas, known as syngas, which can be burned independently in a boiler, engine or gas turbine to produce electricity.

iii. Pyrolysis is carried out in the total absence of oxygen. It also produces an energy-rich gas and solid residue. These can then be burned separately to produce electricity. In some pyrolysis processes, the gases are condensed into a liquid fuel. e.g. pyrolysis of waste. Tyres can be used to produce an alternative to diesel fuel.

iv. Incineration involves burning organic material such as waste to produce electricity and heat. Conventional waste incineration plants use the heat produced to generate electricity using a steam turbine. In some cases it is also possible to use the left-over heat. The government is encouraging the development of such combined heat and power (CHP) plants which may be able to provide businesses with a source of heat, where the necessary transmission infrastructure exists or can be installed at reasonable cost.

v. Biodiesel from waste cooking oils: used cooking oils can be filtered and treated on a domestic scale, and on a larger scale, to run converted diesel cars.

vi. Some landfill sites recover methane which is produced naturally when biological waste breaks down in the absence of oxygen. It can be used to generate energy. Methane is a potent greenhouse gas and contributes towards climate change if it is not captured.

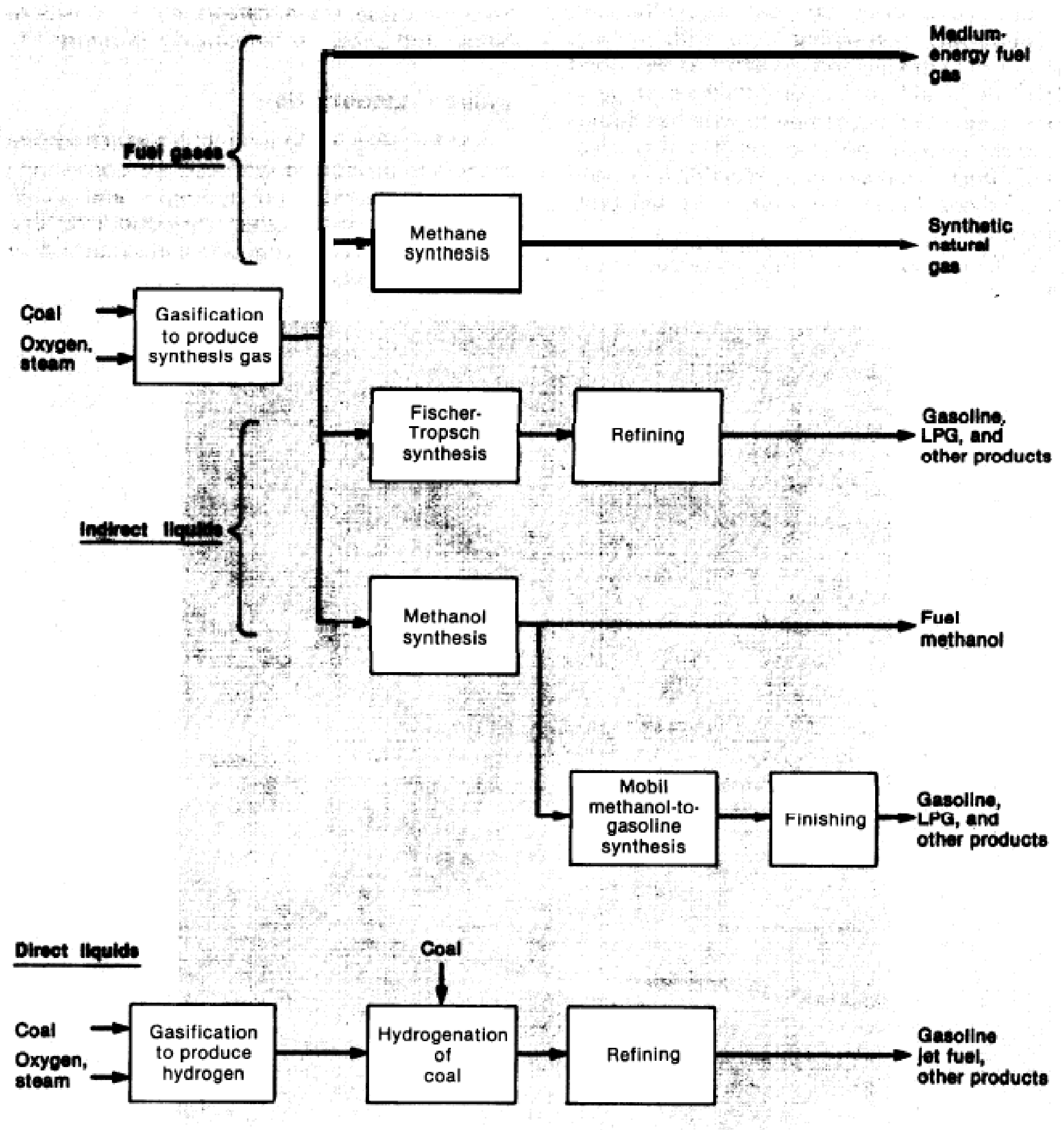
8. Synthetic fuels (gaseous and liquids):

Synthetic fuels are gaseous or liquid fuels that can be used as a substitute for natural gas or oil. They are made from natural resources like biomass, coal, shale oil, or tar sands.

Synthetic fuels are chemically synthesised fuels designed to mimic the chemical and physical properties of fossil fuels. They are typically made from renewable or non-fossil feedstocks, such as biomass, water, and carbon dioxide, through chemical processes that convert these feedstocks into fuel. They can be used in place of fossil fuels in a variety of applications, including transportation, heating, and electricity generation. They have the potential to reduce greenhouse gas emissions, as they can be made from carbon-neutral feedstocks, such as biomass or captured carbon dioxide. As a result, the greenhouse gas becomes a raw material from which alternatives for gasoline, diesel, and natural gas may be synthesised using renewable energy. This means that the carbon dioxide emissions associated with their production and use are offset by the carbon dioxide that is removed from the atmosphere during their production. In contrast, fossil fuels release large amounts of carbon dioxide when they are burned, contributing to climate change. They also offer the potential to provide a more stable and reliable source of energy than electric batteries for transportation. While electric batteries are a clean and efficient source of energy, they rely on the availability of electricity from the grid, which can be disrupted by outages or natural disasters. Synthetic fuels, on the other hand, can be stored and transported like traditional fossil fuels, making them more resilient in the face of disruptions.

Liquid and gaseous fuels can be synthesized by chemically combining coal with varying amounts of hydrogen and oxygen. The coal liquefaction processes are generally categorized according to whether liquids are produced from the products of coal gasification (indirect processes) or by reacting hydrogen with solid coal (direct processes). The fuel gases from coal considered here are medium-Btu gas and a synthetic natural gas (SNG or high-Btu gas).

Figure 13.—Schematic Diagrams of Processes for Producing Various Synfuels From Coal



SOURCE: Office of Technology Assessment.

- **Indirect Liquefaction**: The first step in the indirect liquefaction processes is to produce a synthesis gas consisting of carbon monoxide and hydrogen and smaller quantities of various other compounds by reacting coal with oxygen and steam in a reaction vessel called a gasifier. The liquid fuels are produced by cleaning the gas, adjusting the ratio of carbon monoxide to hydrogen in the gas, and pressurizing it in the presence of a catalyst. Depending on the catalyst, the principal product can be gasoline (as in the Fischer-Tropsch process) or methanol. The methanol can be used as a fuel or further reacted in the Mobil methanol-togasoline (MTG) process (with a zeolite catalyst) to produce Mobil MTG gasoline. The composition of the gasoline and the quantities of other products produced in the Fischer-Tropsch process can also be adjusted by varying the temperature and pressure to which the synthesis gas is subjected when liquefied. With commercially available gasifiers, part of the synthesis gas is methane, which can be purified and sold as a byproduct of the methanol or gasoline synthesis.

- **Direct Liquefaction:** The direct liquefaction processes produce a liquid hydrocarbon by reacting hydrogen directly with coal, rather than from a coal-derived synthesis gas. However, the hydrogen probably will be produced by reacting part of the coal with steam to produce a hydrogen-rich synthesis gas, so these processes do not eliminate the need for coal gasification. The major differences between the processes are the methods used to transfer the hydrogen to the coal, while maximizing catalyst life and avoiding the flow problems associated with bringing solid coal into contact with a solid catalyst, but the hydrocarbon products are likely to be quite similar.

9. Clean fuels

- Clean fuels are alternative fuels with a net-zero carbon footprint, accounting for both their production and combustion. They include renewable natural gas, clean hydrogen, synthetic natural gas, and biofuels. Clean fuels are reliable because they help to reduce emissions and improve air quality when they replace coal and diesel.
- Clean fuel is energy that is treated with ethanol to produce fewer greenhouse emissions. There are multiple kinds of clean fuels, based on the ratio of ethanol or biodiesel mixed with traditional fuel.
- Clean fuel is a fuel whose carbon intensity is lower than the appropriate clean fuel standard for petrol and diesel. Clean fuel is a natural fuel, like compressed natural gas (CNG) or liquified petroleum gas (LNG), or a mix. Clean energy comes from energy sources that are accessible. It produces less pollution than the alternatives and it is used as a substitute for fossil fuels.

- What are some examples of clean fuel?
  Clean fuel includes most types of ethanol, biodiesel, natural gas, biogas, electricity, propane, and hydrogen, CNG, LNG.

- What is natural gas?

There are four naturally occurring gases. When mixed in the correct ratios, they create natural gas. The four natural gases are methane, ethane, butane, and propane.
Methane, a non-toxic gas, is the main ingredient in natural gas, making up over 80% of the mixture. Its chemical formula is CH_4 making it the simplest form of hydrocarbon molecules
Ethane is only two-carbon alkane. Ethane typically makes up 1% to over 6% of the natural gas mixture, making it the second-largest fossil fuel component
Propane's formula is C_3H_8, which makes it a three-carbon alkane. Small amounts of propane are a component of the natural gas mixture.
Butane is highly flammable and is an easily liquified gas. Its chemical formula is C_4H_{10}. Butane makes up a small part of the natural gas mixture.
Most in need of fuel are located far from fuel stations. This makes pipelines impractical or pricey to build for clean fuel. To get about this problem, natural gas can be cooled to make liquid, shrinking its volume for easier, safer storage and transport.

- What is Liquefied Natural Gas?
  LNG is a clear, colorless, and non-toxic liquid that forms when natural gas is chilled to -162ºC (-260ºF). The cooling process shrinks the volume of the gas 600 times. This makes it easier and more secure to store and transport. In its liquid state, LNG does not ignite.

  When LNG reaches its destination, it is converted back into a gas at regasification plants. It is then channeled to homes, businesses, and industries where it is burnt for heat or to generate electricity.

  LNG is now also emerging as a cost-competitive and clean fuel, especially for heavy-duty road transport and doorstep fuel delivery.

- What is CNG ?
  CNG also known as compressed natural gas is an eco-friendly option to gasoline. Made by compressing natural gas (methane) down to less than 1% of its volume, CNG fuel is safer than gasoline and diesel because it is non-toxic and does not contaminate groundwater.

- Why is it called 'clean fuel'?
  The reason behind calling it clean energy –

  ✓ Doesn't leave solid residues
  ✓ Produces lesser harmful substances
  ✓ Can be transported easily
  ✓ No smoke emissions while burning
  ✓ Produces 50% less CO2 when burning
  ✓ It is non-toxic

- ✓ It is safe to be used as a fuel for vehicles and as a chemical in the manufacturing of plastics.
- ✓ CNG is extensively used in industries and in vehicles as a fuel because no pollution is caused by it.
- ✓ Natural gas is considered a cleaner fuel than other fossil fuels such as coal and oil due to its highly efficient combustion.

10. Petrochemicals: Vinyl acetate, Propylene oxide, Isoprene, Butadiene, Toluene and its derivatives Xylene.

Definition: These are the chemicals that are made from petroleum and natural gas. Petroleum and natural gas are made up of hydrocarbon molecules, which comprises of one or more carbon atoms, to which hydrogen atoms are attached. About 5 % of the oil and gas consumed each year is needed to make all the petrochemical products. Petrochemicals play an important role on our food, clothing, shelter and leisure. Because of low cost and easy availability, oil and natural gas are considered to be the main sources of raw materials for most petrochemicals.

Classification: Petrochemicals can be broadly classified into three categories:-

a. Light Petrochemicals: These are mainly used as bottled fuel and raw materials for other organic chemicals. The lightest of these -- methane, ethane and ethylene -- are gaseous at room temperature. The next lightest fractions comprise petroleum ether and light naphtha with boiling points between 80 and 190 degrees Fahrenheit.

b. Medium Petrochemicals: Hydrocarbons with 6 – 12 carbon atoms are called "gasoline", which are mainly used as automobile fuels. Octane, with eight carbons, is a particularly good automobile fuel, and is considered to be of high quality. Kerosene contains 12 to 15 carbons and is used in aviation fuels, and also as solvents for heating and lighting.

c. Heavy Petrochemicals: These can be generally categorized as diesel oil, heating oil and lubricating oil for engines and machinery. They contain around 15 and 18 carbon atoms with boiling points between 570 and 750 degrees Fahrenheit. The heaviest fractions of all are called "bitumens" and are used to surface roads or for waterproofing. Bitumens can also be broken down into lighter hydrocarbons using a process called "cracking."

The two most common petrochemical classes are:-

1- Olefins (including ethylene and propylene) and

2- Aromatics (including benzene, toluene and xylene isomers).

1. Vinyl acetate is an organic compound with the formula $CH_3CO_2CH{=}CH_2$. This colorless liquid is the precursor to polyvinyl acetate, ethene-vinyl acetate copolymers, polyvinyl alcohol, and other important industrial polymers. Vinyl acetate is a

colorless, flammable liquid with a fruity odor. It's used to make adhesives, paints, and plastics

2. Propylene oxide is a petrochemical that is used as a chemical intermediate in the production of other substances. It is a colorless, volatile liquid with a similar odor to ether. Propylene oxide is highly flammable and can polymerize violently.
3. Isoprene is a petrochemical compound that is used to produce synthetic rubber and other natural products. It is a colorless, volatile liquid hydrocarbon that is obtained as a by-product of processing petroleum or coal tar. Isoprene is also known as 2-methyl-1,3-butadiene.
4. Butadiene is a major petrochemical commodity. The compound of commercial interest is 1,3-butadiene, CR_2=CHCH=CH_2. It is a colorless gas normally stored and handled as a liquid under refrigeration and pressure. The isomer, 1,2-butadiene, is of little commercial importance. Butadiene is a petrochemical commodity that is used to make a variety of products, including:
    - Synthetic rubber: Used in shoe soles, tires, and other car parts
    - Adhesives: Used in sealants
    - Shock-resistant polystyrene: A two-phase system that consists of polystyrene and poly-butadiene
    - Polymers: Consisting of acrylonitrile, butadiene, and styrene
    - Co-polymer of methyl methacrylate, butadiene, and styrene: Used as a modifier for polyvinyl chloride
    - Elastomers: Including the very high volume styrene butadiene rubber (SBR) that comprises the bulk of automobile tires
5. Toluene and its derivatives: Toluene is a petrochemical that is a colorless, flammable liquid with a distinctive smell. It is a naturally occurring compound that is primarily derived from petroleum or petrochemical processes.

- toluene - methylbenzene; can be a solvent or precursor for other chemicals
- Benzene
- toluene diisocyanate (TDI) - used as co-monomers with polyether polyols to form polyurethanes or with di- or polyamines to form polyureas polyurethanes
- benzoic acid – carboxybenzene
- caprolactam
- nylon

6. Xylene: Xylene is a petrochemical that is produced through catalytic reforming and coal carbonization. It is also found in crude oil at concentrations of 0.5–1%
    - mixed xylenes - any of three dimethylbenzene isomers, could be a solvent but more often
    - precursor chemicals
    - ortho-xylene - both methyl groups can be oxidized to form (ortho-)phthalic acid
    - phthalic anhydride
    - para-xylene - both methyl groups can be oxidized to form terephthalic acid
    - dimethyl terephthalate - can be copolymerized to form certain polyesters

- polyesters - although there can be many types, polyethylene terephthalate is made from petrochemical products and is very widely used.
- purified terephthalic acid - often copolymerized to form polyethylene terephthalate
- polyesters
- meta-xylene
- isophthalic acid
- alkyd resins
- Polyamide Resins
- Unsaturated Polyesters

11. Classification of lubricants, lubricating oils (conducting and non-conducting) Solid and semisolid lubricants, synthetic lubricants. Properties of lubricants (viscosity index, cloud point, pour point) and their determination.

"Substances which apply between two moving and sliding surface to reduce friction between them are known as **Lubricants**" and the process by which friction between sliding surface is reduce, known as **Lubrication.**

❖ **Classification of lubricants:**

a. Liquid Lubricants: It includes animal oils, vegetable oils, petroleum oils, synthetic lubricants.
   - Animal oils: tallow oil, whale oil etc.
   - Vegetable oils: castor oil, palm oil etc
   - Petroleum oils: petroleum fractions
   - Synthetic lubricants: polyglycol, silicones etc.

b. **Semi-solid Lubricants (Grease)**: Semi-solid Lubricants are formed by emulsifying oil and fat with thickening agents like soap of sodium, calcium, lithium, aluminum at higher temperature.

   Classification
   - Soda based: In this case sodium soaps are used as a thickening agent in mineral or petroleum oil. They are slightly soluble in water. They can be used up to 175oC.
   - Lithium based: In this case lithium soaps are emulsifying with petroleum oil. They are water resistance and used up to 15 degree C.
   - Calcium based: In this case calcium soaps are emulsifying with petroleum oil. They are also water resistant and used up to 80oC. At higher temperature soap and petroleum oil are separate from each other.

c. **Solid Lubricants:** Graphite, molybdenum disulphide (MoS_2), boron nitride $(BN)_x$ are predominantly used as a solid lubricants. They are used under high temperature and high load (pressure).

❖ **Lubricating oils (conducting and non-conducting)**

Lubricating oils, also known as lubricants or lube, are used to reduce friction, heat, and wear between mechanical parts that are in contact with each other. They are used in a variety of applications, including automobiles, industrial machinery, and mechanical equipment.

- Conducting lubricant oil are oils that can conduct electricity to an extent. These types of oils allow the electrons to flow freely from one point to another only when they are connected to a source of power or energy. Whereas, Non-conducting lubricant does not allow electrons to flow freely from one point to another when they are connected to a source of power.
- The main difference between conducting and non-conducting lubricant oil is that conducting lubricants can conduct electricity, whereas non conducting lubricants cannot conduct electricity.
- The difference between a conducting and non-conducting lubricant oils is that the charge exists only on the surface for a conducting lubricants .Whereas, for a non conducting lubricants the surface is uniformly distributed.
- Conducting lubricant oil like mercury, salt water, acetic acid etc. Non-conducting lubricants like vegetable oil and silicon oil.

❖ **Synthetic lubricants** are lubricants made from artificial chemical compounds. They are made from synthetic base oils, which are derived from the chemical reaction of one or more products, and special additives that improve performance. Base oils can be made from synthetic hydrocarbons, organic esters, polyalkylene glycols, phosphatic esters, silicates, silicones, fluorosilicones, polyphenyl esters, and fluorocarbons.

Properties of lubricants (viscosity index, cloud point, pour point) and their determination.

a. Viscosity Index: The variation of viscosity of a liquid with temperature is called viscosity index. A relatively small change in viscosity with temperature is indicated by high viscosity index whereas, a low viscosity index shows, a relatively large change in viscosity with temperature.

b. Cloud Point: The temperature at which lubricating oil becomes cloudy in appearance is called cloud point.

c. Pour Point: The lowest temperature at which the lubricant oil become semi-solid and ceases to flow is called pour point. It indicates the suitability of lubricants used in cold condition. Good lubricant should possess low pour point.