$$(\eta_{th})_{Diesel} > (\eta_{th})_{Dual} > (\eta_{th})_{Otto}$$

(c) For same maximum pressure and temperature

$$(\eta_{th})_{Diesel} > (\eta_{th})_{Dual} > (\eta_{th})_{Otto}$$

(d) For same maximum pressure and output

$$(\eta_{th})_{Diesel} > (\eta_{th})_{Otto}$$

FUELS &FUEL INJECTION

In IC engines, the chemical energy contained in the fuel is converted into mechanical power by burning (oxidizing) the fuel inside the combustion chamber of the engine.

Fuels suitable for fast chemical reaction have to be used in IC engines, they are following types-

(a) Hydrocarbons fuels derived from the crude petroleum by proper refining process such as thermal and catalytic cracking method, polymerisation, alkylation, isomerisation, reforming and blending.

(b) Alternative fuels such as-Alcohols (methanol, ethanol)
Natural gas (methane)
LPG (propane, butane)
Hydrogen

***Classification of petroleum fuels used for IC engine:**

Liquid hydrocarbons- Engine fuels are mainly mixtures of hydrocarbons, with bonds between hydrogen and carbon atoms. During combustion these bonds are broken and new bonds are formed with oxygen atoms, accompanied by the release of chemical energy. Principal products are carbon dioxide and water vapour. Fuels also contain small amounts of S, O_2, N_2, H_2O. The different constituents of crude petroleum which are available in liquid hydrocarbons are- paraffins, naphthenes, naphthenes, olefins, aromatics.

(i) Paraffin-

-Paraffins or alkanes can in general be represented by-C_nH_{2n+2}
-All the carbon bonds are single bonds – they are "saturated" high number of H atoms, high heat content and low density (620 – 770 kg/m3)
-The carbon atoms can be arranged as a straight chain or as branched chain compounds.
-Straight chain group (normal paraffins)

- shorter the chain, stronger the bond
- not suitable for SI engines – high tendancy for autoignition according to the value of "n" in the formula, they are in gaseous (1 to 4), liquid (5 to 15) or solid (>16) state.

-Hexan C_6H_{14} (normal paraffin)

```
    H   H   H   H   H   H
H – C – C – C – C – C – C – H
    H   H   H   H   H   H
```

- Branched chain compounds (isoparaffins)

    When four or more C atoms are in a chain molecule it is possible to form isomers, they have the same chemical formula but different structures, which often leads to very different chemical properties.

    Example: Iso-octane- C_8H_{18}

(ii) Naphthenes-

-Also called as cycloparaffins and represented as C_nH_{2n}
-Saturated hydrocarbons which are arranged in a circle have stable structure and low tendancy to autoignite compared to alkanes (normal paraffins)
-Can be used both in SI-engines and CI-engines
-Low heat content and high density (740 – 790 kg / m^3)

(iii) Olefins-

-Olefins or alkenes are represented as Mono olefins-C_nH_{2n} or Dio-olefins C_nH_{2n-2}
-Olefins have the same C-to-H ratio and the same general formula as naphthenes, their behavior and characteristics are entirely different
-They are straight or branch chain compounds with one or more double bond. The position of the double bond is indicated by the number of first C atom to which it is attached, i.e.,

    CH2=CH.CH2.CH2.CH3 called pentene-1
    CH3.CH=CH3 called butene-2

-Olefinic compounds are easily oxidized, have poor oxidation stability
-Can be used in SI-engines, obtained by cracking of large molecules low heat content and density in the range 620 – 820 kg / m^3

Alkenes are such as,
Hexen (mono-olefin)

```
    H   H   H   H   H   H
H – C – C – C – C – C = C - H
    H   H   H   H
```

Butadien (dio-olefin)

```
    H   H   H   H
H – C = C – C = C – H
```

(iv) Aromatics-

-These are so called due to aromatics odour and represented as C_nH_{2n-6}
-They are based on a six-membered ring having three conjugated double bonds
-Aromatic rings can be fused together to give polynuclear aromatics, PAN, also called polycyclic aromatic hydrocarbons, PAH simplest member is benzene (C_6H_6)

-Can be used in SI-engines, to increase the resistance to knock not suitable for CI-engines due to low cetene number
-Low heat content and high density in the range 800 – 850 kg / m^3

***Refinery processes:**

Crude oil is the liquid part of the naturally occurring organic material composed mostly of HCs that is trapped geologically in underground reservoirs – it is not uniform and varies in density, chemical composition, boiling range etc. for different fields. The refinery processes involved in production of different range of fuel is shown in Fig. 10 and Fig. 11.

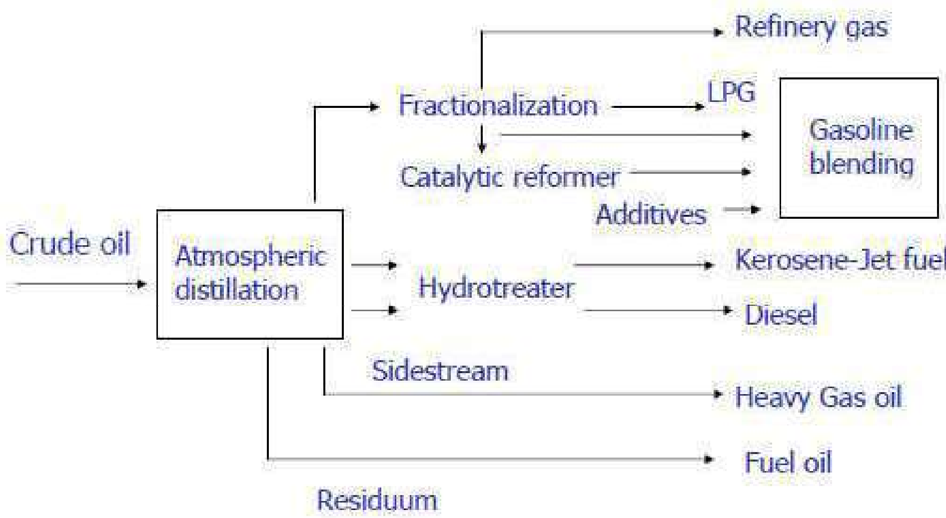

Fig. 10. Refinery processes

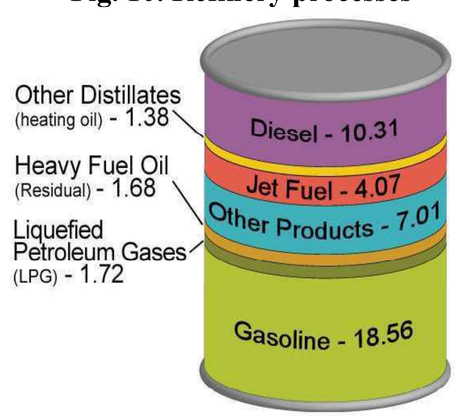

Fig. 11. Products made from crude oil

(i) Distillation process

-This is the initial process used in all refineries – aims to separate the crude oil into different boiling range fractions, each of which may be a product in its own right, a blend component or feed for further processing step
-Crude oil contains many thousands of different HCs, each has its own boiling point – lightest are gases at ambient temperature but can remain dissolved in heavier liquid HCs unless

temperature is raised, heaviest are solids at ambient temperature but stay in solution unless temperature is lowered.

Gasoline distillation temperature is 35 – 200 ^oC
Jet fuel 35 - 150
Diesel fuel 175 – 370
Heavy fuels, oil 370 – 550

-Generally distillation of crude oil produces 30% gasoline, 20-40 % diesel fuel, 20 % heavy fuels, 10-20 % heavy oils.

(ii) Cracking process

-There are two types of cracking process for engine fuel production: thermal cracking and catalytic cracking

(a)Thermal cracking: It takes place through the creation of HC free radicals by C to- C bond scission
-The feed is heated to around 500 - 600 ^OC and 70 - 100 bars and passed into a soaking chamber where cracking takes place. The cracked products are fractionated. The product is relatively unstable and requires the use of antioxidants and other treatments to prevent gum formation in use. It has relatively poor MON (motor octane number).

(b)Catalytic cracking: It is the most important and widely used process for converting heavy refinery streams to lighter products – to increase the ratio of light to heavy products from crude oil.
-Compared to thermal cracking, it has higher yield, improved quality product for gasoline (not for diesel fuel) and superior economics.
-A fluidized bed of catalyst is used – feed is introduced into it. Catalyst flows from one vessel to another through a pipe (between reactor and regenerator). Cracked oil vapour pass to fractionating towers where smaller molecules are separated from heavier products (gas, catalytic naphtha, cycle oils and residue).
-Aluminium silicate known as zeolite is used as a catalyst – has high activity and suppress the formation of light olefins.

(iii)Alkylation: It is a process for producing a high-octane gasoline component (alkylate) by combining light olefins with isobutane in the presence of a strongly acidic catalyst (sulfuric or hydrofluoric acid).

(iv)Isomerization: It is a process for converting straight chain paraffins to branch chain – used to provide isobutane feed for the alkylation process or to convert relatively low-octane quality of straight paraffins to more valuable branch chain molecules.

eg. n-pentane with RON (research octane number) 62 can be converted to isopentane with RON 92

-Process involves contacting HCs with a catalyst (platinum on a zeolite base) and separating any unchanged straight paraffins for recycle through the unit. The product is clean burning and has better RON quality.

(v)Polymerization: It is a process where light olefins such as propene and butenes are reacted together to give heavier olefins which have good octane quality and low vapour pressure in gasoline.
-Most commonly used catalyst is phosphoric acid
-The product is almost 100 % olefinic and has relatively poor MON compared with RON.

eg. $CH_3CH_2CH=CH_2 + CH_3CH=CH_2 \rightarrow CH_3(CH_2)_4CH=CH_2$
butene propene heptene

***Alternative fuels:**

(a) Alcohols: These include methanol (methyl alcohol), ethanol (ethyl alcohol), propanol (propyl alcohol), butanol (butyl alcohol) as compounds
-The OH group which replaces one of the H atoms in an alkane, gives these compounds their characteristic properties
-Specific heating value is lower than gasoline (42 – 43 MJ/kg)
methanol (19.7 MJ/kg) and ethanol (26.8 MJ/kg)
-For air-fuel mixture SHV is comperable with gasoline (MJ/kg-mixture at stoichiometric mixtures)
-Other alcohol groups such as dihydric and trihydric alcohols are not used as a fuel in IC engines

(i) Methanol
-Can be obtained from natural gas – has near and long-term potential
-Has high octane quality (130 RON, 95 MON)
-Can be used in low-concentration (5-15 %) in gasoline to increase octane number of the mixture

Problems;
-Poor solubility in gasoline, toxicity, low energy content (about half of gasoline), high latent heat of vaporization and oxygen content
-Contribute to poor driveability, incompatibility with some metals

(ii) Ethanol
-Produced from biomass
-It is made from the sugars found in grains, such as: Corn, Sorghum, and Barley
Other sources of sugars to produce ethanol include: Potato skins, Rice, Sugar cane, Sugar beets, Yard clippings, Bark, Switch grass etc.
-Has high octane number – can be used in low–concentrations in gasoline
-Most of the ethanol used in the United States today is distilled from corn
-Scientists are working on cheaper ways to make ethanol by using all parts of plants and trees rather than just the grain.
-About 99% of the ethanol produced in the United States is used to make "E10" or "gasohol," a mixture of 10% ethanol and 90% gasoline.
-Any gasoline powered engine can use E10, but only specially made vehicles can run on E85, a fuel that is 85% ethanol and 15% gasoline

(b) Biodiesel:

-It is methyl or ethyl ester of a fatty acid produced from vegetable oil of edible or non edible types or animal fat or algae, by transesterification process using catalysts.
-Has better lubricating properties and much higher cetane ratings than today's low sulfur diesel fuels.
-Its addition reduces the fuel system wear.
-Can be used in the pure form (B100), or may be blended with petroleum diesel in any concentration in most diesel engines for transportation purpose.
-But, the engine may face problems, such as low temperature operation, less durability and drop in power. New diesel fuel injection systems, such as common rail systems are equipped with materials that are compatible with biodiesel (B100).
-Biodiesel offers a substantial reduction in particulate matter (25%-50%) and a marginal increase of NOx (1%-6% when it is used as an alternative fuel in a CI engine.
-The major problems associated with biodiesel are (i) poor oxidation stability, (ii) higher viscosity and density, (iii) lower calorific value, and (iv) cold flow property.
-Blends of 20% and lower biodiesel can be used in diesel engines with no, or only minor modifications.

(c) Biogas:

-Produced by the anaerobic decomposition of organic materials such as cow dung and other waste such as cornhusks, leaves, straw, garbage, flesh of car cusses, poultry droppings, pig dung, human excreta, sewage and the plants specially grown for this purpose like water hyacinth, algae, certain types of grasses. Also any cellulosic organic material of animal or plant origin which is easily bio-degradable is a potential raw material for biogas production. -Also produced by pyrolysis and hydrogasification methods
-Contains a mixture of methane (50-60% vol), CO_2 (30-45%), hydrogen (5-10%), nitrogen (0.5-7%) and small traces of other gases such as hydrogen sulphide and oxygen
-It is a clean, but slow burning gas and having value between 5000 to 5500 kcal/kg or 38131 kJ/m^3
-The octane rating of biogas is 130 and ignition temperature is 650 °C
-Can be used to operate both compression ignition (diesel) and spark ignition (petrol) engines. CI engines can operate on dual-fuel (biogas+diesel) operation and pilot injection operation in which small quantity of diesel is required for igniting the mixture of air and biogas
-80% saving of diesel oil can be achieved
-Drawback of biogas is present of CO_2. The engine performance can be improved by reducing the CO_2 content in biogas.

(d) Hydrogen:

-Clean burning fuel and has the highest energy content per unit mass of any chemical fuels which can reduce the dependency on hydrocarbon based fuels

Production:

Most common method of producing hydrogen involves splitting water (H_2O) into its component parts of hydrogen (H_2) and oxygen (O). There are different methods to produce hydrogen-

i. Steam reformation or partial oxidation of hydrocarbons such as natural gas, naphtha or crude oil. It converts methane into hydrogen and carbon monoxide by reaction with steam over a nickel catalyst.

ii. Coal gasification- Hydrogen made from coal can probably be justified as a fuel for special applications where the unique characteristics of hydrogen can be put to advantage such as its weight or its non-polluting characteristics.

iii. Electrolysis- it uses electrical current to split water into hydrogen at the cathode (+) and oxygen at anode (-) [3].

iv. Thermo chemical method- it utilizes heat to achieve the chemical splitting of water to its elements without the need for intermediate electricity generation and without the need to use the extremity high temperature of 2500 °C or more.

v. Photo-electrolysis- it uses sunlight and catalysts to split water. In this method, a current is generated by exposing on or both electrodes to sunlight. Hydrogen and oxygen gases are liberated at the 2 electrodes by the decomposition of water. A catalyst may be included to facilitate the electrode process.

vi. Biological and photo-biological water splitting use sunlight and biological organisms to split water.

vii. Thermal water splitting uses a very high temperature (approximately 1000 °C) to split water.

viii. Biomass gasification uses selected microbes to break down a variety of biomass feed stocks into hydrogen.

Utilization of hydrogen gas:

Hydrogen can be utilized for the following purpose:

i. Residential use- hydrogen can be used in domestic cooking (stoves), radiant space heaters, electricity for lighting and for operating domestic appliances (e.g. refrigerator) which could be generated by means of fuel cells, with hydrogen gas at one electrode and air at other.

ii. Industrial use- hydrogen can be used as a fuel or a chemical reducing (i.e. oxygen removal) agent. It can also be used instead of coal or coal derived gases, to reduce oxide ores (iron ore) to the material (iron).

iii. Air craft application- The earliest application of liquid hydrogen fuel is expected to be in a jet air craft. Cold liquid hydrogen can be used directly or indirectly to cool the engine and the air frame surfaces of a high speed air craft.

iv. Electric power generation- It comprises the production of electricity by using hydrogen in fuel cell system. Hydrogen could also be used as a means for storing and distributing electrical energy. The objective of developing fuel cell power stations is to centralized and local generation of electricity.

v. As an alternative transport fuel- Hydrogen is tried as an alternative fuel in internal combustion engine. The stoichiometric hydrogen air mixture burns seven times as fast as the corresponding gasoline air mixture which is a great advantage in internal combustion engines, leading to higher engine speeds and greater thermal efficiency [2]. Hydrogen fuel used in IC engines is in automobiles, buses, trucks and farm machinery.

Methods of using Hydrogen as a fuel in CI engines

i. A mixture of fuel gas and air, with an approximately constant fuel to air ratio is introduced into the cylinder intake manifold. The engine power is controlled by varying the quantity of mixture entering the cylinder by means of throttle valve. It is not safe because the mixture is formed in the manifold.

ii. The hydrogen is injected directly into the engine cylinder through a valve under pressure and air is inducted through another intake valve. This method is safer one, since hydrogen and air are supplied separately; an explosive mixture is occurred inside the cylinder only. The engine power output is controlled by varying the pressure of hydrogen gas from about 14 atm at low power to 70 atm at high power.

iii. During the intake stroke, the hydrogen gas at normal or moderate pressure is drawn through the throttle valve into the engine cylinder whereas unthrottled air is drawn in through the intake port. The variation of engine power can be achieved with adjustment of hydrogen inlet throttle. The changes in fuel proportion as well as power is developed due to supply of un throttle air and power variation is possible because of the wide composition range over which hydrogen-air mixture can be ignited [1].

Advantages of using Hydrogen fuelled engine

i. It provides high efficiency because it utilizes a higher proportion of the energy in the fuel.

ii. The amount of carbon monoxide and hydrocarbons in the exhaust is very small since they are originating only from the cylinder lubricating oil.

iii. It can be easily available because it is produced by electrolysis of water.

iv. Fuel leakage to environment is not pollutant.

Disadvantages of using Hydrogen fuelled engine

i. Due to high heat release the combustion temperature may be high and also a level of nitrogen oxide is high. It can be reduced by reducing the combustion temperature by injecting water vapor into the cylinder from the exhaust.

ii. It requires heavy, bulky fuel storage both in vehicle and at the service station.

iii. Difficulty in refueling and possibility of detonation.

iv. Poor engine volumetric efficiency- gaseous fuel will displace some of inlet air and poor volumetric efficiency will result.

v. Fuel cost would be high at present day technology [2].