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SCHOOL OF MECHANICAL

DEPARTMENT OF AUTOMOBILE

UNIT – I – Alternate Fuels and Energy systems –SAUA3013

INTRODUCTION

Alternative fuels, known as non-conventional and advanced fuels, are any materials or substances that can be used as fuels, other than conventional fuels like; fossil fuels, as well as nuclear materials such as uranium and thorium, as well as artificial radioisotope fuels that are made in nuclear reactors.

Some well-known alternative fuels include

- Bio-diesel,
- Bio-alcohol (methanol, ethanol, butane)
- Refuse-derived fuel
- Chemically stored electricity (batteries and fuel cells)
- Hydrogen
- Non-fossil methane
- Non-fossil natural gas
- Vegetable oil
- Propane and
- other biomass sources.

Energy consumption in the world

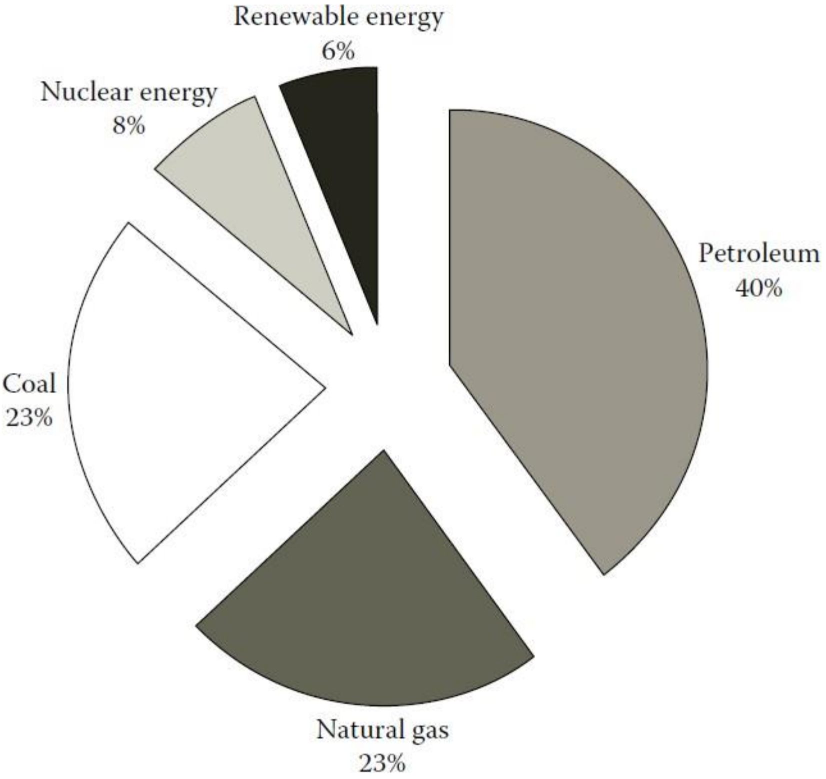


Fig.1.1

NEED FOR ALTERNATE FUELS

1. Conventional fuels are going to run out

- One day, our sources for traditional fuels including petroleum would be depleted. Owing to the fact that these fuels are typically not renewable
- Non-environmentalists also concur with the opinion that the majority of oil fields (situated in the Middle East) in the world are associated with problems – both political and economic.
- Determining a new method or solution with respect to finding different countries to create new fuels would reduce the unrest and conflict resulting from the world's dependence on fuel supply from the Middle East.

2. To reduce pollution

- The use of alternative fuels considerably decreases harmful exhaust emissions (such as carbon dioxide, carbon monoxide, particulate matter and sulfur dioxide) as well as ozone-producing emissions.

3. To protect against global warming

- According to a commonly accepted scientific theory, burning fossil fuels was causing temperatures to rise in the earth's atmosphere (global warming).

4. To save money

- Alternative fuels can be less expensive to use not just in terms of the fuel itself but also in terms of a longer service life. This in turn means savings for the long term.

5. Can reuse waste

- Biofuels, bio products, and bio power provide modern and fresh relevance to the old belief that trash for one person is a treasure for another. That's good news considering that Americans produce in excess of 236 million tons of waste each year.

6. More choices

- People are different. Each person has his own requirements, opinions, and preferences.
- One great thing about alternative fuels and the corresponding vehicles that run on them is that there is something to suit any lifestyle.

7. You'll be helping the farmers

- The use of biofuels that depend on crops produced and processed locally help to support farmers for their dedicated and hard labor.
- Biodiesel and ethanol cooperatives are a result of the great outmoded farmer cooperatives that assist with returning power to the hands of the people.

8. Can frequently be produced domestically

- Often, alternative fuels can be developed domestically, utilizing a country's resources and thereby strengthening the economy.

9. Fuel economy

- Vehicles driven on hydrogen fuel cells and diesel are more economical with respect to fuel compared to an equivalent gasoline vehicle.

10. Meeting Current Global Energy Demand

Alternative fuels are receiving attention because of the following reasons:

- Alternative fuels are mostly produced from domestic resources that reduce the energy dependence. Use of locally available resources for fuel purposes can reduce crude oil import bill.
- Most of the alternative fuels, for example, alcohols, biodiesel can be produced from biomass resources and agricultural wastes and electricity for battery operated vehicles can be produced from solar and fuel cells.
- Hydrogen can be produced from biomass gasification or electrolysis of water. Hence, even a small percentage substitution of different alternative fuels reduces the crude oil import significantly.
- Alternative fuels generally reduce the vehicle exhaust emission and hence improve the environmental air quality.
- Alternative fuels are capable of reducing the engine emissions as compared to petroleum products.
- The molecular structure of alternative fuels (CH_3OH, C_2H_5OH, and CH_4, etc.) is much simpler than gasoline/diesel (mixture of different molecules). Moreover, a low C:H ratio of alternative fuels generates less hydrocarbon emissions on combustion.
- Hydrogen is the clean fuel and generates nil hydrocarbon emissions. Emissions released from a centralized plant can be more easily controlled than vehicular emissions.
- Some alternative fuels have the potential to operate at a lower cost compared to petroleum products.
- Success of any new product or fuel depends on its cost. Currently, cost of the most alternative fuels is a little bit higher than conventional fuel.
- However, the cost of biodiesel and compressed natural gas (CNG) are cost competitive with petroleum.
- For the development of alternative fuels, government legislations and incentives are required to a certain extent.

- The large-scale production of alternative fuel could make these alternative fuels cost competitive

Parameters are to be considered while deciding the alternative fuel

- The fuel should have high volumetric and mass energy density.
- Ease of transportation from production site to delivery points.
- Long-storage life of fuel, minimum handling, and distribution problems.
- Environmental compatibility: While using alternative fuel, the engine performance is expected to improve significantly with regard to regulated emissions and unregulated emissions.
- Manufacturer's warranty: The alternative fuel must guarantee the lifetime of the equipment; its reliability and operational capability are not modified.
- Investment cost: Additional investment on an existing engine must be small to ensure that the operation is competitive with petroleum fuel.
- Modification of existing engines: Engine modification should be simple, inexpensive, and easily reversible.

Some of the important fuels are listed here:

1. Alcohols (methanol and ethanol)
2. Vegetable oils and biodiesel
3. Gaseous fuels (natural gas, hydrogen, and liquefied petroleum gas)
4. Ethers
5. Electric/fuel cell/hybrid vehicles
6. Future Fuels

1. Alcohols

Alcohols are considered as a substitute or additive component for gasoline as they possess a higher octane number.

1.1 Methanol

- With the advent of flexi-fuel vehicles (FFV) in the 1990s, the methanol became a prime candidate for use in vehicles because of its lower emission characteristics and high-octane rating.
- To solve the cold-start problems in methanol, a percentage of gasoline is added. Blends of 15% gasoline and 85% of methanol are called M85.
- The FFV vehicles are also able to operate on gasoline, methanol, and their blends.

- Though it is a commercial success, methanol has not become the competitor of gasoline because of its higher cost.

Currently, methanol is again considered for fuel cell vehicles; that is, methanol is used as fuel to derive the hydrogen for the operation of fuel cells

1.2. Ethanol

- Ethyl alcohol, commercially known as ethanol, possesses a number of characteristics favoring its use as an automobile fuel.
- Ethanol is a by-product in the production of sugar. Ethanol is a renewable fuel made from corn and other plant materials.
- At present, ethanol is blended with gasoline for improving the octane number of gasoline
- Ethanol molecules contain oxygen and therefore, it allows the engine to completely combust the fuel, resulting in less emission of carcinogenic gases like carbon monoxide, NOx, and so on.
- Ethanol use is widespread, and more than 98% of gasoline in the U.S. contains some ethanol. The most common blend of ethanol is E10 (10% ethanol, 90% gasoline).
- Ethanol is also available as E85 (or flex fuel)—a high-level ethanol blend containing 51% to 83% ethanol, depending on geography and season—for use in flexible fuel vehicles. E15, another blend, is increasing its market presence.
- The auto ignition temperature of ethanol is significantly higher than gasoline and this makes ethanol less susceptible to ignition.

2. Vegetable Oils and Biodiesel

- Vegetable oils and derivatives have the potential to substitute for a fraction of the petroleum distillates and petroleum-based petrochemicals.
- Vegetable oil fueled engines require frequent maintenance (like injector and combustion chamber cleaning) and hence these are suitable for stationary engines that are used for power generation and generator-motor pump sets in rural areas.
- These could reduce a significant amount of energy savings in terms of diesel or electricity consumption.
- Use of neat oils causes varieties of engine problems. Based on the results obtained, research focused on esters due to their superior fuel properties than neat vegetable oils.
- Biodiesel is methyl or ethyl esters of fatty acids derived from edible and nonedible type vegetable oils (used or fresh) and animal fats. The major sources for biodiesel production can be jatropha, karanji, palm, soy bean, and sun flower.
- Biodiesel can be blended with diesel at any ratio (however currently the blend is limited to 20%) and operates the diesel engine, which requires little or no modification.

- The use of biodiesel in conventional diesel engines substantially reduces the exhaust emissions.

3. Gaseous Fuels

3.1 Natural Gas

- Natural gas has received a great deal of attention and has been successfully implemented in various parts of the world, such as Argentina, Russia, Italy, and India and gaining importance for transport vehicles.
- Natural gas occurs as gas under pressure in rocks beneath the earth's surface or more often in solution with crude oil as the volatile fraction of petroleum.
- It is composed of mainly methane with varying amounts of the paraffinic hydrocarbon family, ethane, propane, butane, (methane hydrate).
- Research Octane Number (RON) of CNG is approximately 130. The excellent anti knocking property of CNG allows use of a higher compression ratio for increased power output and fuel economy compared to petrol.
- The CNG has an excellent lean flammability limit and has the potential to reduce regulated and non methane hydrocarbon emissions compared to conventionally fueled engines.
- Natural gas can be stored in gaseous form at ambient temperatures and under high pressure (approx. 200 bar) as CNG and in liquid form at cryogenic temperatures (–161°C) and at atmosphere pressure as liquefied natural gas

3.2 Liquefied Petroleum Gas

- Liquefied petroleum gas (LPG), a mixture of propane (C_3H_8) and butane (C_4H_{10}) gas, is a popular fuel for internal combustion engines.
- It is a nonrenewable fossil fuel that is prepared in a liquid state under certain conditions.
- This popularity comes from many features of the fuel such as its high octane number for spark ignited engines, comparable to gasoline heating value that ensures similar power output.
- The LPG is stored as a liquefied gas under pressure at ambient temperature.
- The percentage composition of the mixture depends upon the season, as a higher percentage of propane is kept in winter and the same for butane in summer.

3.3 Hydrogen

- Hydrogen is one of the clean fuels in the world, as it does not contain carbon compounds. Hydrogen is a clean and efficient energy carrier with the potential to replace liquid and gaseous fossil fuels.
- Hydrogen can be combusted directly in the IC engines or it can be used in the fuel cell to produce electricity, which can operate the vehicle.

- Hydrogen can be introduced into the engines by manifold induction, direct injection to the cylinder, and hydrogen–diesel duel fuel mode.
- The methods to produce hydrogen include electrolysis, photolysis, thermochemical water splitting, and thermal water splitting.
- In near term, hydrogen can also be produced from coal gasification and from petroleum and natural gases. Hydrogen can also be produced from various biomass sources.
- Hydrogen is a low-density gas. At ambient temperature and atmospheric pressure, 1 kg of the gas has a volume of about 11 m^3.

3.4 Biogas

- It is the mixture of gases produced by the breakdown of organic matter in the absence of oxygen (anaerobically), primarily consisting of methane and carbon dioxide.
- **Biogas** can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste.
- After **biogas** is captured, it can produce heat and electricity for use in engines, micro turbines, and fuel cells.
- **Biogas** can also be upgraded into bio methane, also called renewable natural gas or RNG, and injected into natural gas pipelines or **used** as a vehicle fuel.

4. Ethers

- Ethers are oxygenating fuel that improves the combustion efficiency. Dimethyl ether is the commonly used blending component in gasoline fuel.
- Moreover, DME is a potential alternative fuel that can be used in engines as well as onboard hydrogen generation fuel cells. DME can be produced from natural gas and gasification of coal or biomass and synthesis.
- DME is a colorless gas at room temperature with an ethereal odor, has a vapor pressure of 5.93 bar at 25ºC, and is highly flammable in air.
- DME has no corrosive effects on metals but it is a good solvent.
- DME has high Cetane number (55–60).
- However, the calorific value of DME is 28.5 MJ/kg whereas for diesel 42.5 MJ/kg.
- DME contains oxygen but no C–C bonds and has the advantage of reducing carbon particulate matter emissions formation. DME is a gas at ambient conditions but it can be liquefied under pressure like LPG

Diethyl ether

- Diethyl ether (DEE) can be used as a renewable fuel additive.

- DEE has long been known as a cold-start aid for engines, but little is known about using DEE as a significant component in a blend or as a complete replacement for fuel.
- It is an excellent engine fuel with higher energy content than ethanol.
- DEE is liquid at ambient conditions that make it attractive for fuel handling and infrastructure requirements.
- Storage stability of DEE and its blends are of concern because of its tendency to oxidize and form peroxides in storage.
- DEE has several favorable properties, including an outstanding cetane number and reasonable energy density for onboard storage.

5. Electric/Fuel Cell/Hybrid Vehicles

- The control of tailpipe emissions and maximum possible reduction in fuel consumption are the top priority objectives for any automobile designer and manufacturer.
- Electricity stored in the battery can be used to operate the vehicles by means of an electric motor. These electric vehicles are noiseless.
- Electricity normally is generated from coal, natural gas, solar, fuel cell, on board diesel engine, gas, and nuclear energy
- If the electricity produced from non fossil fuel, then electric vehicles become zero emission vehicles.
- Thermal energy is converted to electricity and stored in a battery, and again it is converted into work. So, while calculating overall efficiency of vehicles, these conversion efficiencies have to be considered.
- The storage capability of the battery plays an important role in the success of electric vehicles.
- Pure electric vehicles currently do not have adequate range when powered by batteries alone, and hence it cannot be used for driving long distances. Electric vehicles require recharging of the battery.
- Hybrid electric vehicles (HEV) combine the alternative energy source (engine/fuel cell) to run the vehicle and charge the battery.
- Hybrid electric vehicles combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle resulting in better fuel economy.
- The power of the hybrid vehicle’s internal combustion engine generally ranges from 1/10th to 1/4th of the conventional automobile.

- In a HEV, when the driver applies the brakes, the motor becomes a generator, using the kinetic energy of the vehicle to generate electricity that can be stored in the battery for later use.
- A hybrid can achieve the cruising range and performance advantages of conventional vehicles with the low-noise, low-exhaust emissions, and energy independence benefits of electric vehicles.
- The fuel cell can be used in hybrid vehicles to charge the battery instead of the internal combustion engine.
- Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy.
- The basic physical structure or building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side.
- Gaseous fuels are fed continuously to the anode (negative electrode) compartment and an oxidant (i.e., oxygen from air) is fed continuously to the cathode (positive electrode) compartment; the electrochemical reactions take place at the electrodes to produce an electric current.
- Biomass generated gaseous fuels such as hydrogen can also be used as fuel for the fuel cells.

PROPERTIES OF ALTERNATIVE FUELS

1. AUTO IGNITION TEMPERATURE

Auto ignition temperature is a minimum temperature of a substance to initiate self-sustained combustion independent of any ignition source.

2. BOILING TEMPERATURE

Boiling temperature is a temperature at which the transformation from liquid to vapor phase occurs on a substance at atmospheric pressure. Fuels that are pure compounds (such as methanol) have a single temperature as their boiling points, while fuels with mixtures of several compounds (like gasoline) have boiling points of each individual compound in the mixture. For these mixtures, the 10% point of distillation is often used as the boiling point.

3. CETANE NUMBER

- **Cetane rating**, also known as **cetane number** is a measurement of the quality or performance of diesel fuel.
- The cetane number measures the delay in the ignition time of the fuel.
- A higher cetane number simply means the time between when the fuel is injected into the combustion chamber and when the fuel ignites is minimized.
- This means the fuel has the ability to ignite more easily and readily due to compression. This shorter delay time results in more complete fuel combustion

- expressed as the percentage of cetane in a mixture of cetane and 1methylnapthalene of the same quality as the given fuel

4. FLAMMABLE LIMITS

- **Flammable limits** apply generally to vapors and are defined as the concentration **range** in which a **flammable** substance can produce a fire or explosion when an ignition source (such as a spark or open flame) is present. The concentration is generally expressed as percent fuel by volume.
- The minimum concentration of a particular combustible gas or vapor necessary to support its combustion in air is defined as the Lower Explosive Limit (LEL) for that gas. Below this level, the mixture is too “lean” to burn.
- The maximum concentration of a gas or vapor that will burn in air is defined as the Upper Explosive Limit (UEL). Above this level, the mixture is too “rich” to burn. The range between the LEL and UEL is known as the flammable range for that gas or vapor.

5. FLASH POINT

- **Flash point**, the lowest temperature at which a liquid (usually a petroleum product) will form a vapour in the air near its surface that will “**flash**,” or briefly ignite, on exposure to an open **flame**. The **flash point** is a general indication of the flammability or combustibility of a liquid.
- **Flammable** liquids have a **flashpoint** below 37.8°C(100°F). **Combustible** liquids have a **flash point** at or above 37.8°C (100°F) and below 93.3°C (200°F).

6. CALORIFIC VALUE (HEATING VALUE)

- Calorific value is defined as the amount of calories generated when a unit amount of substance is completely oxidized and is determined using the bomb calorimeter.
- Heating value is a very significant property of fuels, because it gives the energy content of the fuel.
- The heating value is expressed as gross and net calorific value, depending on the status of water present in the exhaust.
- If water is present as liquid, then heating value is called gross calorific value.
- If water is present as vapor, then the heating value is called net calorific value.
- In real operating situations, water in exhaust gases is present as vapor, so net calorific value is more important for energy efficiency calculations.
- The unit of calorific value is kJ/Kg or kJ/m^3

7. LATENT HEAT OF VAPORIZATION

Latent heat of vaporization is the quantity of heat absorbed by a fuel on passing between liquid and gaseous phases. The condition under which latent heat of vaporization is measured is the boiling point and atmospheric pressure, 101.4 kpa.

8. OCTANE NUMBER

- **Octane number**, also called **Antiknock Rating**, measure of the ability of a fuel to resist knocking when ignited in a mixture with air in the cylinder of an internal-combustion engine.
- The octane number is determined by comparing, under standard conditions, the knock intensity of the fuel with that of blends of two reference fuels: iso-octane, which resists knocking, and heptane, which knocks readily.
- The octane number is the percentage by volume of iso-octane in the iso-octane–heptane mixture that matches the fuel being tested in a standard test engine.
- Octane numbers are determined using n- heptanes that has an octane number of 0, and isooctane that has an octane number of 100.

9. STOICHIOMETRIC AIR- FUEL RATIO

The exact air — fuel ratio required to completely combust a fuel to water and carbon dioxide.

10.POUR POINT

The lowest temperature at which a petroleum product will just flow when tested under standard conditions.

11. CLOUD POINT

The temperature at which a petroleum product just shows a cloud or haze of wax crystals when it is cooled under standard test conditions

12. VOLATILITY

- The property of a liquid that defines its evaporation characteristics; important for complete combustion.
- Volatility is expressed in terms of the temperature at which successive portions are distilled from a sample of the fuel under controlled heating.
- Volatility will effect viscosity, flash point, cetane number, density, and smoking (exhaust).
- Too high, or too low volatility negatively impacts these factors.

13. SULFUR

Sulfer content (ppm); important to minimize engine wear and to meet legislation. Forms acidic by-products that are harmful to the environment, and eat away the engine (SO, SO2, SO3)

14. VISCOSITY

- The measure of resistance to flow of a liquid; important for consistency, injector flow, and good atomization.
- An **upper limit** on viscosity ensures that fuel will flow readily during cold starting, and a **minimum limit** is often specified to avoid the possibility of a serious power loss at high temperatures.

15. DENSITY

Mass of a substance per unit volume; important for consistency and good fuel economy. Higher density produces more power and more smoke.

16. ASH CONTENT

- Fuels may contain small amount of ash forming material, such as suspended solids and soluble organometallic compounds.
- Can cause damage to close tolerances of fuel injection system, and abrasive wear on engine components (piston rings).

17. CARBON RESIDUE

- Indicates the tendency of the fuel to form carbonaceous deposits.
- In brief, the carbon residue of a fuel is the tendency to form carbon deposits under high temperature conditions in an inert atmosphere.

18. CORROSIVITY

To minimize attack on metals in the distribution and storage network, and in the engine fuel system.

19. AROMATICS CONTENT

Reducing aromatic hydrocarbon composition will reduce emissions.

20. OXIDATION STABILITY

It refers to the tendency of fuels to react with oxygen at temperatures nearer ambient—mechanism. It describes the relative susceptibility of the fuel to degradation by **oxidation**.

Oxidation Stability is one of the most important properties of fuels and primarily affects the stability of fuel during extended storage

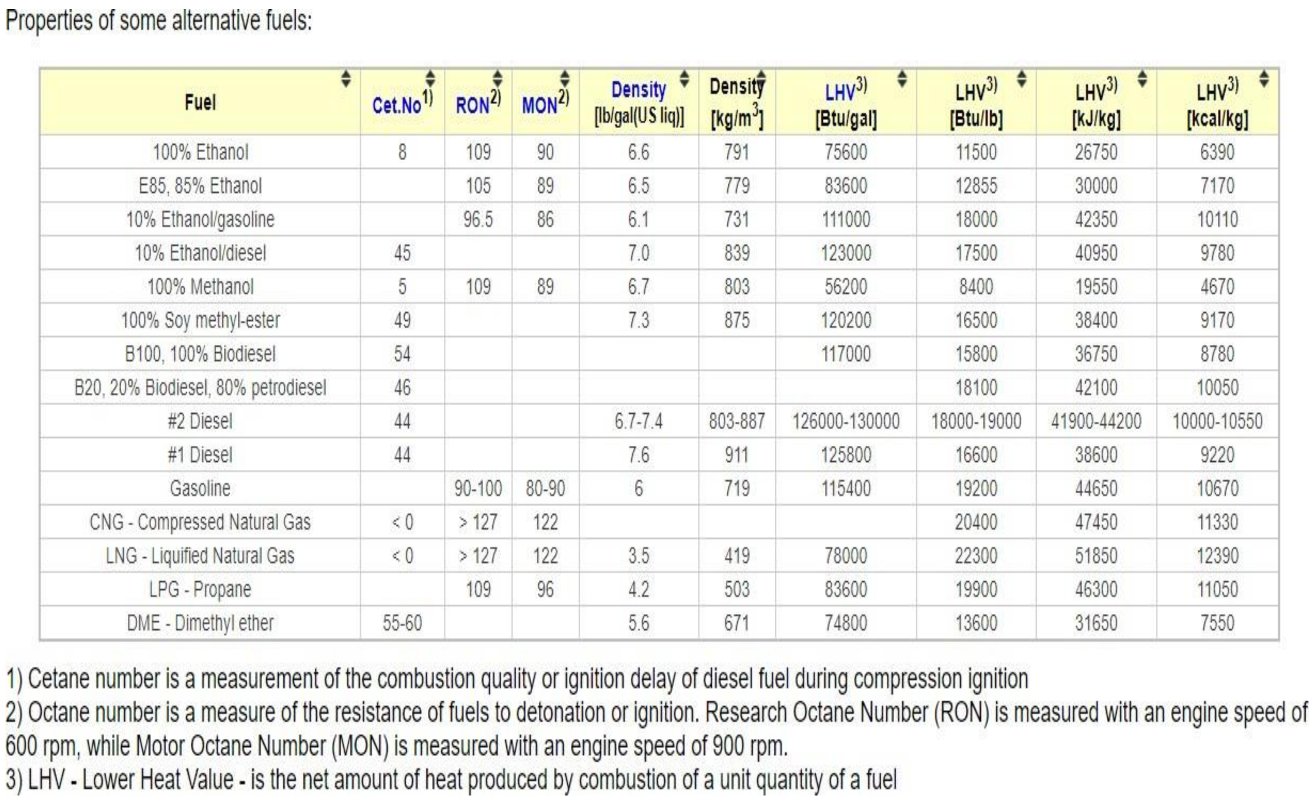
Degradation by oxidation yields products that may compromise fuel properties, impair fuel quality and engine performance.

21. REID VAPOR PRESSURE (RVP)

- It is a common measure of the volatility of gasoline and other petroleum products. It is defined as the absolute vapor pressure exerted by the vapor of the liquid and any dissolved gases/moisture at 37.8 °C (100 °F)

- The matter of vapor pressure is important relating to the function and operation of gasoline-powered, especially carbureted, vehicles and is also important for many other reasons.
- High levels of vaporization are desirable for winter starting and operation and lower levels are desirable in avoiding vapor lock during summer heat.
- Fuel cannot be pumped when there is vapor in the fuel line (summer) and winter starting will be more difficult when liquid gasoline in the combustion chambers has not vaporized.
- Thus, oil refineries manipulate the Reid Vapor Pressure seasonally specifically to maintain gasoline engine reliability.

Table 1.1



Properties of some alternative fuels:

Fuel	Cet.No$^{1)}$	RON$^{2)}$	MON$^{2)}$	Density [lb/gal(US liq)]	Density [kg/m^3]	LHV$^{3)}$ [Btu/gal]	LHV$^{3)}$ [Btu/lb]	LHV$^{3)}$ [kJ/kg]	LHV$^{3)}$ [kcal/kg]
100% Ethanol	8	109	90	6.6	791	75600	11500	26750	6390
E85, 85% Ethanol		105	89	6.5	779	83600	12855	30000	7170
10% Ethanol/gasoline		96.5	86	6.1	731	111000	18000	42350	10110
10% Ethanol/diesel	45			7.0	839	123000	17500	40950	9780
100% Methanol	5	109	89	6.7	803	56200	8400	19550	4670
100% Soy methyl-ester	49			7.3	875	120200	16500	38400	9170
B100, 100% Biodiesel	54					117000	15800	36750	8780
B20, 20% Biodiesel, 80% petrodiesel	46						18100	42100	10050
#2 Diesel	44			6.7-7.4	803-887	126000-130000	18000-19000	41900-44200	10000-10550
#1 Diesel	44			7.6	911	125800	16600	38600	9220
Gasoline		90-100	80-90	6	719	115400	19200	44650	10670
CNG - Compressed Natural Gas	< 0	> 127	122				20400	47450	11330
LNG - Liquified Natural Gas	< 0	> 127	122	3.5	419	78000	22300	51850	12390
LPG - Propane		109	96	4.2	503	83600	19900	46300	11050
DME - Dimethyl ether	55-60			5.6	671	74800	13600	31650	7550

1) Cetane number is a measurement of the combustion quality or ignition delay of diesel fuel during compression ignition
2) Octane number is a measure of the resistance of fuels to detonation or ignition. Research Octane Number (RON) is measured with an engine speed of 600 rpm, while Motor Octane Number (MON) is measured with an engine speed of 900 rpm.
3) LHV - Lower Heat Value - is the net amount of heat produced by combustion of a unit quantity of a fuel

ALCOHALS

Potential of Methanol

Methanol is the chemically simplest alcohol, containing one carbon atom per molecule. It is a toxic, colorless, tasteless liquid with a very faint odor and commonly known as “wood alcohol.” Because it is produced as a liquid, methanol is stored and handled like gasoline.

Methanol has the advantage of being a liquid fuel that can be synthesized from gasification and reforming in a variety of feed stocks like coal and natural gas using well-established thermochemical technology.

Methanol can also be made from a wide range of renewable sources, such as wood, waste paper, coal, and biomass.

Methanol is a good candidate for alternative fuel investigations because of its abundances, physical, and chemical properties.

It can serve as a low carbon emitting fuel. Methanol can be an important option for the replacement of gasoline.

The main uses of methanol as an alternative fuel are:

Direct use: blend with diesel or gasoline and

Indirect use: conversion of methanol to dimethyl ether, ingredient in production of biodiesel and hydrogen for use in fuel cell vehicles

METHANOL PRODUCTION :

1.Methanol Production Via Synthesis gas

Natural gas is the largest source of synthesis gas. Methane (CH_4) is the chief constituent of natural gas. Methanol is made from CH_4 in a series of three reactions.

Steam reforming reaction

In steam reforming, CH_4 reacts in a highly endothermic reaction with steam over a catalyst, typically based on nickel, at high temperatures (800–1000°C, 20–30 atm) to form CO and H_2.

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \qquad \Delta H\mathrm{r} = 206\ \mathrm{kJ/mol}$$

Water–gas shift (WGS) reaction

A part of the CO formed reacts consequently with steam in the WGS reaction to yield more H_2 and also CO_2. The gas obtained is thus a mixture of H_2, CO, and CO_2. The compressed synthesis gas enters the converter containing copper zinc and catalyst and the methanol synthesis occurs according to the methanol synthesis reaction.

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H\mathrm{r} = 206\ \mathrm{kJ/mol}$$

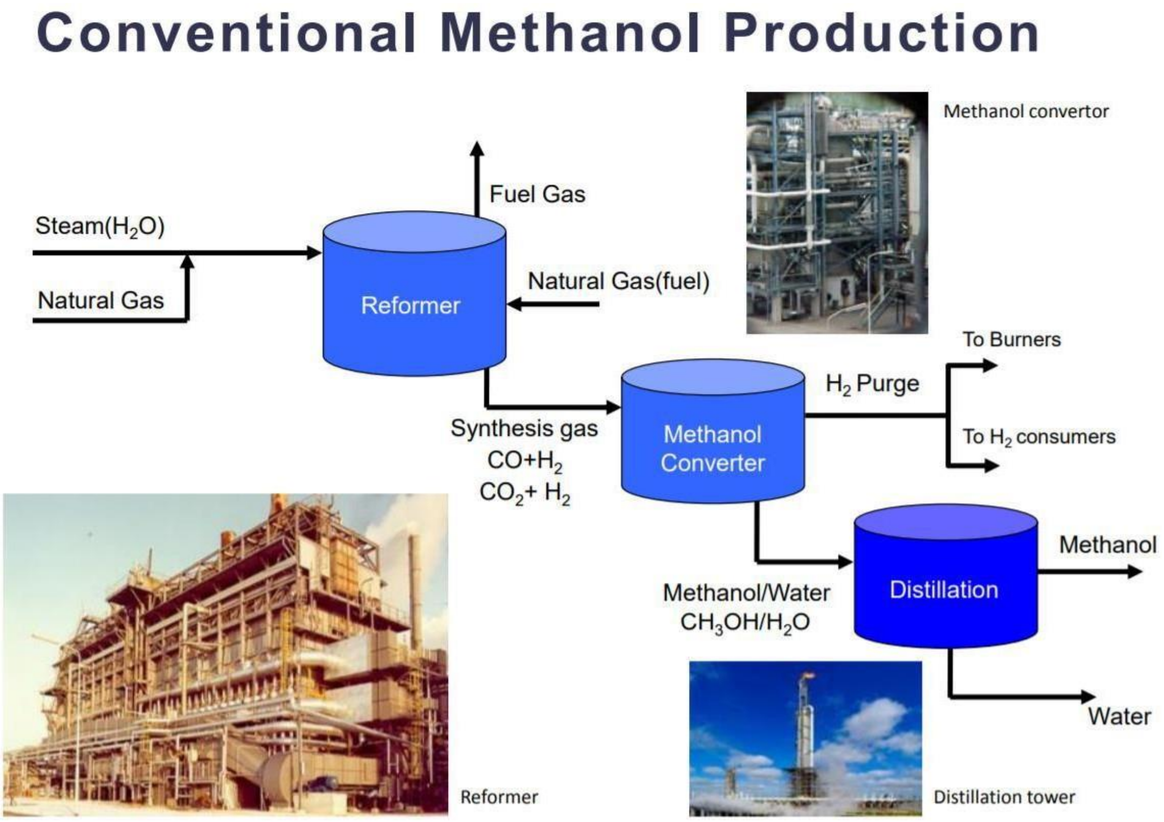


Fig.1.2

Methanol synthesis reaction

$$2H_2 + CO \leftrightarrow CH_3OH \qquad \Delta Hr = -92\ \text{kJ/mol}$$

If CO is used up in the methanol synthesis reaction the WGS reverses producing more CO.

$$H_2 + CO_2 \leftrightarrow CO + H_2O \qquad \Delta Hr = 41\ \text{kJ/mol}$$

This reaction combines to produce approximately 40% conversion of CO to methanol. The gas mixture is cooled and methanol and water condense out. The remaining gas is returned to the circulator, mixed with incoming compressed synthesis gas and recycled through the methanol converter.

Hence, the overall reactions by which methanol are produced from synthesis gas may be summarized into the following equation

$$CO_2 + CO + 5H_2 \rightarrow 2CH_3OH + H_2O + \text{heat.}$$

2. METHANOL PRODUCTION BY COAL GASIFICATION

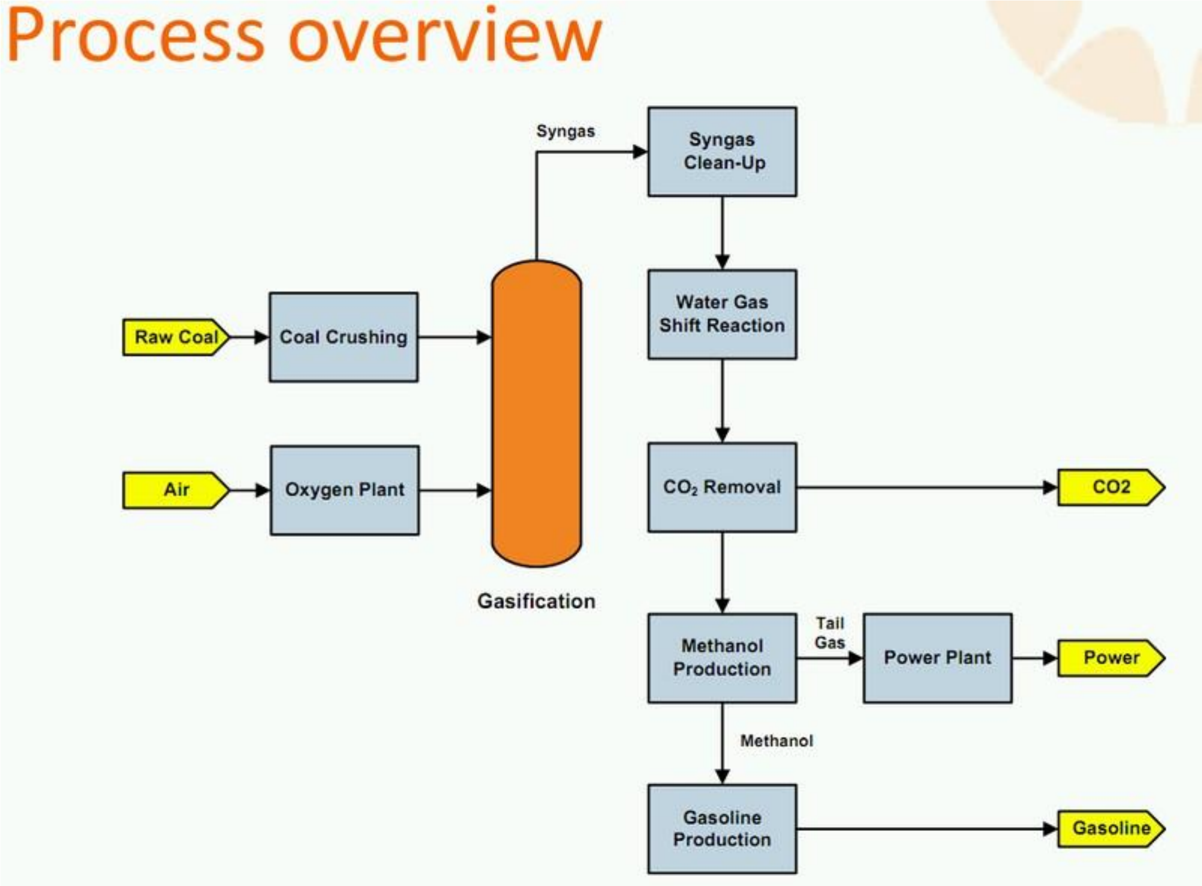


Fig.1.3

Methanol production from coal involves several steps that are

- coal gasification,
- acid gas removal,
- WGS reaction,
- methanol synthesis, a
- methanol refining.

The first step in the production of methanol is the gasification of coal to CO and H2. The overall reaction for coal gasification is

$$C_xH_y + (x/2)\,O_2 \rightarrow x\,CO + (y/2)\,H_2,$$

The main by-product of coal gasification is acid gas, which is composed of hydrogen sulfide (H2S) and CO2. The H2S needs to be removed from the synthesis gas. The first stage involves the combustion of one-third the total H2S to form SO2 and water; the second is a low temperature catalytic stage that involves the reaction of SO2 with the remaining H2S to ultimately yield water and elemental sulfur. The reaction is presented as follows:

$$H_2S + \frac{3}{2}O_2 \leftrightarrow SO_2 + H_2O$$

$$2H_2S + SO_2 \leftrightarrow 2H_2O + \frac{3}{8}S_8$$

$$3H_2S + \frac{3}{2}O_2 \leftrightarrow 3H_2O + \frac{3}{8}S_8.$$

The following step of the WGS reaction usually utilizes a high-temperature shift reaction with Fe3O4 as a catalyst. The purpose of the WGS reaction is to adjust the ratio of H2 to CO to 2:1.

In the last step, CO and H2 produce methanol by the methanol synthesis reaction. The most widely used catalyst is a mixture of copper, zinc oxide, and alumina, and we can use it to catalyze the production of methanol with better selectivity

$$2H_2 + CO \leftrightarrow CH_3OH \qquad \Delta Hr = -92\ \mathrm{kJ/mol}$$

If CO is used up in the methanol synthesis reaction the WGS reverses producing more CO

$$H_2 + CO_2 \leftrightarrow CO + H_2O \qquad \Delta Hr = 41\ \mathrm{kJ/mol}$$

Hence, the overall reactions by which methanol are produced from synthesis gas may be summarized into the following equation

$$CO_2 + CO + 5H_2 \rightarrow 2CH_3OH + H_2O + \text{heat}.$$

3. Methanol from renewable resources

Biomass is an organic material, such as urban wood wastes, primary mill residues, forest residues, agricultural residues, and dedicated energy crops (e.g., sugar cane and sugar beets) that can be made into fuel.

Biomass can be converted to synthesis gas by a process called partial oxidation and later converted to methanol

Biomass → synthesis gas (CO, H2) → CH3OH

In the first step biomass undergoes gasification to produce synthesis gas. Carbon source is reacted with steam (or steam and oxygen) at very high temperatures to produce CO, and H2 in the gasification is a process

$$CH_xO_y + H_2O \leftrightarrow CO + H_2 + CO_2.$$

The following equation shows that the synthesis gas is then reacted in the presence of a catalyst to yield CH3OH by methanol synthesis reaction

$$2H_2 + CO \leftrightarrow CH_3OH \qquad \Delta Hr = -92\ \mathrm{kJ/mol}.$$

PROPERTIES WHICH ARE IMPORTANT TO METHANOL Methanol has several physical and chemical characteristics that make it a good fuel but also some shortcomings.

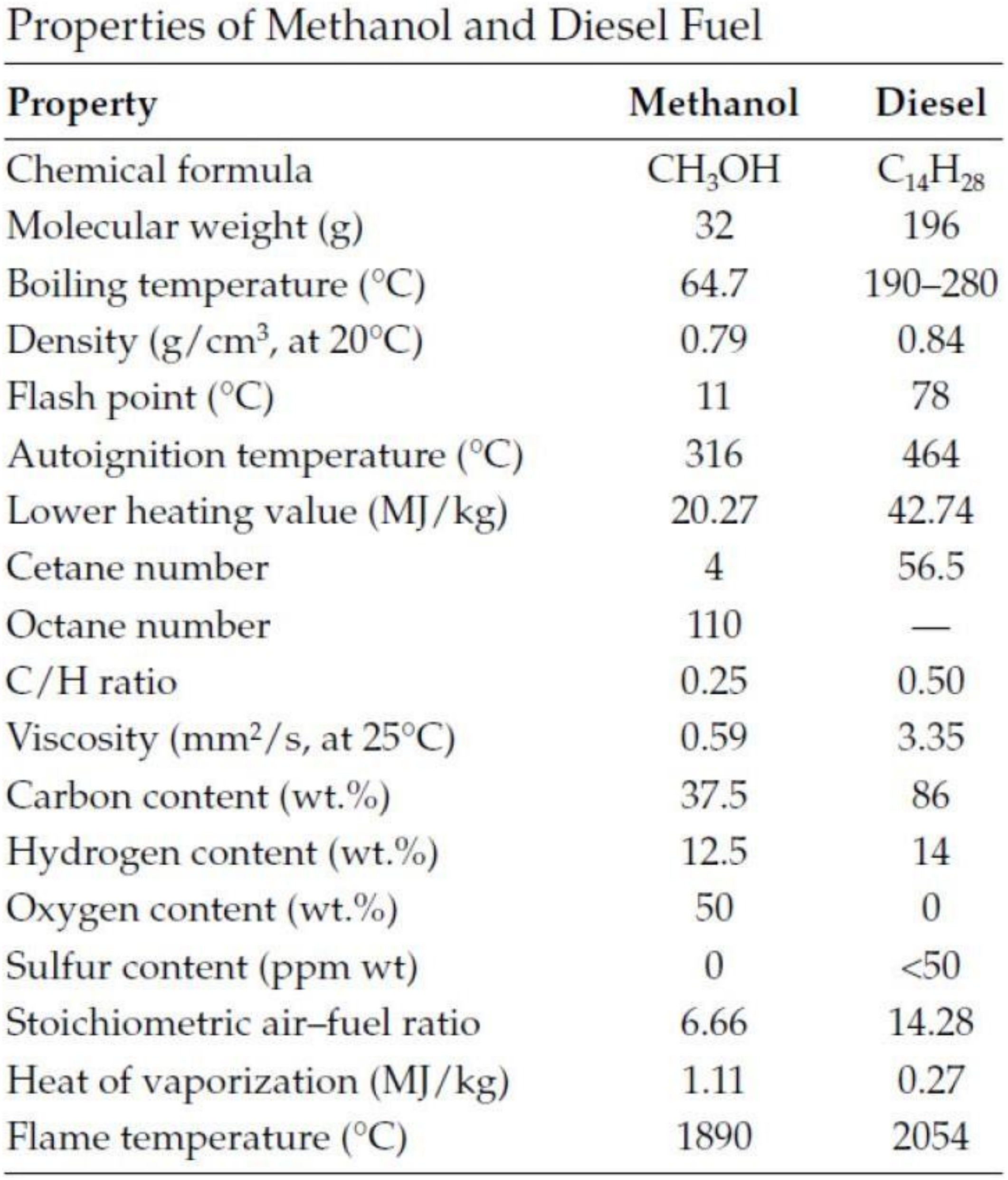
BENEFITS

- High resistance to knocking combustion (high octane number), due to which higher compression ratios may be applied, resulting in very high efficiency of the engine
- Cleaner (soot-free) combustion
- Lower lean flammability limit, resulting in the possibility of lean mixture application and, consequently, better economy and lower emissions of NOX, hydrocarbon (HC) and carbon monoxide (CO)
- Higher heat of evaporation, resulting in a higher temperature drop in the Venturi nozzle of the carburetor and therefore higher volumetric efficiency
- Lower combustion temperature, resulting in lower NOX, emission
- Higher volatility, resulting in better distribution among cylinders of air-fuel ratios and mass of fuel per cycle of multi-cylinder carburetor engines

SHORTCOMINGS

- Poor self-ignition properties (long ignition delay)
- Poor miscibility with mineral fuels (especially with diesel oil) in the presence of water
- Difficulty in starting a cold engine
- Corrosion and chemical degradation of materials
- Evaporation in fuel lines (vapor locks)
- Poor lubrication properties resulting from low viscosity
- Degradation of oil lubrication properties

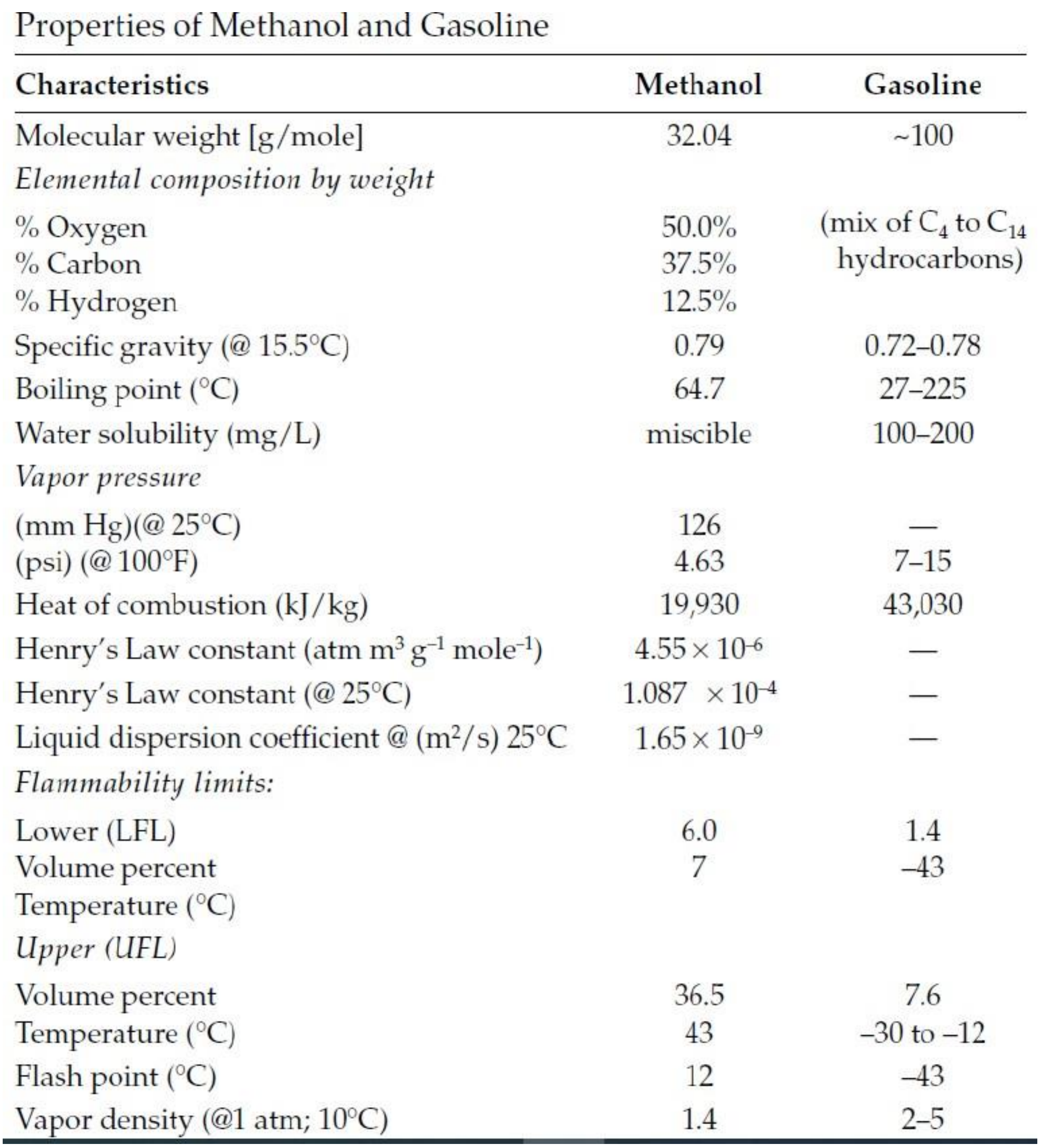
Table 1.2



Properties of Methanol and Diesel Fuel

Property	Methanol	Diesel
Chemical formula	CH_3OH	$C_{14}H_{28}$
Molecular weight (g)	32	196
Boiling temperature (°C)	64.7	190–280
Density (g/cm^3, at 20°C)	0.79	0.84
Flash point (°C)	11	78
Autoignition temperature (°C)	316	464
Lower heating value (MJ/kg)	20.27	42.74
Cetane number	4	56.5
Octane number	110	—
C/H ratio	0.25	0.50
Viscosity (mm^2/s, at 25°C)	0.59	3.35
Carbon content (wt.%)	37.5	86
Hydrogen content (wt.%)	12.5	14
Oxygen content (wt.%)	50	0
Sulfur content (ppm wt)	0	<50
Stoichiometric air–fuel ratio	6.66	14.28
Heat of vaporization (MJ/kg)	1.11	0.27
Flame temperature (°C)	1890	2054

Table 1.3



Properties of Methanol and Gasoline

Characteristics	Methanol	Gasoline
Molecular weight [g/mole]	32.04	~100
Elemental composition by weight		
% Oxygen	50.0%	(mix of C_4 to C_{14} hydrocarbons)
% Carbon	37.5%	
% Hydrogen	12.5%	
Specific gravity (@ 15.5°C)	0.79	0.72–0.78
Boiling point (°C)	64.7	27–225
Water solubility (mg/L)	miscible	100–200
Vapor pressure		
(mm Hg)(@ 25°C)	126	—
(psi) (@ 100°F)	4.63	7–15
Heat of combustion (kJ/kg)	19,930	43,030
Henry's Law constant (atm m^3 g^{-1} $mole^{-1}$)	4.55×10^{-6}	—
Henry's Law constant (@ 25°C)	1.087×10^{-4}	—
Liquid dispersion coefficient @ (m^2/s) 25°C	1.65×10^{-9}	—
Flammability limits:		
Lower (LFL)	6.0	1.4
Volume percent	7	–43
Temperature (°C)		
Upper (UFL)		
Volume percent	36.5	7.6
Temperature (°C)	43	–30 to –12
Flash point (°C)	12	–43
Vapor density (@1 atm; 10°C)	1.4	2–5

Methanol: gasoline Blends

- Methanol may be used directly as an engine fuel just as LPG and ethanol. The direct use of methanol as an engine fuel has advantages and disadvantages.
- The relative very high-latent heat of vaporization of methanol results in a lower burning temperature in the engine cylinders as it does for ethanol.

- The direct use of methanol as an engine fuel in passenger vehicles would require nontrivial engine modifications and substantial changes in the lubrication system.
- Due to its high Reid Vapor Pressure (RVP) that is a measure of affected volatility of blended gasoline, use of methanol as gasoline blending is limited even though it has a high octane rating and is an excellent candidate of oxygenated hydrocarbons.
- When pure methanol is used, cold start problems can occur because it lacks the highly volatile compounds (butane, iso-butane, propane) that provide ignitable vapor to the engine even under the most frigid conditions.
- The addition of more volatile components to methanol is usually the preferred solution.

Methanol: Diesel Blends

- Methanol and diesel are not very miscible, which makes it difficult to mix the PM together as a diesel engine fuel.
- Methanol–diesel blends gave good performance when the amount of methanol in the mixed fuel does not exceed 30% by weight and combustion characteristics when the maximum methanol mass fraction was 20% by weight
- Methanol can be blended with diesel fuel although its corrosive nature creates a need for caution in the design of the engine and fuel system like in ethanol.
- Methanol has half the volumetric energy density relative to gasoline or diesel. It is usually mixed in percentages ranging from 5 to 85%.
- The combination rate of methanol in the fuel is 85%, which is called M85.
- At the same time, the aldehyde compound that comes along with burning methanol forms a strong acid. Therefore, the researchers should pay more attention to this fuel.

Dimethyl ether

•Methanol can be used to make methyl tertiary-butyl ether (MTBE), which is blended with gasoline to enhance octane and create cleaner burning fuel. But MTBE production and use also has disadvantages because it contaminates groundwater.

•The closely related derivative of methanol, dimethyl ether (DME) is a highly desirable alternative fuel. It is generally produced by dehydration of methanol.

•Also DME has been known as an ultra-clean fuel, which can be used in diesel engines, households, power generation, and for other purposes.

•Because of its high cetane number and favorable combustion properties, it is a particularly effective fuel for diesel engines. DME blends well with gasoline or diesel to be used as fuels in internal combustion engines or electricity generators.

•DME is also a potential substitute for liquefied natural gas (LNG) and LPG for heating homes and in industrial uses.

•Another methanol derivative is dimethyl carbonate (DMC), which can be obtained by converting methanol with phosgene or by oxidative carbonylation of the methanol.

•DMC has a high cetane rating, and can be blended into diesel fuel in a concentration up to 10%, reducing fuel viscosity and improving emissions.

Biodiesel Production ingredient

- Another way to use methanol in diesel engines and generators is through biodiesel.
- Biodiesel can be produced from a large variety of vegetable oils and animal fats that react with methanol in a transesterification process to produce biodiesel.
- Biodiesel can be blended without major problems with regular diesel oil in any proportion.
- Methanol and its derivatives (such as DME, DMC, and biodiesel) have many existing and potential uses.
- They can be used, for example, as a substitute fuel for diesel engine powered cars with only minor modifications to the existing engines and fuel systems.

Fuel Cell Fuel

- Methanol can also be used in fuel cells—for fuel cell vehicles—which are considered to be the best alternative to internal combustion engines in the transportation field.
- One of the most efficient uses of methanol is in fuel cells, particularly in direct methanol fuel cells (DMFC), in which methanol is directly oxidized with air to carbon dioxide (CO2) and H2O while producing electricity.
- DMFC systems are currently being developed as battery replacements for the portable power market.
- With the exception of compressed hydrogen and the DMFC, all fuel cell vehicle designs require some kind of steam reforming or partial oxidation to release the hydrogen in the fuel.
- These processes can create NOx emissions that, even in very small quantities, can compromise air quality when multiplied by millions of vehicles in use.

- NOx is an essential precursor to the formation of ground level ozone, or smog. Because the DMFC breaks methanol into hydrogen and oxygen directly without requiring steam reforming or partial oxidation, there are no NOx emissions from the vehicle.

Engine Tests

- The simplest method of using methanol in a CI engine is to blend it with diesel fuel using an additive to prevent phase separation. This application requires no modification on the engine and fuel system.
- However, other methods such as dual-fueling and fumigation require additional equipments such as another fuel-injection system and storage tank, which means additional cost.
- In the fumigation mode, diesel fuel is injected through the original high-pressure fuel injectors into the engine cylinder while the methanol is injected in the air intake for each cylinder through low-pressure fuel injectors.

Engine Performance Tests

Brake Specific Fuel Consumption: The BSFC is defined as the ratio of the fuel consumption to the brake power. The effects of methanol–diesel fuel blends and injection timings on the BSFC are shown in Figures for different engine load and injection timing, respectively.

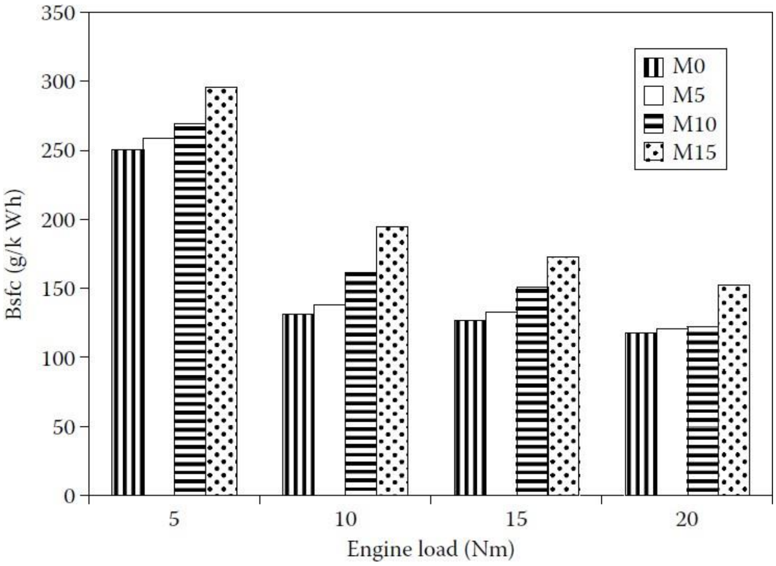


Fig.1.4

The results showed that increasing methanol ratio in the fuel blend caused it to increase in the BSFC. This behavior is attributed to lower heating value (LHV) per unit mass of the methanol, which is noticeably lower than that of the diesel fuel.

BSFC decreased about two times as the engine load increased from 5 to 20 Nm constant load.

Brake thermal efficiency

Brake thermal efficiency indicates the ability of the combustion system to accept the experimental fuel, and provides comparable means of assessing how efficient the energy in the fuel was converted to mechanical output.

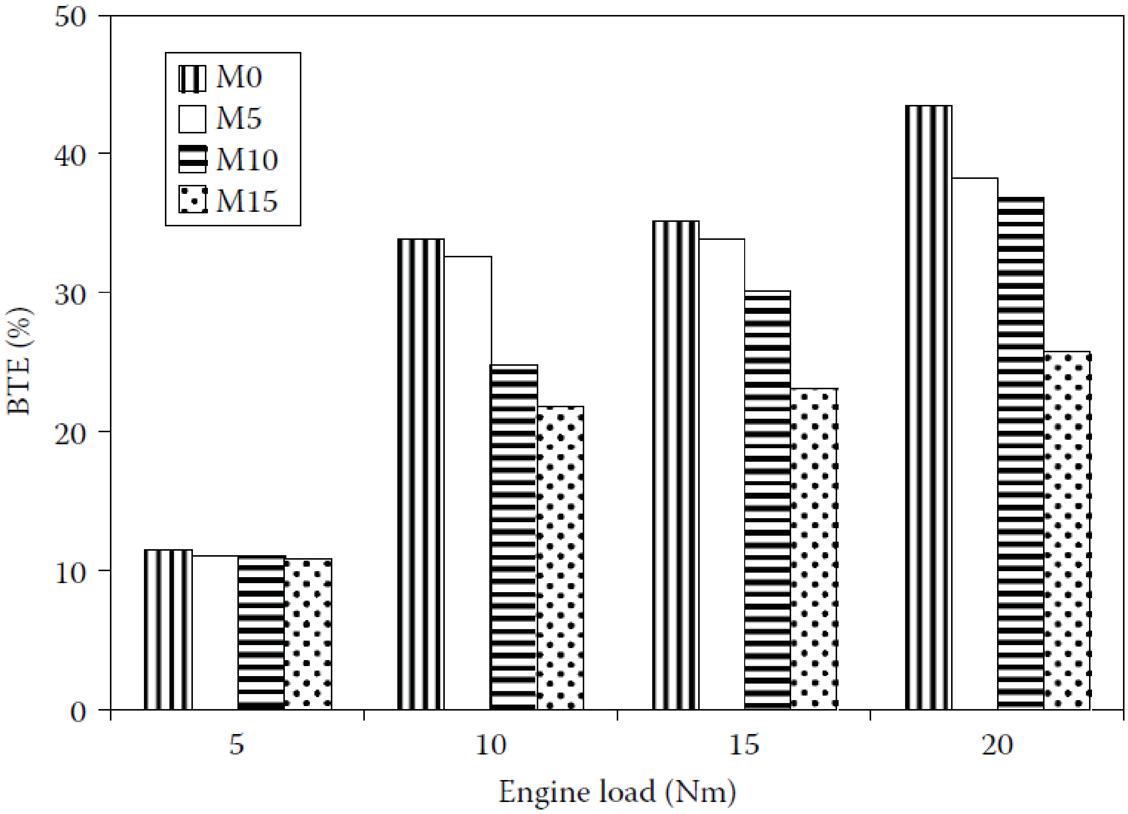


Fig.1.5

The maximum BTE was recorded with M0 for all the engine loads. The M0 fuel at 20 Nm with ORG injection timing produced the highest BTE. The higher BTE of M0 operation can be attributed to its LHV.

Exhaust temperature

The exhaust temperature increased with an increasing methanol ratio in the fuel mixture

Methanol has a higher latent heat of vaporization than diesel fuel. This can lead to a cooling effect on the cylinder charge.

Methanol has poor ignition behavior because of its low cetane number, high latent heat of vaporization, and high ignition temperature. Thus, it can cause a longer ignition delay.

The cetane number and oxygen content are more effective than latent heat of vaporization with regard to increasing peak temperature in the cylinder.

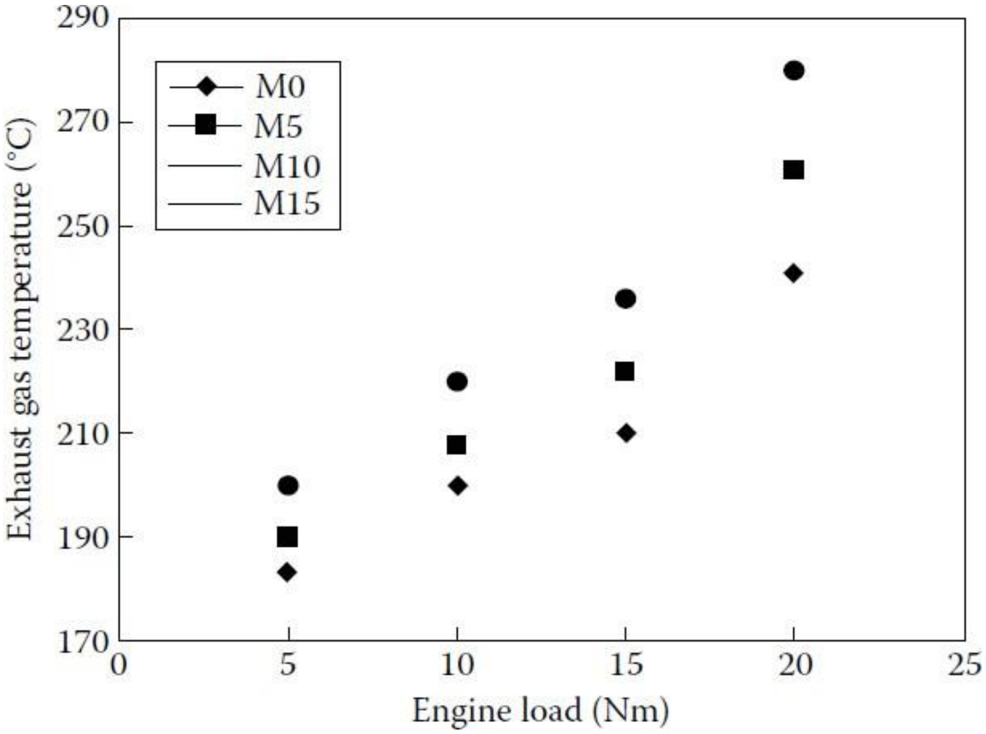


Fig.1.6

Engine emissions Tests

Regulated emissions are carbon monoxide (CO), nitrogen oxides (NOx), and unburned fuel or partly oxidized hydrocarbons (HC). The levels of these emissions are specified by legislations.

Unregulated emissions include polycyclic aromatic hydrocarbons (PAHs), methane, aldehydes, carbon dioxide (CO2), other trace organic emissions, and carbon deposits.

Carbon Monoxide (CO) Emissions

CO is a colorless, odorless, poisonous gas, and it must be restricted. CO results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes.

The most important parameters that affect CO emissions are an insufficient amount of air and an insufficient time in the cycle for complete combustion.

Methanol is an oxygenated fuel and leads to more complete combustion; hence, CO emissions reduce in the exhaust. CO emission decreased gradually when the engine load increased.

Concerning the effect of different fuels on CO emissions, it was uncovered that increasing the methanol ratio in the fuel–blend lessened CO emissions.

In comparison to M0, the change in CO emissions was around 19%, 32%, and 39% for M5, M10, and M15, respectively, at 5 Nm load and advanced injection timing, as demonstrated in Figure

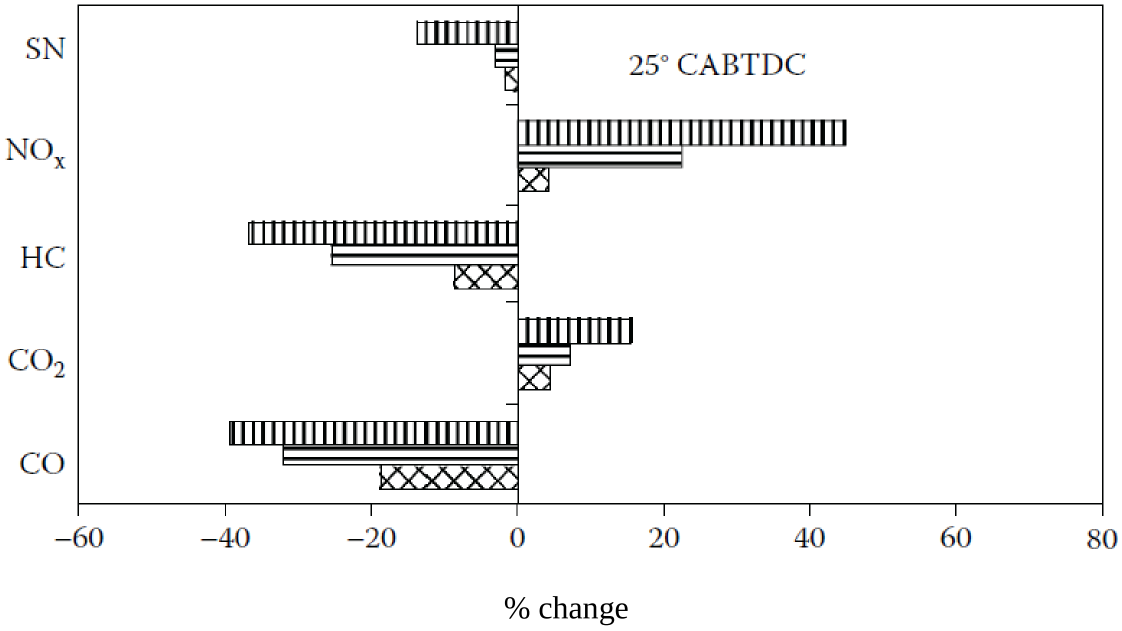


Fig.1.7

Unburned Hydrocarbon (UHC) Emissions

•The UHC emissions consist of fuel that is incompletely burned. Most of the UHC is caused by an unburned fuel–air mixture, whereas the other source is the engine lubricant and incomplete combustion.

•The term UHC means organic compounds in the gaseous state; solid HCs are the part of the PM.

•Typically, HCs are a serious problem at low loads in CI engines. At low loads, the fuel is less apt to impinge on surfaces; but, because of poor fuel distribution, large amounts of excess air and low exhaust temperature, lean fuel–air mixture regions may survive to escape into the exhaust

- it was found that increasing the methanol ratio in the fuel-blend reduced UHC emissions.

•For instance, the UHC emissions compared to M0 at ORG injection timing decreased by 14%, 24%, and 40% for M5, M10, and M15, respectively, at 10 Nm load

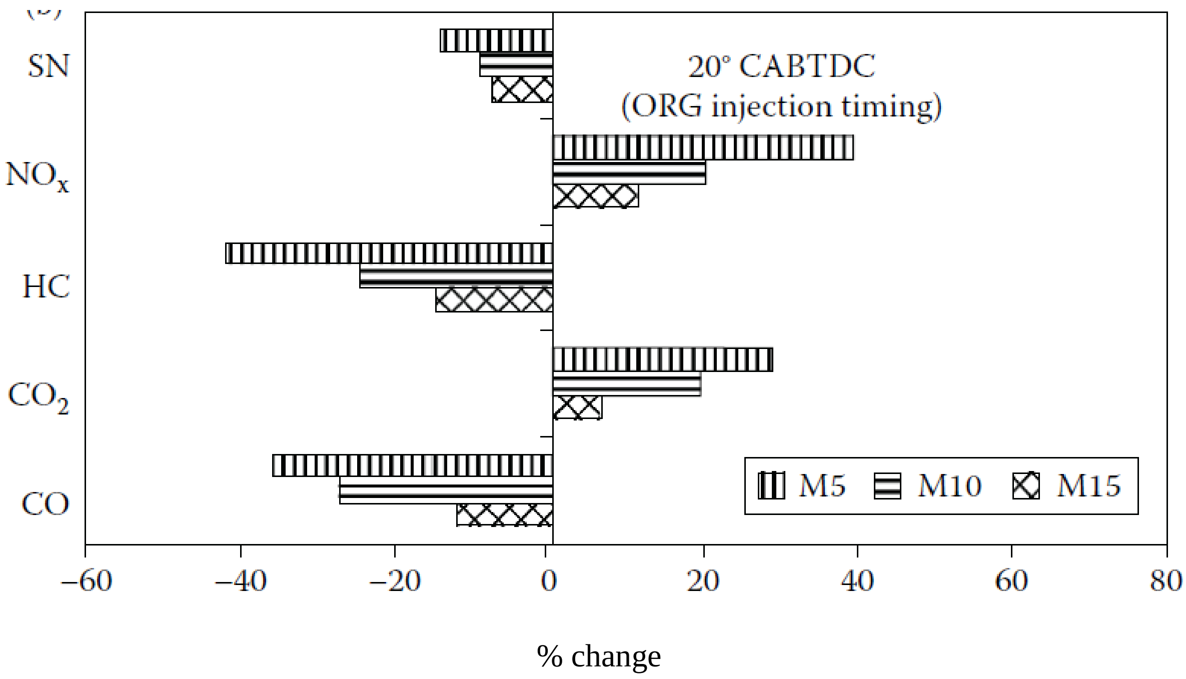


Fig.1.8

Nitrogen Oxides (NOx) Emissions

•The most troublesome emissions from CI engines are NOx emissions. The oxides of nitrogen in the exhaust emissions contain nitric oxide (NO) and nitrogen dioxides (NO2).

- The formation of NOx is highly dependent on in-cylinder temperatures, the oxygen concentration and residence time for the reaction to take place.

•In a diesel engine, the fuel distribution is nonuniform. The pollutant formation process is strongly dependent upon the changes in the fuel with time because of mixing.

•The oxides of nitrogen form in the high-temperature burned region, which is non-uniform, and the formation rates are highest in the regions closest to the stoichiometric region

•It was found that increasing the methanol ratio in the blend raised NOx emissions.

•The change in NOx emissions was compared to M0 and showed that NOx augmented by 14%, 35%, and 49% for M5, M10, and M15, correspondingly, at 15 Nm load and ORG injection timing.

Smoke Number (SN)

The emitted PM is essentially composed of soot, though some hydrocarbons, generally referred to as a soluble organic fraction (SOF) of the particulate emissions, are also adsorbed on the particle surface or simply emitted as liquid droplets.

Smoke opacity formation occurs at the extreme air deficiency. This air or oxygen deficiency is present locally in the very rich core of the fuel sprays in the combustion chamber. It increases as the air–fuel ratio decreases.

Soot is produced by oxygen deficient thermal cracking of long-chain molecules

Regarding the effect of different methanol contents on SNs, it was observed that increasing methanol ratio in the blend reduced SNs.

The change in SNs compared to M0 implied that they diminished by 15%, 19%, and 26% for M5, M10, and M15, respectively, at 20 Nm load.

Carbon Dioxide (CO2) Emission

CO2 emissions are released into the atmosphere when fuel is completely burned in an engine. As illustrated in the Figure when the methanol amount increased in the fuel mixture, the percentage change in CO and UHC decreased.

The percentage change in CO2 had an opposite behavior when compared to the CO concentrations, and this was due to improving the combustion process as a result of the oxygen content in the methanol.

The maximum increase in the change of CO2 was observed at 24%, 33%, and 74% for M5, M10, and M15, respectively, compared to M0 at 20 Nm engine load and advanced injection timing.

CO2 emissions increased with the advanced injection timing for all fuel mixtures. As shown in Figure for M10, advanced injection timing increased the change in CO2 by 6% and retarded injection timing diminished in CO2 by 8% compared to ORG and retarded injection timing, respectively.

Ethanol production

Substrates

Ethanol is produced from various kinds of substrates. The substrate used for ethanol production is chosen based on the regional availability and economical efficiency.

1. Sucrose containing materials

Ethanol is produced by fermentation. Fermentation process is a process to convert sugar to ethanol. Sucrose containing materials could simplify the ethanol production process.

• Sugarcane • Sugar beet • Sugar sorghum

2. Starchy materials

Starch is converted to sugar by saccharification followed by fermentation. Today, saccharification and fermentation are done simultaneously (SSF: simultaneous saccharification and fermentation). • Corn • Other starchy materials. Any kind of starch containing crop can be used to produce ethanol. sweet potato , cassava, and wheat

3. Lignocellulosic biomass

Lignocellulosic materials include maize silage, barely hull, and paper sludge

The difficulties of using lignocellulosic materials are there poor porosity, high crystallinity, and lignin contents.

There are six main steps in the ethanol production process

Milling: Whole corn kernels are ground into a form of flour, or meal. The meal is mainly starch. A starch is a carbohydrate made up of long chains of sugar molecules.

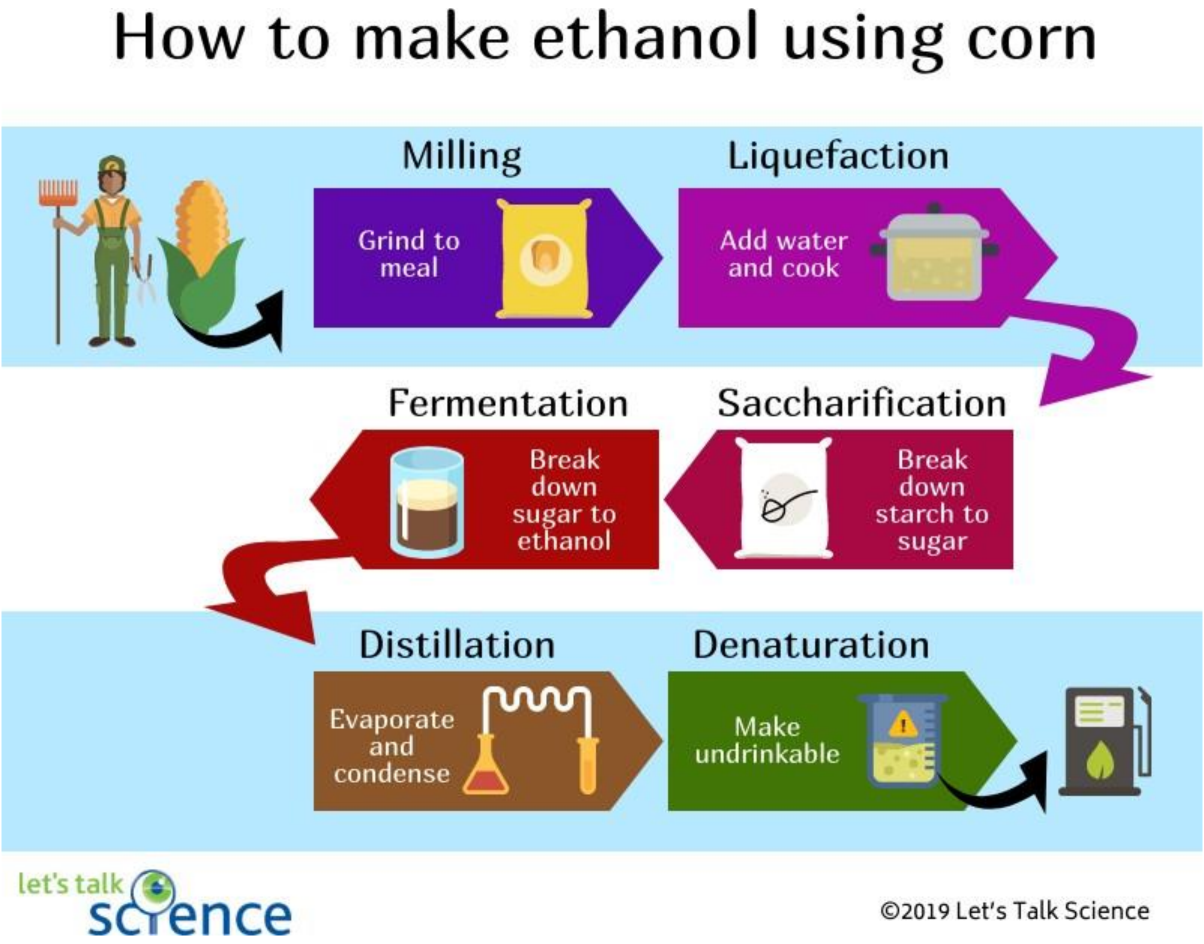
Liquefaction: Water is added to the meal to make ‘slurry.’ The slurry is heated to break the long starch molecules into smaller pieces. The enzyme alpha-amylase is added to catalyze (or speed up) the breakdown of the starch molecules.

Saccharification: Starch molecule pieces are broken down into the simple sugar glucose. This reaction is catalyzed by an enzyme called glucoamylase.

Fermentation: Single-celled microorganisms called yeast are added to the slurry. Fermentation is the biochemical process that occurs when yeast break down glucose. Yeast gets energy from glucose. As a result, ethanol is produced.

Distillation and Dehydration: The product of the fermentation process is only 10-15% ethanol. It must be concentrated to become pure (100%) ethanol. Ethanol has a lower boiling point than water. It is selectively evaporated and condensed in a process called distillation. This process produces ethanol that is 95% pure. The remaining 5% of the mixture is water. The mixture is strained and dehydrated to produce pure ethanol.

Denaturation: A small amount of gasoline is added to fuel ethanol to make it undrinkable.


How to make ethanol using corn
Milling
Grind to meal
Liquefaction
Add water and cook
Fermentation
Break down sugar to ethanol
Saccharification
Break down starch to sugar
Distillation
Evaporate and condense
Denaturation
Make undrinkable
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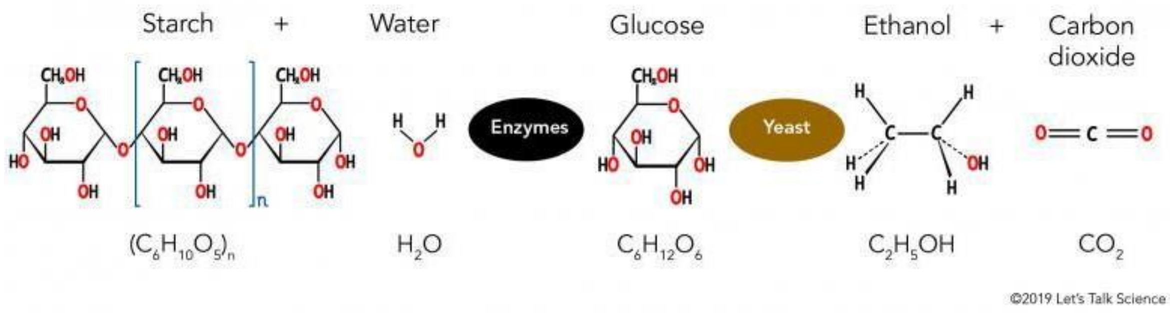
Starch
+
Water
Glucose
Ethanol
+
Carbon dioxide
Enzymes
Yeast
(C6H10O5)n
H2O
C6H12O6
C2H5OH
CO2
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Fig.1.9

Schematic of dry milling ethanol production

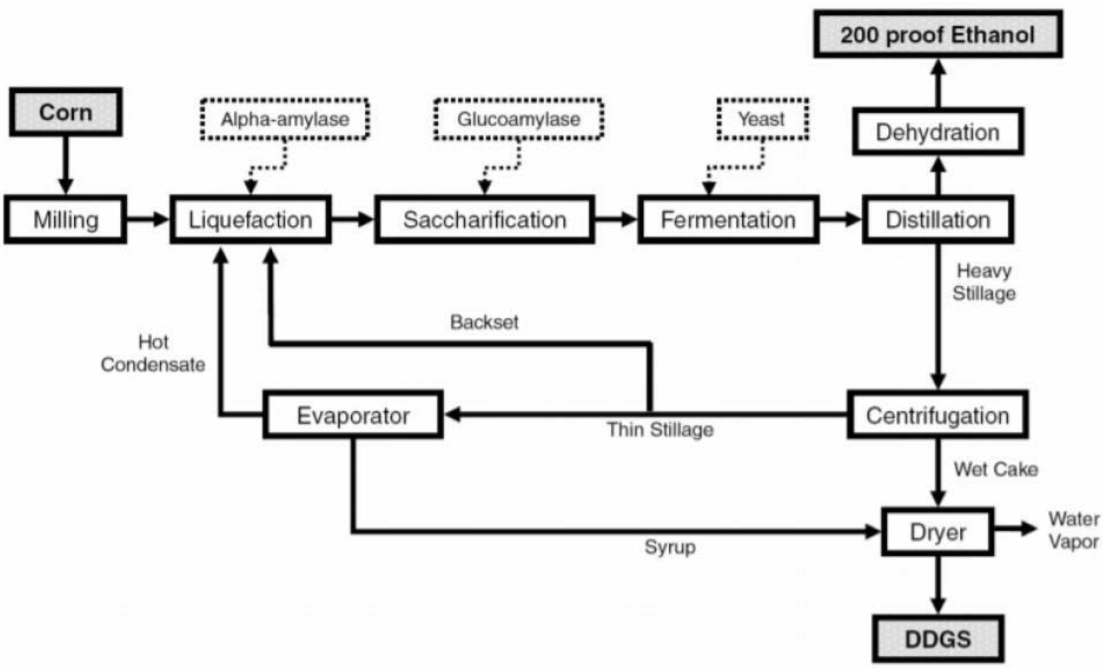


Fig.1.10

Ethanol Properties

•Ethanol contains about 35% of oxygen, which improves the combustion and reduces the partial combustion of fuel. Ethanol is the preferred ingredient for the biodiesel transesterification process as it is produced from agricultural products and renewable in nature and it is less objectionable to environment.

•Ethanol has higher research octane numbers (RON; > 100) than gasoline. When ethanol is blended with gasoline, the RON is boosted.

•High octane helps prevent engine knocking and is extremely important in engines designed to operate at a high compression ratio to generate more power. High compression ratios result in higher energy efficiency.

•Low-level blends of ethanol, such as E10 (10% ethanol, 90% gasoline), generally have a higher octane rating than unleaded gasoline.

•Ethanol is an effective solvent and can be considered a fuel detergent. Thus ethanol use as a gasoline additive helps to remove gum and deposits from fuel systems.

•Blends of gasoline and ethanol form azeotropes that cause a disproportionate increase in vapor pressure and a reduction in front-end distillation temperature.

.The increase in vapor pressure could cause hot drivability problems in vehicles. Hence, random mixing of gasoline and ethanol should be avoided for hot drivability problems. This effect varies with the amount of ethanol content but becomes significant at ethanol concentrations around 10%v.

•Moreover, high ethanol concentrations in blends can cause cold drivability problems because ethanol has a higher latent heat of vaporization than gasoline, therefore, volatile additives should be used

•Alcohol is completely miscible with water in all proportions, while gasoline and water are immiscible. Ethanol is completely miscible with gasoline.

•But even a small percentage of water in gasoline or ethanol leads to phase separation. Such separation can result in poor engine performance and damage to the engine. Hence, it is necessary to ensure that ethanol to be blended with gasoline is anhydrous

•Alcohol can react with most rubber, causing deterioration that can jam in the fuel lines. Therefore, when ethanol is included in the fuel, it is better to use fluorocarbon rubber as a replacement for rubber

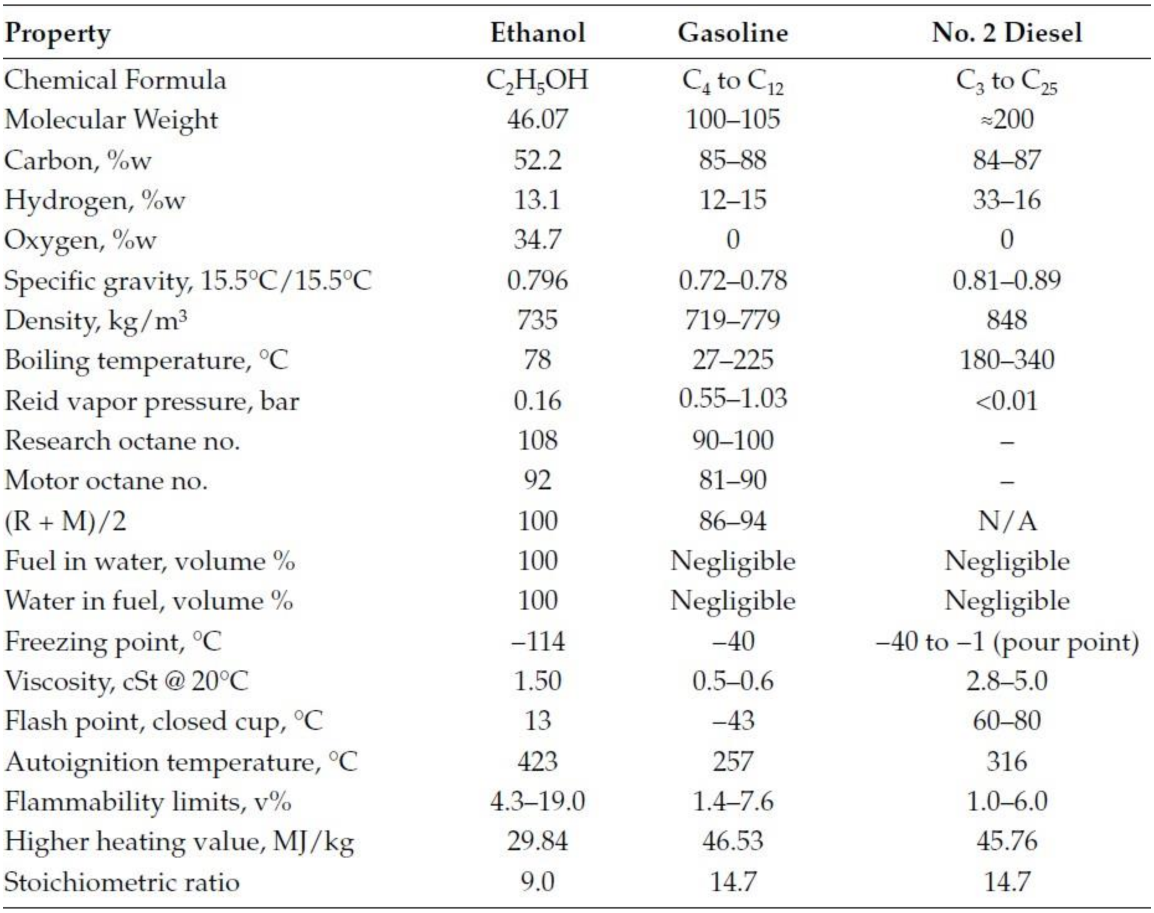
•The autoignition temperature and flash point of alcohol are higher than those of gasoline, which make it safer for transportation and storage.

•Latent heat of evaporation of alcohol is more than three times higher than that of gasoline. This leads to a reduction in the intake temperature in the manifold and hence increases the volumetric efficiency.

•The calorific value of ethanol is lower than that of gasoline and hence more ethanol is required to achieve the same energy output.

•Ethanol fuel contains a lower percentage of carbon than gasoline or diesel fuel.

Table.1.4



Property	Ethanol	Gasoline	No. 2 Diesel
Chemical Formula	C_2H_5OH	C_4 to C_{12}	C_3 to C_{25}
Molecular Weight	46.07	100–105	≈200
Carbon, %w	52.2	85–88	84–87
Hydrogen, %w	13.1	12–15	33–16
Oxygen, %w	34.7	0	0
Specific gravity, 15.5°C/15.5°C	0.796	0.72–0.78	0.81–0.89
Density, kg/m³	735	719–779	848
Boiling temperature, °C	78	27–225	180–340
Reid vapor pressure, bar	0.16	0.55–1.03	<0.01
Research octane no.	108	90–100	–
Motor octane no.	92	81–90	–
(R + M)/2	100	86–94	N/A
Fuel in water, volume %	100	Negligible	Negligible
Water in fuel, volume %	100	Negligible	Negligible
Freezing point, °C	−114	−40	−40 to −1 (pour point)
Viscosity, cSt @ 20°C	1.50	0.5–0.6	2.8–5.0
Flash point, closed cup, °C	13	−43	60–80
Autoignition temperature, °C	423	257	316
Flammability limits, v%	4.3–19.0	1.4–7.6	1.0–6.0
Higher heating value, MJ/kg	29.84	46.53	45.76
Stoichiometric ratio	9.0	14.7	14.7

Ethanol–Gasoline Engine Tests

Gasoline-ethanol blends at low proportions can be used without any engine modification but pure ethanol requires major modifications to the engine design and fuel system.

Engine Dynamometer Tests

Brake thermal efficiency of the engine increased with increased ethanol concentration in the blends. The maximum brake thermal efficiency was achieved with an E20 blend. Torque and power increased with ethanol content up to 20%v but decreased with higher ethanol concentrations

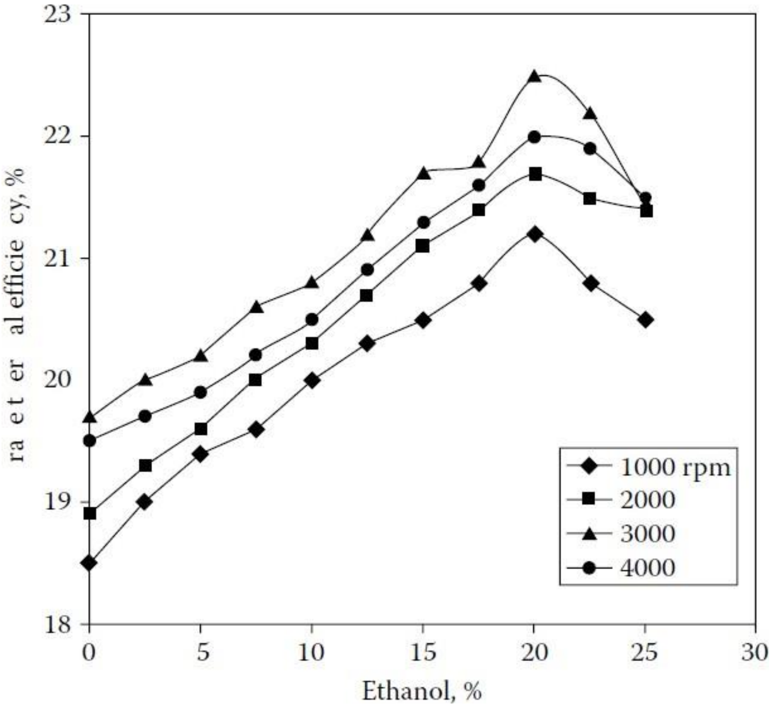


Fig.1.11

CO emissions

The CO emissions for ethanol–gasoline blends are reduced due to oxygen enrichment coming from ethanol. This result can be regarded as a “premixed oxygen effect” to make the reaction go to a more complete state. carbon monoxide emissions decrease with increased ethanol concentration in blends up to 20%v.

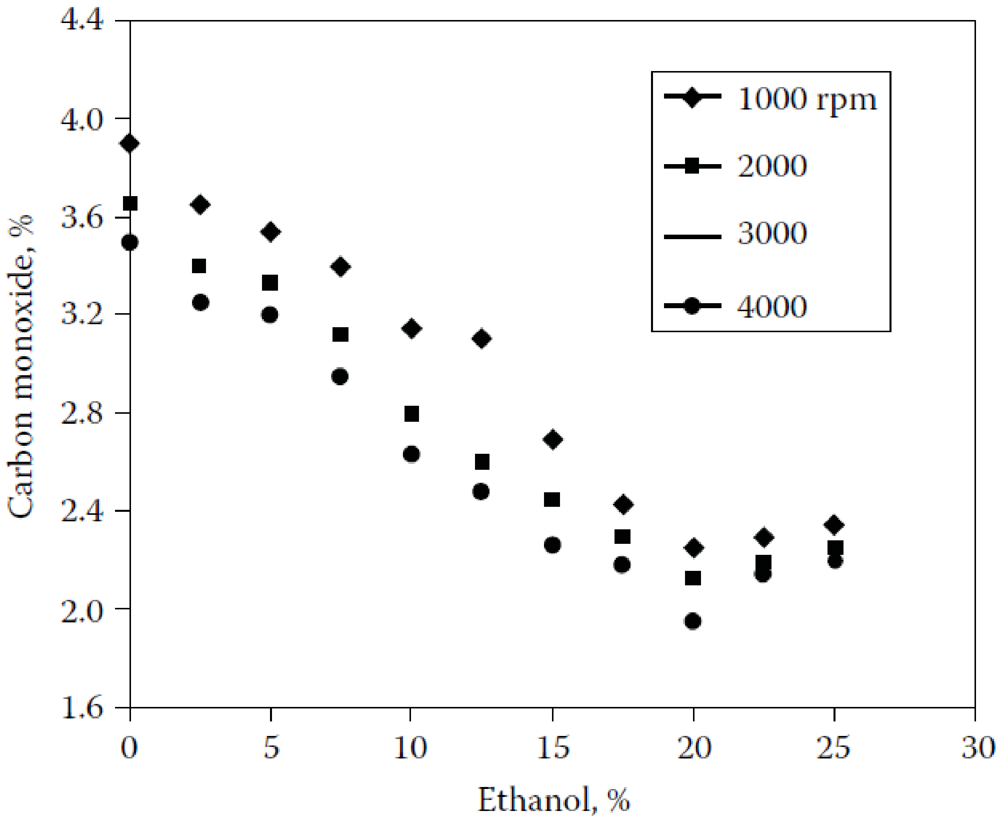


Fig.1.12

Carbon dioxide emissions

Carbon dioxide emissions increase with increased ethanol concentration up to 20%v.

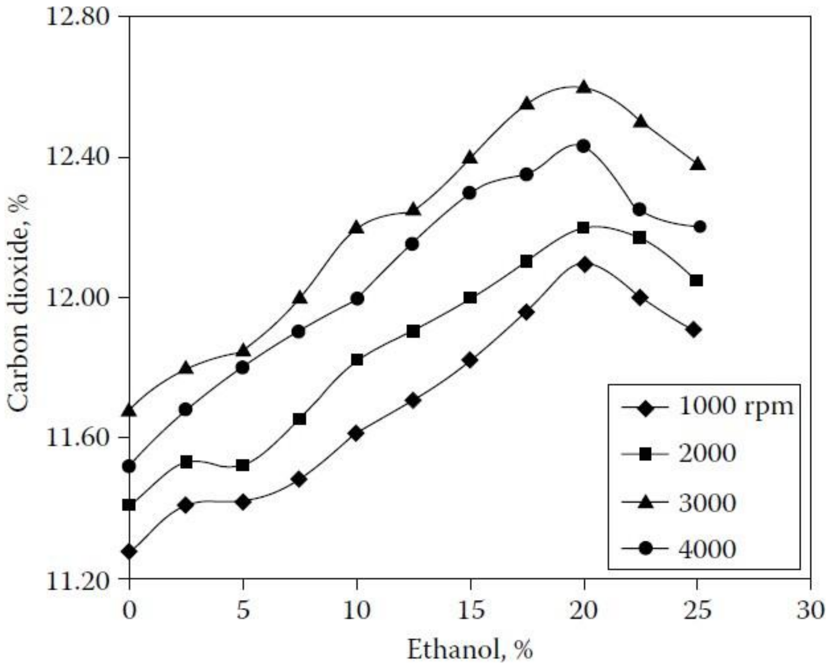


Fig.1.13

Hydrocarbon emissions

Hydrocarbon emissions decrease with increased ethanol concentration in blends up to 20%v. Ethanol molecules are polar, and cannot be absorbed easily by the unpolar molecules in the lubricating oil layer; and therefore ethanol can lower the possibility of producing HC emissions.

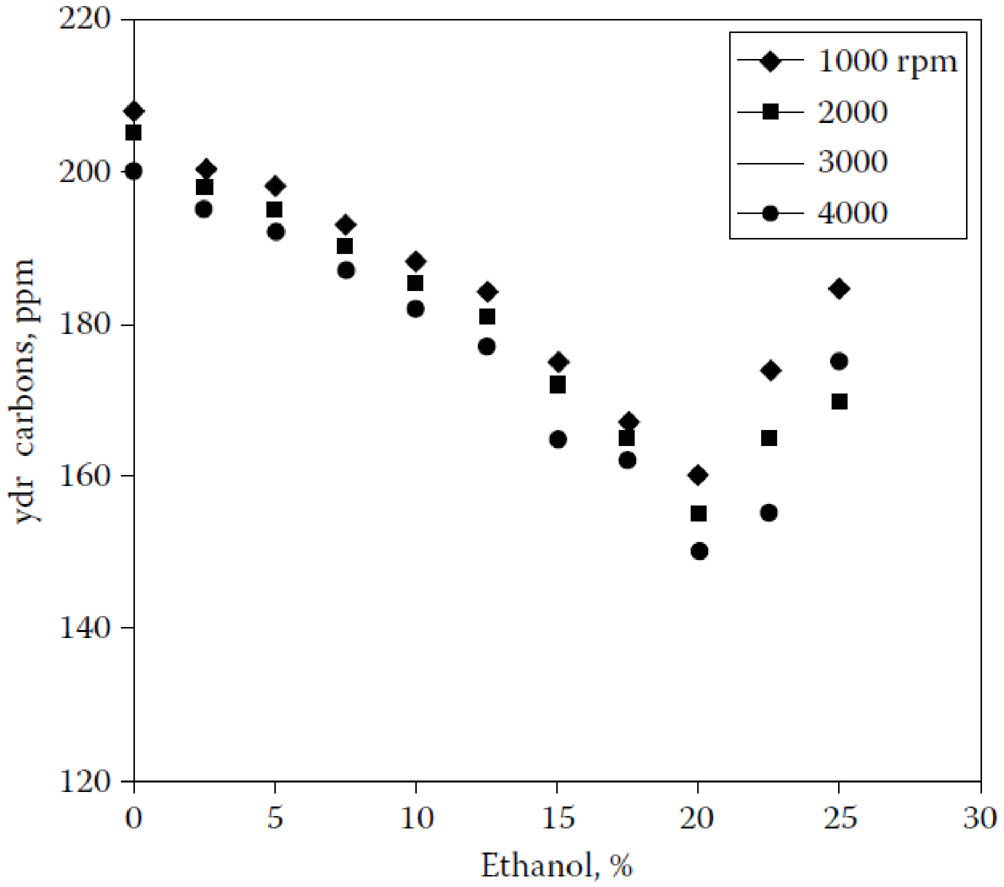


Fig.1.14

Exhaust emissions of an ethanol–gasoline vehicle

CO emissions decreased by about 30.8% for E10 fuel, compared to base fuel. This is due to improving the combustion process as a result of the oxygen content in ethanol fuels.

•HC emissions were reduced by nearly 31.7% with E10 fuel for one whole cycle. The oxygenate characteristics of ethanol in blend fuels are more effective in enhancing oxidation of hydrocarbons.

•The reduction of NOx emissions was relatively small, about 5.9% for E10 fuel. The ethanol blends produced minor effect on the decrease of NOx emissions.

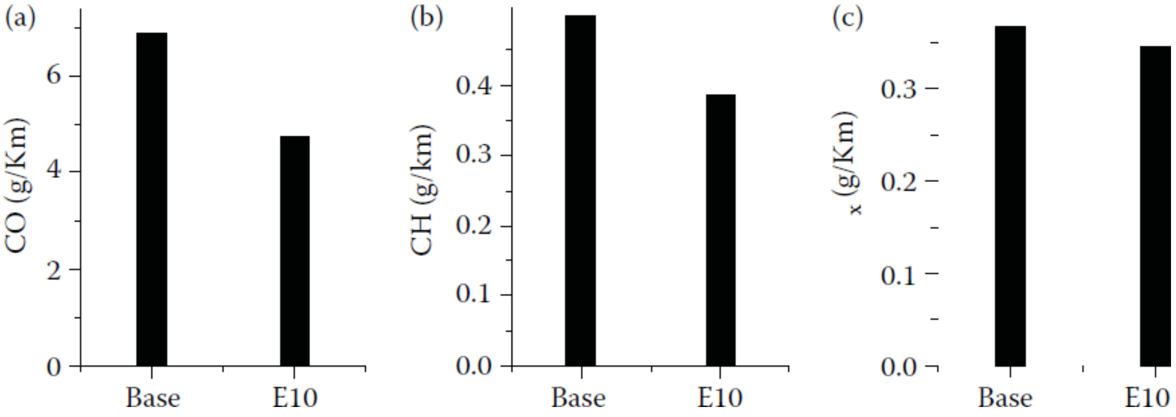


Fig.1.15

Ethanol–Diesel Engine Tests

Ethanol has low-cetane rating and thus, when used as the complete fuel, will not self-ignite in an ordinary CI engine. However, there are a number of techniques available to use ethanol fuel in a CI engine.

1. Alcohol fumigation:

- Fumigation is the addition of alcohols to the intake air charge, displacing up to 50% of the diesel fuel demand. This requires the addition of a carburetor, vaporizer or injector, along with a separate fuel tank, lines, and controls.
- The intake manifold and intake valves of a conventional CI engine handle only air but, in a technique known as fumigation, ethanol can be blended with the air to supply partial fueling to the engine, while the primary fuel of adequate cetane rating is injected through the usual fuel injection system.

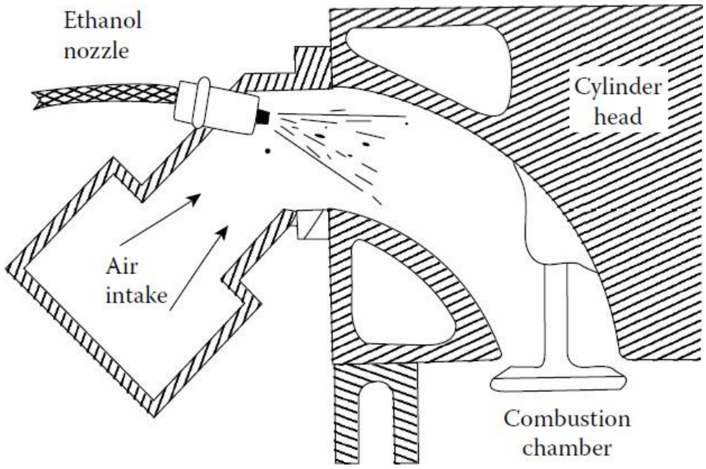


Fig.1.16

.When fumigated ethanol is used to replace a portion of the primary fuel rather than being used to over fuel the engine, most investigators have found a substantial reduction in exhaust smoke, little change in carbon monoxide emissions but a large increase in unburned hydrocarbons, especially at lighter loads.

•They found that fumigation greatly reduced NOx emissions at light loads but slightly increased them at moderate to full loads.

•Most investigators found that brake thermal efficiency was slightly reduced by fumigation under light loads but slightly increased under a full load.

2. Glow Plug Assisted ignition

Glow plugs were used to assist autoignition of the ethanol at start-up, during warm-up and for low-speed, light-load operations. Exhaust scavenging control was used to increase the residual fraction of exhaust gases in the combustion chambers to aid auto ignition.

3. Cetane enhanced ethanol

•Attempts to burn ethanol in unmodified CI engines have highlighted the need for the use of fuel additives, both when burning ethanol on its own and when blended with diesel fuel.

•Special ignition improvers are available that, when blended with ethanol, can raise the cetane rating of ethanol high enough for combustion in a CI engine.

4. Ethanol Blended with Diesel

•E-diesel fuel refers to blends of ethanol with diesel fuel, which typically contain an additive to ensure diesel-like combustion and lubricity, as well as providing a stable blend.

•The physical properties of diesel fuel are changed when ethanol is added into the solution (blend). The addition of ethanol causes the viscosity of diesel fuel to decrease. Also, the addition of ethanol in solutions with diesel fuel causes the cetane rating to drop and the heating values to be lower.

•Ethanol and diesel fuel will separate when any water is added to the blend, or when the blend is cooled below about 10°C in the case of dry ethanol blends

•Prevention of this separation can be accomplished through the use of either emulsifiers or co-solvents.

•Micro emulsions are used to solve the phase separation problem. Micro emulsions are transparent, thermodynamically stable colloidal dispersions in which the diameter of the dispersed-phase particles is less than one-fourth the wave length of visible light.

•A surface-active agent (i.e., a surfactant) is added to the ethanol–diesel blend to form the microemulsion.

- Emersol 315, a commercial surfactant containing a blend of soy oil fatty acids, and 4.1% of N,N-dimethylethanolamine.

Emissions characteristics of ethanol–diesel blends

- Blends with 5%, 10%, and 15% ethanol content. Their results also showed a substantial reduction in smoke density with the reduction being higher with higher ethanol content.
- CO and NOx emissions were also reduced with the same trend relative to ethanol content.
- However, HC emissions increased and the increase was higher with higher ethanol content. The possible reasons for the HC increase being higher heat of evaporation and therefore slower fuel–air mixing, as well as increased spray penetration and possible unwanted fuel impingement on the piston.
- Measurements of unregulated emissions have indicated increases of aldehydes with ethanol–diesel blends
- Acetaldehyde is a potential intermediate product from partial oxidation of ethanol. The studies showed that acetaldehyde emissions increased particularly at high loads.

Dimethyl ether

Dimethyl ether, also called DME, is one of the newer candidates for replacement of conventional fuels in the transport, energy generation, and domestic cooking and heating markets. It has been used for many years as an aerosol propellant. DME in the atmosphere decomposes to CO2 and water in the time frame of a day or so and, therefore, does not react with ozone in the upper atmosphere as fluorocarbons previously used for aerosol propellants did. It is also attractive in this respect due to its vapor pressure, very low toxicity, and high activity as a solvent.

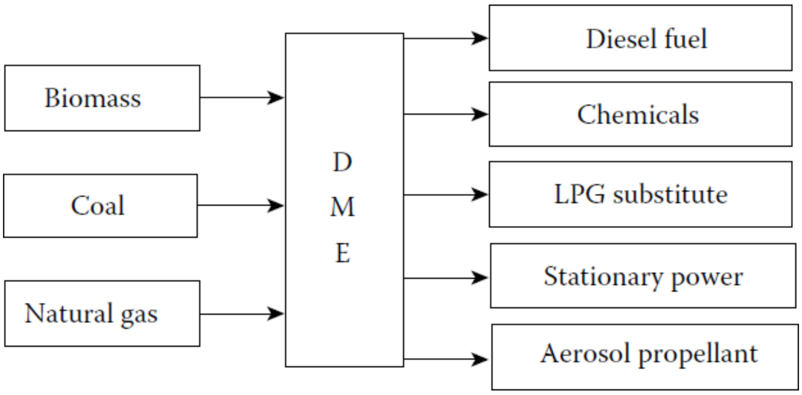
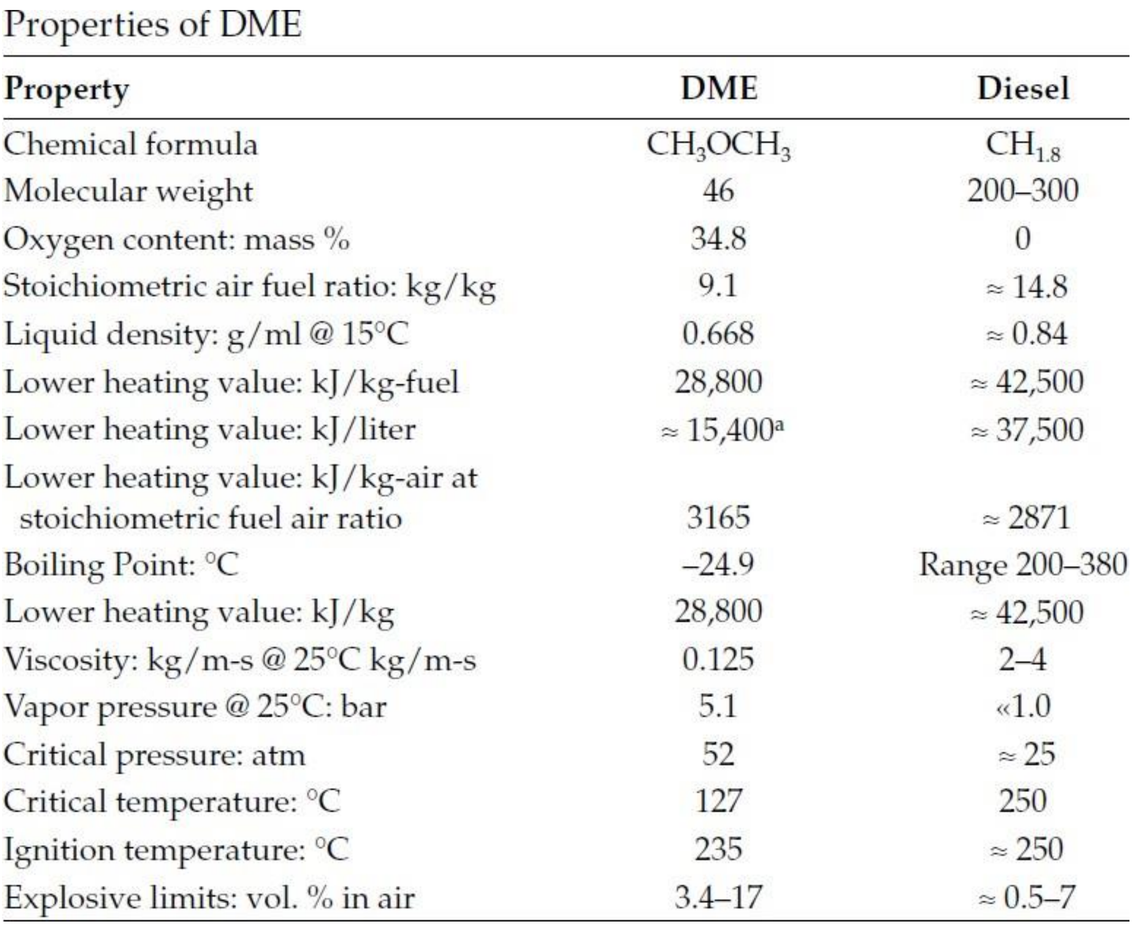


Fig.1.17

Properties of DME

DME is the simplest of all ethers, organic compounds that consist of an oxygen molecule bonded to two organic radicals. The chemical formula of DME is CH3 OCH 3. DME is a colorless gas, with a slight odor at room temperature and pressure. As such, it is necessary to keep DME in closed, low pressure containers for normal use and distribution.

Table 1.5



Properties of DME

Property	DME	Diesel
Chemical formula	CH_3OCH_3	$CH_{1.8}$
Molecular weight	46	200–300
Oxygen content: mass %	34.8	0
Stoichiometric air fuel ratio: kg/kg	9.1	≈ 14.8
Liquid density: g/ml @ 15°C	0.668	≈ 0.84
Lower heating value: kJ/kg-fuel	28,800	≈ 42,500
Lower heating value: kJ/liter	≈ 15,400[a]	≈ 37,500
Lower heating value: kJ/kg-air at stoichiometric fuel air ratio	3165	≈ 2871
Boiling Point: °C	–24.9	Range 200–380
Lower heating value: kJ/kg	28,800	≈ 42,500
Viscosity: kg/m-s @ 25°C kg/m-s	0.125	2–4
Vapor pressure @ 25°C: bar	5.1	«1.0
Critical pressure: atm	52	≈ 25
Critical temperature: °C	127	250
Ignition temperature: °C	235	≈ 250
Explosive limits: vol. % in air	3.4–17	≈ 0.5–7

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SCHOOL OF MECHANICAL

DEPARTMENT OF AUTOMOBILE

UNIT – II – Alternate Fuels and Energy systems – SAUA3013

Vegetable oils

Vegetable oils have two broad classifications:

- Edible oils (sunflower, soy bean, palm oil, etc.) and
- Nonedible oils (jatropha, karanji, rubber seed oil, etc.).
- Edible type oils are mainly used for food purposes whereas nonedible oils are used for food purposes.
- The nonedible vegetable oils serve as an important raw material for the manufacture of soaps, paints, varnishes, hair oil, lubricants, textile auxiliaries, and various sophisticated products.
- After extraction of oil from oil seeds, the oil cakes can be used as cattle feed and fertilizer. Moreover, these oil cakes can be used as biomass feed stock for gasification process.

Vegetable oils are derived mainly from four sources. These are

- Cultivated oil seeds (i.e., groundnut, rape-mustard, soybean, sesame, sunflower, safflower, castor, and linseed)
- Perennial oil-bearing materials (i.e., coconut and palm)
- Derived oil-bearing material (i.e., cottonseed and rice bran)
- Oil seeds of forest and tree origin (i.e., karanji and rubber seed oil)

Characterization of Vegetable Oils

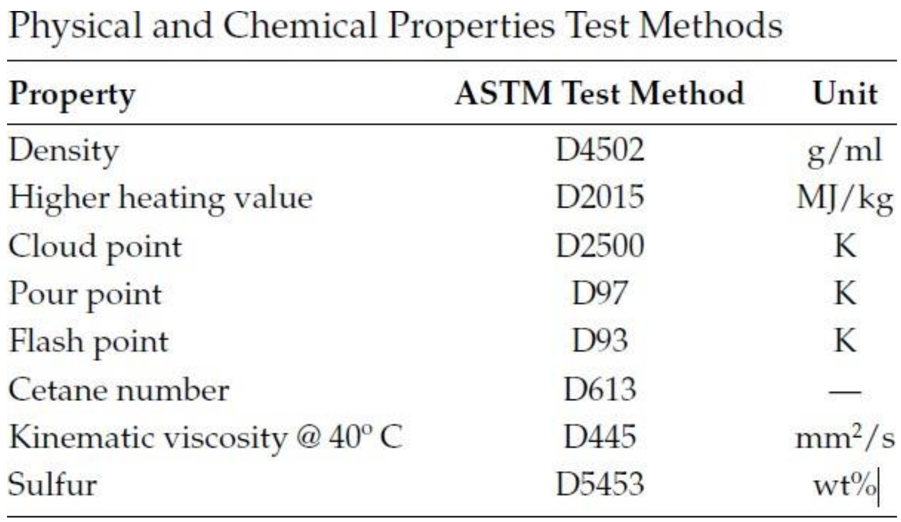
- Vegetable oil molecules are triglycerides with unbranched chains of different lengths and different degree of saturation.
- The natural organic compound in the animal and vegetable fats are made up of various combinations of fatty acids (in sets of three) connected to a glycerol molecule, making them triglycerides.
- Each molecule of a fatty acid consists of a carboxyl group (oxygen, carbon, and hydrogen) attached to a chain of carbon atoms with their associated hydrogen atoms.
- The chain of carbon atoms may be connected with single bonds of hydrogen between them, making a saturated fat; or it may be connected with double bonds, making an unsaturated fat.
- The number of carbon and hydrogen atoms in the chain are what determines the qualities of that particular fatty acid

The important properties of vegetable oils in groups are

- ➢ Physical properties (viscosity, cloud point, pour point, flash point, etc.)

- ➢ Chemical properties (chemical structure, acid value, saponification value, sulfur content, copper corrosion, oxidation resistance, and thermal degradation, etc.)
- ➢ Thermal properties (distillation temperature, thermal conductivity, carbon residue, and calorific value, etc.)

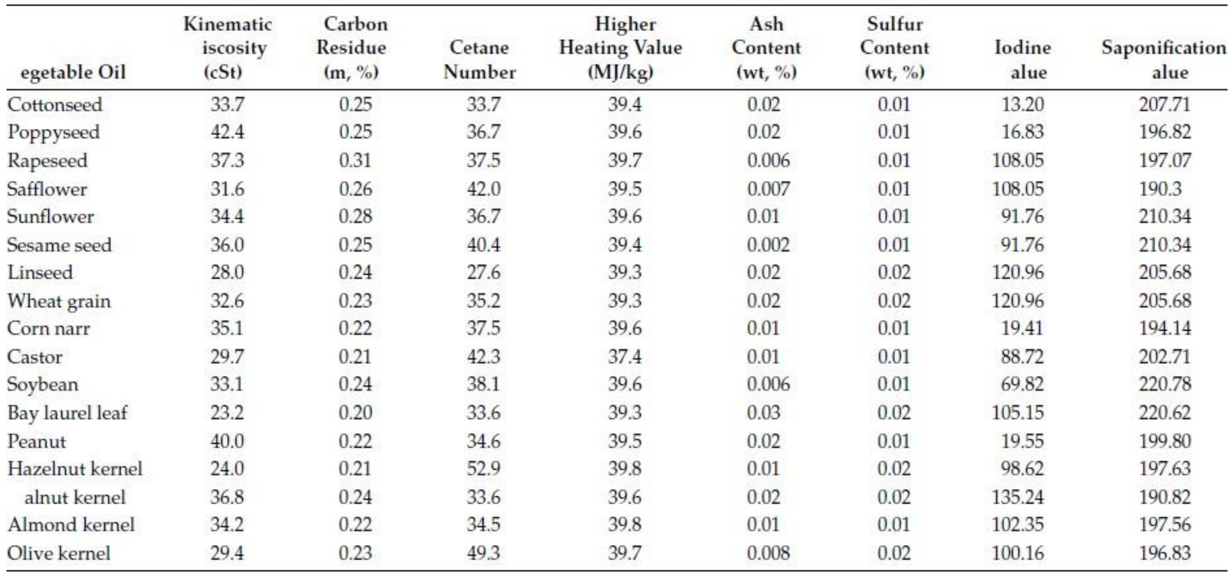
Table 2.1



Physical and Chemical Properties Test Methods

Property	ASTM Test Method	Unit
Density	D4502	g/ml
Higher heating value	D2015	MJ/kg
Cloud point	D2500	K
Pour point	D97	K
Flash point	D93	K
Cetane number	D613	—
Kinematic viscosity @ 40° C	D445	mm^2/s
Sulfur	D5453	wt%

Table 2.2



egetable Oil	Kinematic iscosity (cSt)	Carbon Residue (m, %)	Cetane Number	Higher Heating Value (MJ/kg)	Ash Content (wt, %)	Sulfur Content (wt, %)	Iodine alue	Saponification alue
Cottonseed	33.7	0.25	33.7	39.4	0.02	0.01	13.20	207.71
Poppyseed	42.4	0.25	36.7	39.6	0.02	0.01	16.83	196.82
Rapeseed	37.3	0.31	37.5	39.7	0.006	0.01	108.05	197.07
Safflower	31.6	0.26	42.0	39.5	0.007	0.01	108.05	190.3
Sunflower	34.4	0.28	36.7	39.6	0.01	0.01	91.76	210.34
Sesame seed	36.0	0.25	40.4	39.4	0.002	0.01	91.76	210.34
Linseed	28.0	0.24	27.6	39.3	0.02	0.02	120.96	205.68
Wheat grain	32.6	0.23	35.2	39.3	0.02	0.02	120.96	205.68
Corn narr	35.1	0.22	37.5	39.6	0.01	0.01	19.41	194.14
Castor	29.7	0.21	42.3	37.4	0.01	0.01	88.72	202.71
Soybean	33.1	0.24	38.1	39.6	0.006	0.01	69.82	220.78
Bay laurel leaf	23.2	0.20	33.6	39.3	0.03	0.02	105.15	220.62
Peanut	40.0	0.22	34.6	39.5	0.02	0.01	19.55	199.80
Hazelnut kernel	24.0	0.21	52.9	39.8	0.01	0.02	98.62	197.63
alnut kernel	36.8	0.24	33.6	39.6	0.02	0.02	135.24	190.82
Almond kernel	34.2	0.22	34.5	39.8	0.01	0.01	102.35	197.56
Olive kernel	29.4	0.23	49.3	39.7	0.008	0.02	100.16	196.83

Disadvantages of using vegetable oil as C.I. Engine fuel

- The high viscosity of vegetable oils leads to pumping and atomization problems in the normal diesel fuel injection systems.
- High carbon residue causes heavy smoke emission and carbon deposition on the injection nozzle tips and in the combustion chamber.
- There are also problems of incompatibility with engine lubricants.

- The poor volatility makes the vegetable oil difficult to vaporize and ignite. This leads to thermal cracking resulting in the heavy smoke emission and carbon deposits in the combustion chamber. This tendency is partly due to higher fuel viscosity.
- Vegetable oils dilute the lubricant oil and forms sludge on all parts of engine, which come in contact with lubricating oil.

Remedies

1. Filter plugging is minimized if crude degummed oils are passed through a four Micrometer filter.
2. Starting problems should be overcome by starting aids such as glow plugs and fuel heaters.
3. Modification of fuel.

Methods to Use Vegetable Oils in Engines

1. Pyrolysis

- Pyrolysis is a promising method for the production of environmentally friendly liquid fuels. It is the chemical reaction caused by the application of thermal energy in the absence of air. Vegetable oils and animal fats can be pyrolyzed.
- Pyrolysis process takes place at higher temperatures of about 250–400ºC and at higher heating rates. Heating of vegetable oils breaks the bigger molecules into smaller molecules and a wide range of HC are formed.
- The pyrolyzed products can be divided into gaseous, liquid fractions consisting of paraffins, olefins and naphthenes, and solid residue.
- The pyrolyzed vegetable oils contain acceptable amounts of sulfur, water, and sediment and give acceptable copper corrosion values but unacceptable ash, carbon residue, and pour point.
- Pyrolyzed vegetable oil contains compounds in the boiling range of gasoline.
- The properties of bio-oil depends upon the nature of the feedstock, temperature of pyrolysis process, thermal degradation degree and catalytic cracking, the water content of the pyrolysis oil, the amount of light ends that have collected, and the pyrolysis process used.
- The high oxygen content of pyrolysis oil results in a very low energy density in comparison to conventional fuel oils.

2. Microemulsification

- The formation of microemulsions (cosolvency) is one of the potential solutions for solving the problem of vegetable oil viscosity.

- Microemulsions are defined as transparent, thermodynamically stable colloidal dispersions. The droplet diameters in microemulsions range from 100 to 1000 Å.
- The micro-emulsion can be made of vegetable oils with an ester and dispersant (cosolvent), or of vegetable oils, an alcohol and a surfactant and a cetane improver, with or without diesel fuels.
- Water (from aqueous ethanol) may also be present in order to use lower-proof ethanol, thus increasing water tolerance of the microemulsions.
- Microemulsion can improve the spray characteristics due to explosive vaporization of low-boiling constituents in the micelle.

3. Dilution

- Vegetable oils can be directly mixed with diesel fuel and may be used for running diesel engine.
- Blending of diesel with vegetable oil reduces its viscosity and hence improves its combustion characteristics

4. Transesterification

- Transesterification is a chemical process of transforming large, branched triglyceride molecules of bio-oils and fats into smaller, straight chain molecules, almost similar in size to the molecules of the species present in diesel fuel.
- This process has been widely used to reduce the viscosity of triglycerides. The transesterification reaction is represented by the general equation

$$R\text{-}COOR' + R''\text{–}OH \quad RCOOR'' + R'OH$$

- Triglycerides are readily transesterified in the presence of alkaline catalyst at atmospheric pressure and at a temperature of approximately 60–70°C with an excess of methanol.
- The mixture at the end of a reaction is allowed to settle. The lower glycerol layer is drawn off while the upper methyl ester layer is washed to remove entrained glycerol and is then processed further.
- The excess methanol is recovered by distillation and sent to a rectifying column for purification and recycled.

Advantages of Vegetable Oils

1. Vegetable oils can be used as substitute fuel for diesel engine application.
2. Use of vegetable oil for fuel purposes reduces the import of costly petroleum and improves the economy of agricultural countries.

3. They are biodegradable and nontoxic.
4. Vegetable oils are of low aromatics and low sulfur content and hence reduce the particulate matter emissions.
5. They have a reasonable cetane number and hence possesses less knocking tendency.
6. Vegetable oils are environmentally friendly fuels.
7. Enhanced lubricity, thereby no major modification is required in the engine.
8. Use of vegetable oils improves the personal safety also (flash point of vegetable oil is above 100ºC).
9. These are usable within the existing petroleum diesel infrastructure with minor or no modification in the engine.

Challenges for Vegetable Oils

1. The price of vegetable oil is dependent on the seed price and it is market based. Moreover, feed stock homogeneity, consistency, and reliability are questionable.
2. Production of vegetable oil derived biofuels are at an optimum cost.
3. Studies are needed to reduce the production cost and identify potential markets in order to balance cost and availability.
4. Studies are needed on oxidation stability and long storage of vegetable oils.
5. Manufacturer warranty and compatibility with IC engine material needs to be studied further.
6. Durability and emission testing with a wide range of feed stocks.
7. Environmental benefits to be offered by vegetable oil over diesel fuel needs to be popularized.
8. Development of additives for improving cold flow properties, material compatibility, and prevention of oxidation in storage, etc.
9. Continuous and long-term availability of the vegetable oils.

BIO DIESEL

- Vegetable oils can be modified into various, more useful forms that are suitable for diesel engine application. These include microemulsion, pyrolysis, and transesterification.
- Pyrolysis of the vegetable oil resulted in products with low viscosity, high cetane number, accepted amounts of sulfur, water and sediments, and accepted copper corrosion values. But these are unacceptable in terms of their ash contents, carbon residues, and pour points.

- Microemulsion of vegetable oil lowered the viscosity of the vegetable oil but resulted in irregular injector needle sticking, heavy carbon deposits, and incomplete combustion.
- Among these various conversion methodologies, the transesterification process has become commercial success.
- Biodiesel refers to diesel equivalent, processed fuel derived from biological sources such as vegetable oils. It can also be made from animal fats. It is the ester based oxygenated fuel derived from biological sources.
- Chemically, biodiesel is defined as mono alkyl esters of long-chain fatty acids of lipids.
- Biodiesel used for blending with diesel should meet the ASTM D 6751 or particular country's national fuel standards. Biodiesel can be used as combustion extender for reducing the engine exhaust emissions.

Key advantages of biodiesel include

1. Biodiesel is an alternative fuel that can be used to operate any conventional, unmodified diesel engine. Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel in diesel engines.
2. The life cycle production and use of biodiesel produces approximately 80% less carbon dioxide emissions, and almost 100% less sulfur dioxide than diesel.
3. Combustion of biodiesel alone provides over 90% reduction in total unburned hydrocarbons and 75–90% reduction in aromatic hydrocarbons.
4. Biodiesel further provides significant reductions in particulates and carbon monoxide compared to petroleum diesel fuel.
5. Biodiesel provides a slight increase or decrease in nitrogen oxides emissions depending on engine family and testing procedures.
6. Biodiesel has about 11% oxygen by weight and no sulfur. The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel, while fuel consumption, auto ignition, power output, and engine torque are relatively unaffected by biodiesel.
7. Biodiesel is safe to handle and transport because it is biodegradable as sugar, 10 times less toxic than table salt, and has a high flashpoint about 110°C compared to petroleum diesel fuel whose flash point is 45–55°C).
8. Biodiesel can be made from domestically produced, renewable oil seed crops such as soybeans, jatropha, cottonseed, rubber seed, and mustard seed.

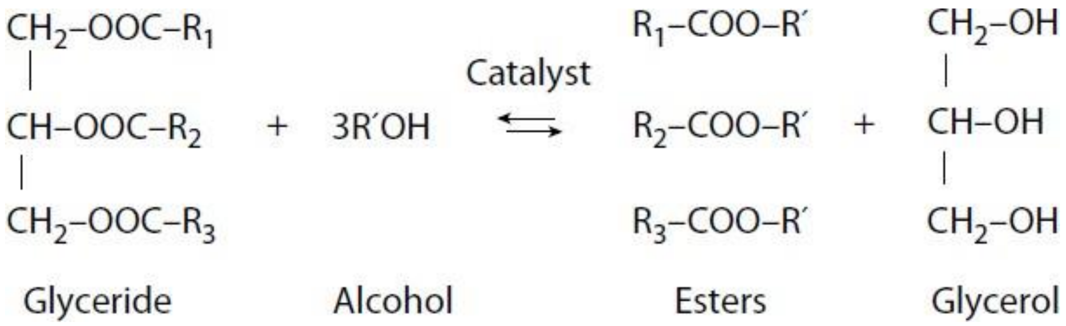
Biodiesel Production

Vegetable oil reacts with alcohol (typically methanol or ethanol) in the presence of catalyst produced biodiesel. Biodiesel production process consists of three steps; namely,

1. Conversion of triglycerides (TG) to diglycerides and one ester molecule
2. Followed by the conversion of diglycerides (DG) into monoglycerides (MG) and one ester molecule
3. Monoglycerides into glycerol and one ester molecule catalyst

Alkaline Transesterification

- Alkaline-catalyzed transesterification process is the commercially well-developed biodiesel production process. Alkaline catalysts (NaOH, KOH) are used to improve the reaction rate and to increase the yield of the process.
- To complete the transesterification stoichiometrically, 3:1 molar ratio of alcohol to triglycerides is needed. In practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield.
- Alcohols such as methanol, ethanol, or butanol are used in the transesterification.



Alkaline esterification is suitable for the triglycerides having an acid value less than four and all reactants should be substantially anhydrous.

Variables Influence Transesterification

1. Free fatty acid (FFA)

- The free fatty acid (FFA) and moisture content are key parameters for determining the suitability of the vegetable oil transesterification process.
- To carry the alkaline-catalyzed reaction to completion, a FFA value lower than 2% (i.e., acid value of less than four) is needed. The higher acidity of the oil reduces biodiesel production efficiency.

2. Alcohol to Oil Molar Ratio

- The stoichiometric transesterification requires 3 mol of the alcohol per mol of the triglyceride to yield 3 mol of the fatty esters and 1 mol of the glycerol. However, the transesterification reaction is an equilibrium reaction in which a large excess of the alcohol is required to drive the reaction close to completion in a forward direction.
- Lower molar ratios require a longer time to complete the reaction.
- Excess molar ratios increase the conversion rate but lead to difficulties in the separation of the glycerol. At optimum molar ratio only the process gives higher yield and easier separation of the glycerol. The optimum molar ratios depend upon the type and quality of the vegetable oil used

3. Catalyst

- As a catalyst in the process of alkaline methanolysis, mostly sodium hydroxide or potassium hydroxide have been used, both in concentration from 0.4 to 2% w/w of oil.
- These catalysts increase the reaction rate several times faster than that of acid catalysts. The alkaline catalyst concentration in the range of 0.5–1.0% by weight gives 94–99% conversion efficiency.
- Further increase in catalyst concentration does not increase the yield, but it adds to the extra cost and increases the complication in the separation process.

4. Purity of Reactants

- The impurities present in the vegetable oil also affect ester conversion levels significantly. The vegetable oil (refined or raw oil) is to be filtered before the transesterification reaction. The oil settled at the bottom of the tank during storage would give lesser yield because of deposition of impurities like wax.

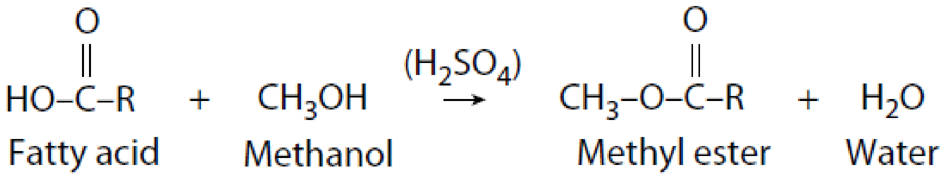
5. Effect of Reaction Time

- The conversion rate increases with reaction time. Transesterification of peanut, cottonseed, sunflower, and soybean oils under the condition of methanol to oil ratio of 6:1, 0.5% sodium methoxide catalyst, and 60ºC the conversion efficiency of about 80% was obtained after 1 minute for soybean and sunflower oils; and after completion of 60 minutes the conversions were almost the same for all four oils (93–98%)

Acid Catalyst Transesterification

- Alkaline esterification is suitable for the triglycerides having an acid value less than four and all reactants should be substantially anhydrous.

- If the acid value is greater than four the conversion efficiency would reduce drastically. The alkaline catalyst reacts with the high FFA feedstock to produce the soap and water.
- Acid catalyzed process can be used for esterification of these FFAs. The nonedible type oil, crude vegetable oils, and used cooking oils typically contain more than 2% FFA, and the animal fats contain from 5 to 30% FFA. Low quality feedstock, such as trap grease, can contain FFA up to 100%.
- Moisture or water present in the vegetable oils increase the FFA value.
- The standard conditions of the reaction consisted of 60°C reaction temperature, 3% sulfuric acid, 6:1 molar ratio of the methanol to the oil, and reaction duration of 48 hours.



$$\underset{\text{Fatty acid}}{HO-\overset{\overset{O}{\|}}{C}-R} + \underset{\text{Methanol}}{CH_3OH} \xrightarrow{(H_2SO_4)} \underset{\text{Methyl ester}}{CH_3-O-\overset{\overset{O}{\|}}{C}-R} + \underset{\text{Water}}{H_2O}$$

Biodiesel Quality Standards

Biodiesel processing and its quality are closely related. The processes used to convert the feedstock into biodiesel determine whether the product will meet the desired biodiesel production or not. The biodiesel quality can be influenced by several factors:

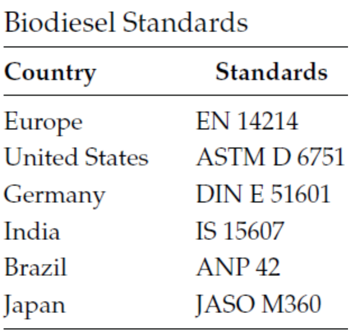
•Quality of feedstock

•Fatty acid composition of vegetable oils/animal fats

•Production process and ingredients used

•Postproduction parameters

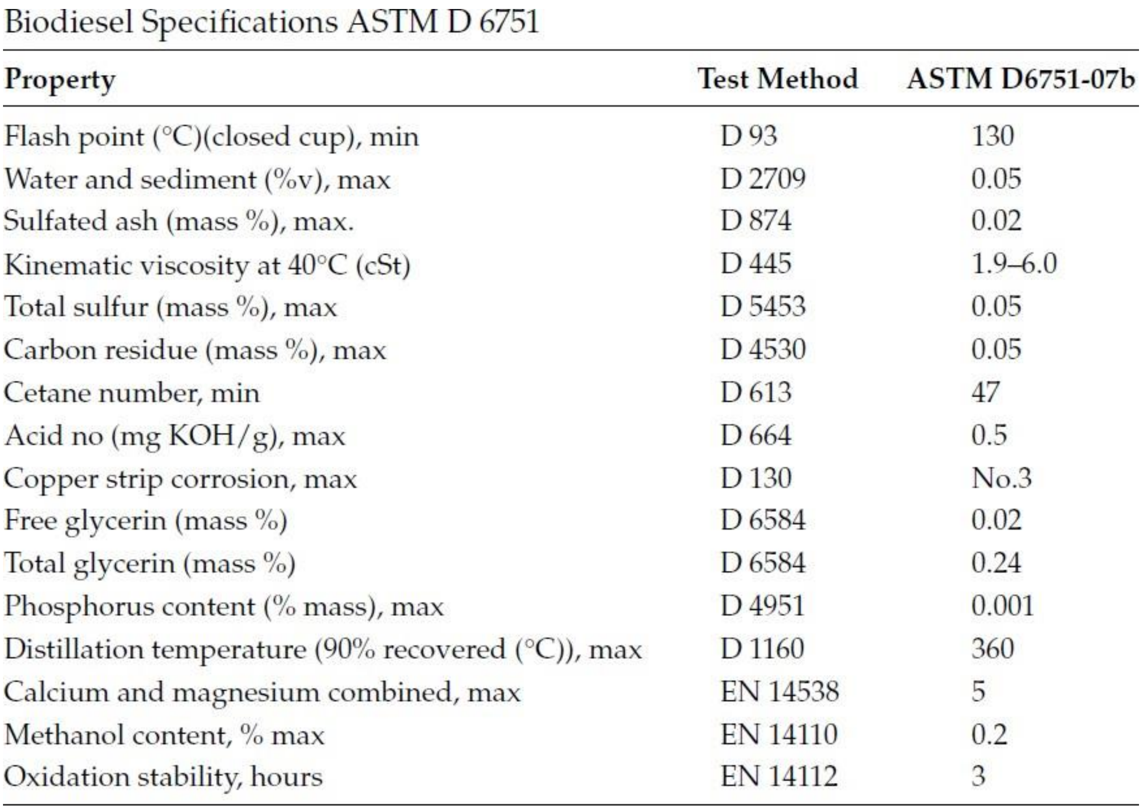
If biodiesel met the desired limits, then only the biodiesel can be used in engines while maintaining the engine manufacturer’s durability and reliability. Biodiesel should meet its specification when it is blended with diesel even in small percentages.



Biodiesel Standards

Country	Standards
Europe	EN 14214
United States	ASTM D 6751
Germany	DIN E 51601
India	IS 15607
Brazil	ANP 42
Japan	JASO M360

Table 2.3



Biodiesel Specifications ASTM D 6751

Property	Test Method	ASTM D6751-07b
Flash point (°C)(closed cup), min	D 93	130
Water and sediment (%v), max	D 2709	0.05
Sulfated ash (mass %), max.	D 874	0.02
Kinematic viscosity at 40°C (cSt)	D 445	1.9–6.0
Total sulfur (mass %), max	D 5453	0.05
Carbon residue (mass %), max	D 4530	0.05
Cetane number, min	D 613	47
Acid no (mg KOH/g), max	D 664	0.5
Copper strip corrosion, max	D 130	No.3
Free glycerin (mass %)	D 6584	0.02
Total glycerin (mass %)	D 6584	0.24
Phosphorus content (% mass), max	D 4951	0.001
Distillation temperature (90% recovered (°C)), max	D 1160	360
Calcium and magnesium combined, max	EN 14538	5
Methanol content, % max	EN 14110	0.2
Oxidation stability, hours	EN 14112	3

Engine Performance and emission Studies

Brake Thermal Efficiency

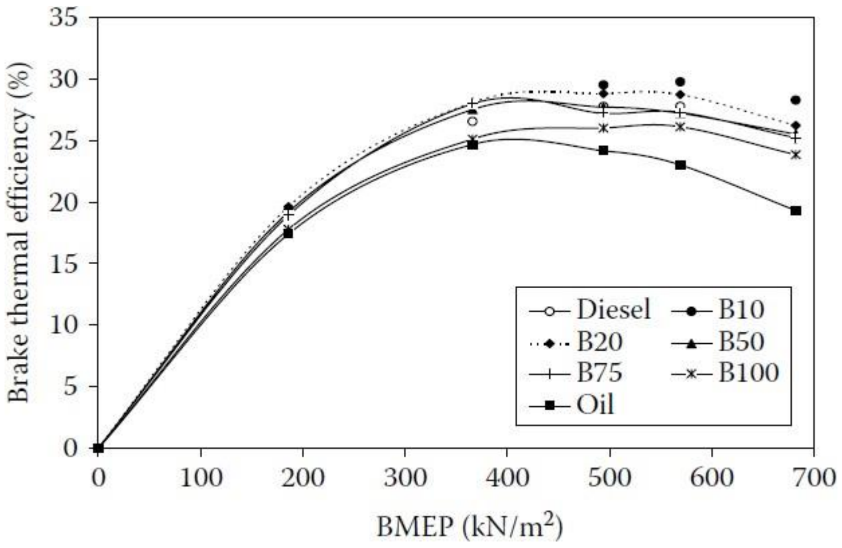


Fig 2.1

- The maximum brake thermal efficiency obtained is about 28% for B10, which is higher than that of diesel (25%).

- At a lower percentage concentration of biodiesel, brake thermal efficiency of the engine is improved (Figure). This is due to the additional lubricity provided by the biodiesel. The molecules of biodiesel (i.e., methyl esters of the oil) contain some amount of oxygen, which takes part in the combustion process.
- However, at the higher percentage concentration of biodiesel, the brake thermal efficiency decreases as a function in concentration of blend. This lower brake thermal efficiency was obtained for B100, which could be due to the reduction in calorific value and increase in fuel consumption as compared to B10 or diesel.

Specific Fuel Consumption

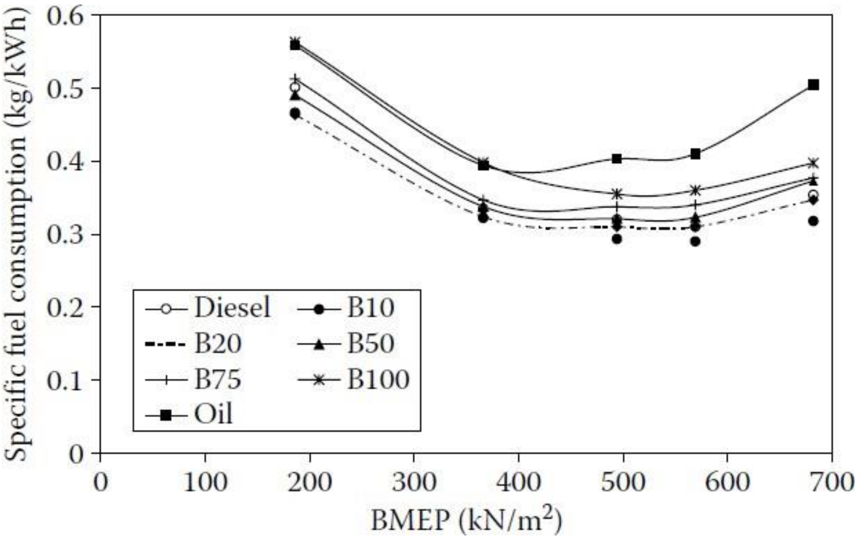


Fig 2.2

- Using a lower percentage of biodiesel in blends, the specific fuel consumption of the engine is lower than that of diesel for all loads.
- In case of B50–B100, the specific fuel consumption is found to be higher than that of diesel.
- At maximum load conditions, specific fuel consumption of neat biodiesel is about 12% higher than that of diesel. The calorific value of rubber seed oil biodiesel is approximately 14% lower than diesel.
- Calorific value of biodiesel blends decreases with an increase in percentage concentration of biodiesel.

HC Emissions

- Biodiesel blends 19.4%, 39.4%, 59.4%, and 79.4% are denoted as blend 1, 2, 3, and 4, respectively.

- Hydrocarbon emissions decrease with increase of engine load due to an increase in higher temperature associated with higher engine load.
- The hydrocarbon emissions decrease with increase in biodiesel percentage in the blend. Lower volatility of biodiesel reduces the HC emissions at low load conditions

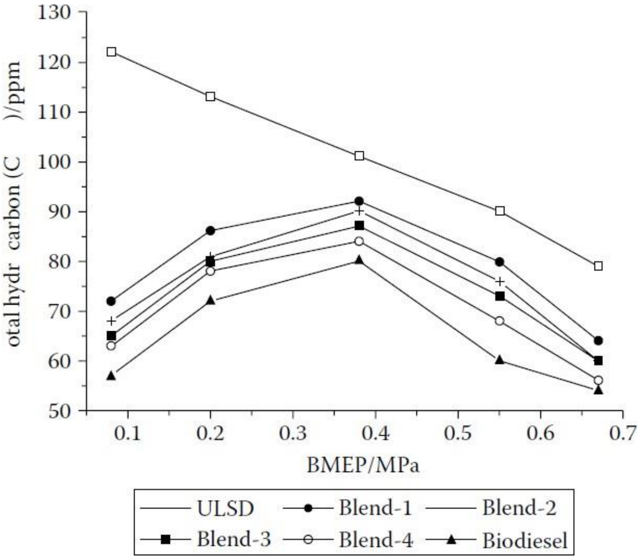


Fig 2.3

CO Emission

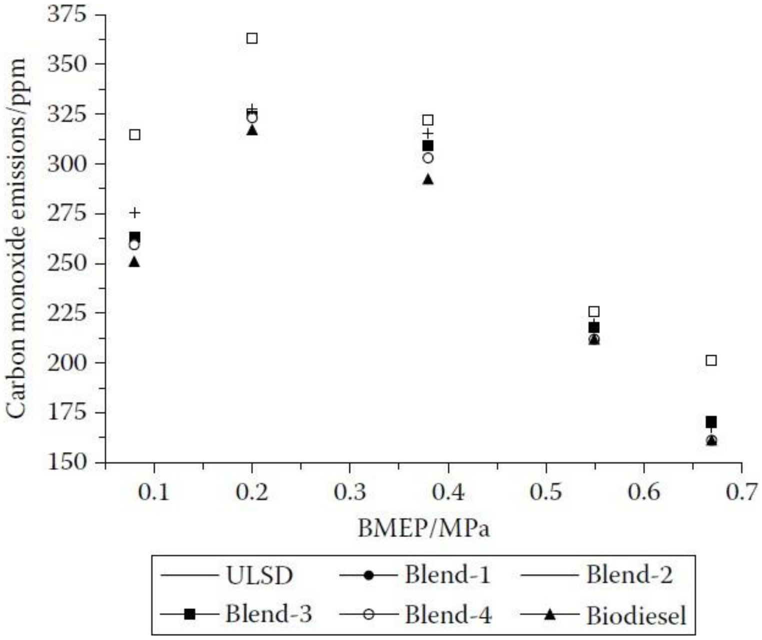


Fig 2.4

With the addition of biodiesel, CO emissions also decrease. Biodiesel itself contains oxygen that promotes complete combustion of fuel and hence reduces the CO emissions

NOx Emission

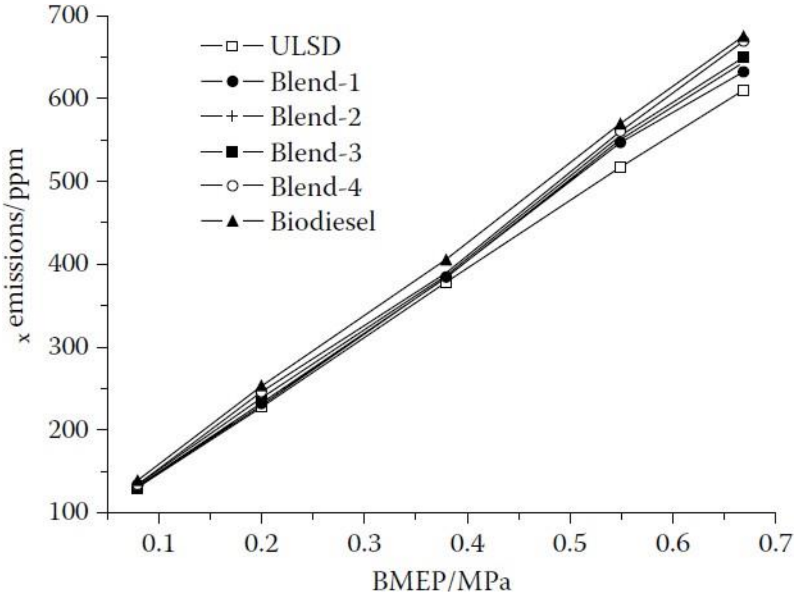


Fig 2.5

- Nitrogen oxides emission increases with an increase in load for all fuel samples.
- Biodiesel blends increase NOx emissions at all load conditions (Figure).
- Biodiesel that contains oxygen is taking part in combustion and hence increases the temperature of the combustion chamber.

Particulate matter Emission

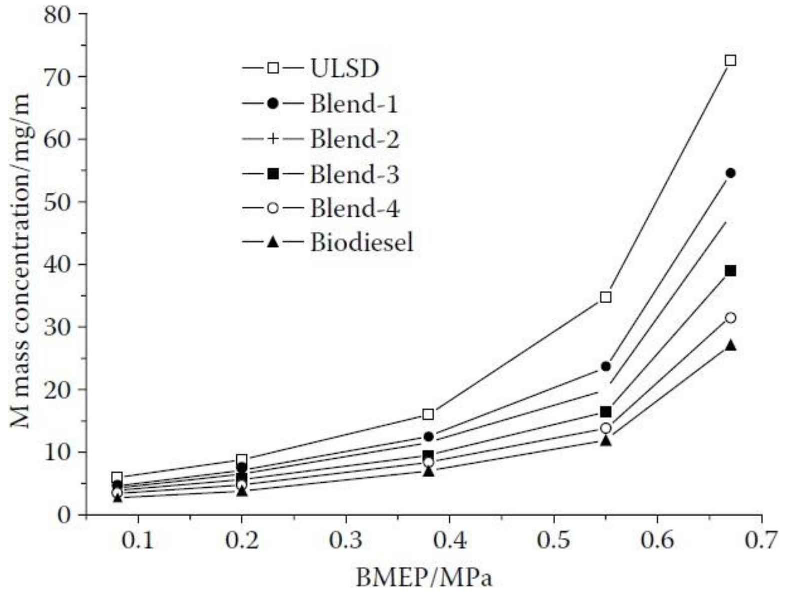
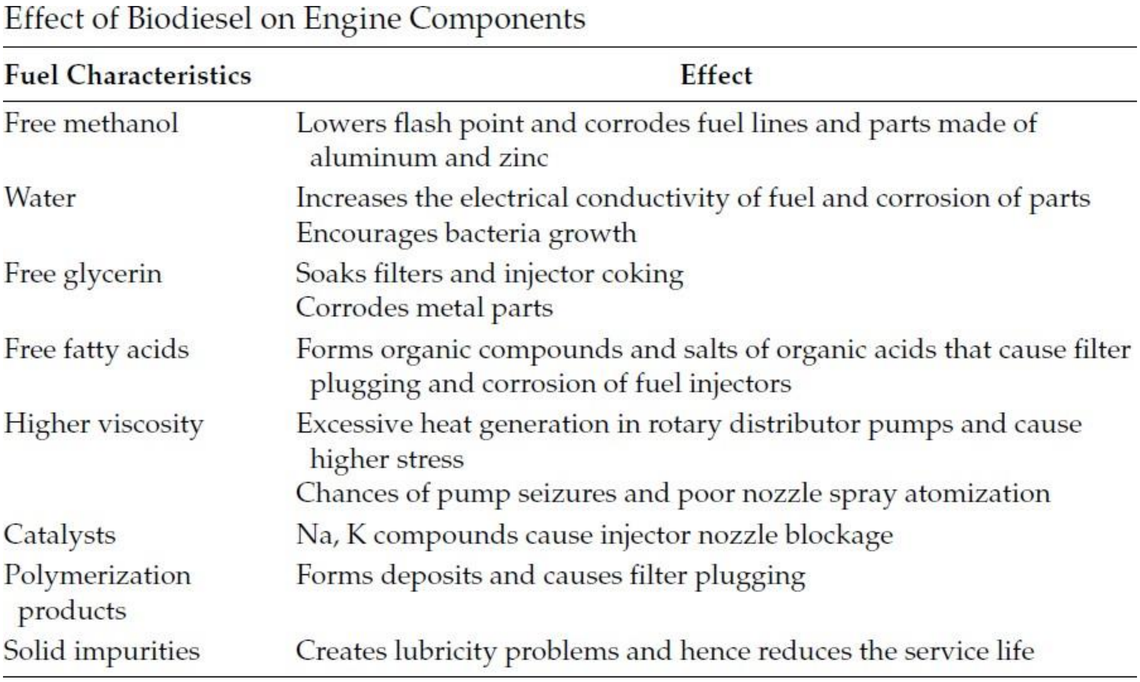


Fig 2.6

- Biodiesel blends reduce both smoke and particle mass concentration of exhaust emissions.
- Reduction in PM emissions is associated with reduction in soot and sulfate formation. Biodiesel has about 11–14% oxygen content and no sulfur content.
- Reduction in sulfur in fuel leads to reduction in sulfate formation. This leads to reduction in soot formation and reduces PM emissions (Figure).
- Aromatics, polycyclic aromatic hydrocarbons (PAH), are soot precursors and sources of particulate-phase PAH. Biodiesel contains no aromatics and hence this leads to the reduction in PM emission.



Effect of Biodiesel on Engine Components

Fuel Characteristics	Effect
Free methanol	Lowers flash point and corrodes fuel lines and parts made of aluminum and zinc
Water	Increases the electrical conductivity of fuel and corrosion of parts Encourages bacteria growth
Free glycerin	Soaks filters and injector coking Corrodes metal parts
Free fatty acids	Forms organic compounds and salts of organic acids that cause filter plugging and corrosion of fuel injectors
Higher viscosity	Excessive heat generation in rotary distributor pumps and cause higher stress Chances of pump seizures and poor nozzle spray atomization
Catalysts	Na, K compounds cause injector nozzle blockage
Polymerization products	Forms deposits and causes filter plugging
Solid impurities	Creates lubricity problems and hence reduces the service life

Challenges for Biodiesel

1. Biodiesel-fueled vehicles increase the NOx emissions.
2. Studies to be conducted when biodiesel used with the lower sulfur fuel will produce any emission benefits in the latest generation of engines.
3. While vehicles that run on B20 and displace some amount of petroleum, they are still dependent on diesel fuel to operate.
4. Biodiesel is significantly more expensive than diesel fuel and hence government incentives are required to promote it.
5. Because there is less energy in a gallon of biodiesel than in a gallon of petroleum diesel, the driving range of vehicles operating on biodiesel blends is less.
6. Requirement of warranty on biodiesel fueled vehicles from manufacturers.

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SCHOOL OF MECHANICAL
DEPARTMENT OF AUTOMOBILE

UNIT – III – Alternate Fuels and Energy systems – SAUA3013

Hydrogen

- Hydrogen is the ideal candidate as an energy carrier for both mobile and stationary applications while averting adverse effects on the environment and reducing dependence on imported oil for countries without natural resources.
- Hydrogen is by far the most abundant element in the universe (90% on the basis of number of atoms), and in the earth's crust it is one of the most abundant elements.
- When hydrogen is put in contact with oxygen, it reacts with it, releasing large quantities of energy
- Hydrogen is not available free in nature, it is embedded in a lot of natural substances such as water, carbohydrates, and hydrocarbons. To draw hydrogen from these substances, energy must be spent.
- If, for instance, hydrogen is taken out of water using electrolysis, the theoretical energy needed for this operation is the same theoretically made available during hydrogen recombination with oxygen.
- These twin reactions that allow creation of hydrogen from natural substances (e.g., water) with energy expense and recreation of water by hydrogen reaction with oxygen, makes it possible to use hydrogen as an energy carrier.
- Hydrogen is produced using nonrenewable technologies such as steam reformation of natural gas (~50% of global H_2 supply), petroleum refining (~30%), or the gasification of coal (~20%).
- Hydrogen has an approximate three-fold higher energy content than gasoline (119 MJ/kg for hydrogen vs. 44.2 MJ/kg for gasoline), while bioethanol has 50% less energy content (22.1 MJ/kg for ethanol) compared to gasoline and 84% less energy content compared to hydrogen

Hydrogen Production

Hydrogen can be produced from renewable as well as nonrenewable fuels sources. Renewable fuel sources includes water, biomass, and from conventional fuels.

Fuel processing technologies convert a hydrogen containing material such as gasoline, ammonia, or methanol into a hydrogen rich stream. Fuel processing of methane is the most common hydrogen production method in commercial use today.

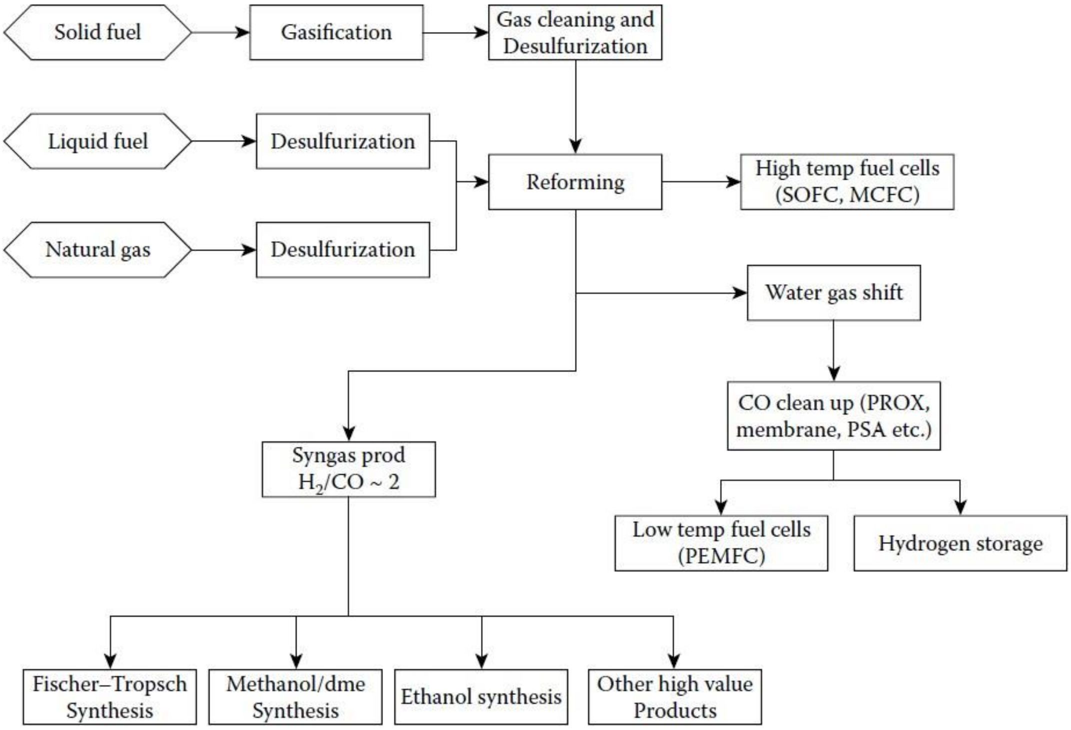


Fig 3.1

1. Hydrocarbon reforming

- There are three primary techniques used to produce hydrogen from hydrocarbon fuels: steam reforming, partial oxidation (POX), and auto thermal reforming (ATR).
- The reforming process produces a gas stream composed primarily of hydrogen, carbon monoxide, and carbon dioxide. Steam reforming does not require oxygen, has a lower operating temperature than POX and ATR, and produces reformate with a high H_2/CO ratio (3:1).
- Partial oxidation converts hydrocarbons to hydrogen by partially oxidizing (combusting) the hydrocarbon with oxygen.
- Auto thermal reforming uses the POX to provide the heat and steam reforming to increase the hydrogen production resulting in a thermally neutral process.
- Since POX is exothermic and ATR incorporates POX, these processes do not need an external heat source for the reactor.
- However, these require either an expensive and complex oxygen separation unit in order to feed pure oxygen to the reactor or the product gas is diluted with nitrogen.

2.Pyrolysis

- Pyrolysis converts the hydrocarbon into hydrogen and carbon without air/ water/oxygen. Pyrolysis can be done with any organic material. If air or water is present then significant CO_2 and CO emissions will be produced.
- Among the advantages of this process are fuel flexibility, relative simplicity and compactness, clean carbon by-product, and reduction in CO_2 and CO emissions. The chemical reaction can be written as,

$$C_nH_m \rightarrow nC + \frac{1}{2}mH_2 .$$

3. Plasma reforming

- In plasma reforming the overall reforming reactions are the same as conventional reforming, however, energy and free radicals used for the reforming reaction are provided by plasma typically generated with electricity or heat.
- When water or steam is injected with the fuel, H, OH, and O radicals in addition to electrons are formed, thus creating conditions for both reductive and oxidative reactions to occur. This process operates at lower temperatures than traditional reforming and is high sulfur tolerant.

4. Hydrogen from Water

- Electrolysis of water can produce very high purity hydrogen with high efficiency. Electrical current passes through two electrodes to separate water into hydrogen and oxygen. Commercial low temperature electrolyzers have system efficiencies of 56–73%.
- Solid oxide electrolysis cells (SOEC) electrolysers are more efficient. The SOEC technology has challenges with corrosion, seals, thermal cycling, and chrome migration. Electrolyzers are not only capable of producing high purity hydrogen, but recently, high-pressure units.

5. BIOHYDROGEN

- Hydrogen, produced from water and biomass feedstock, is called biohydrogen. Current technologies for the production of hydrogen are much more expensive than that of petroleum fuel.

- Hydrogen can be produced from biomass by **gasification and fast pyrolysis**. The gasification process converts biomass into synthesis gas; that is, carbon monoxide and hydrogen, which depends upon the process applied, oxidation medium, and fuel/ oxygen ratio. Low temperature gasification processes (less than 1000°C) yield products containing significant amounts of hydrogen as compared to higher temperature processes.
- Hydrogen can also be produced from **pyrolysis of lignocelluloses biomass** (second-generation biofuel). Pyrolysis is carried out at temperatures in the range of 650–800 K and at atmospheric pressure or slightly higher pressure and converts biomass into bio-oils.
- This is a complex mixture of compounds including acids, alcohols, aldehydes, esters, chemicals, and aromatics. Bio-oils are used as boiler fuel for stationary power plants and heating applications. However, this fuel can be upgraded to use as automobile engine fuel.
- Biohydrogen can also be produced from the **Supercritical Water Gasification (SCWG) method**. It is a relatively novel gasification method, in which biomass is transformed into a hydrogen-rich gas by introducing it in super-critical water.
- Supercritical water is obtained at pressure above 221 bar and temperatures above 374°C. By treatment of biomass in supercritical water— but in the absence of added oxidants—organics are converted into fuel gases and are easily separated from the water phase by cooling to ambient temperature. The produced high pressure gas is very rich in hydrogen
- SCWG process consists of operations such as feed pumping, heat exchanging, reactors, gas-liquid separators, and product upgrading. The reactor operating temperature is typically between 600°C and 650°C; the operating pressure is around 300 bar.
- A residence time of 0.5–2 minutes is required to achieve complete carbon conversion depending on the feedstock. This process is in particular suitable for the conversion of wet organic materials (renewable or nonrenewable) with moisture content in the range of 70–95%. This process is very cost effective as it uses wet feedstock also reducing the pretreatment processes.
- The main source of hydrogen during a biological, **fermentative process** is carbohydrates, which are very common in plant tissues, either in the form of oligosaccharides or as polymers, cellulose, hemicellulose, and starch.

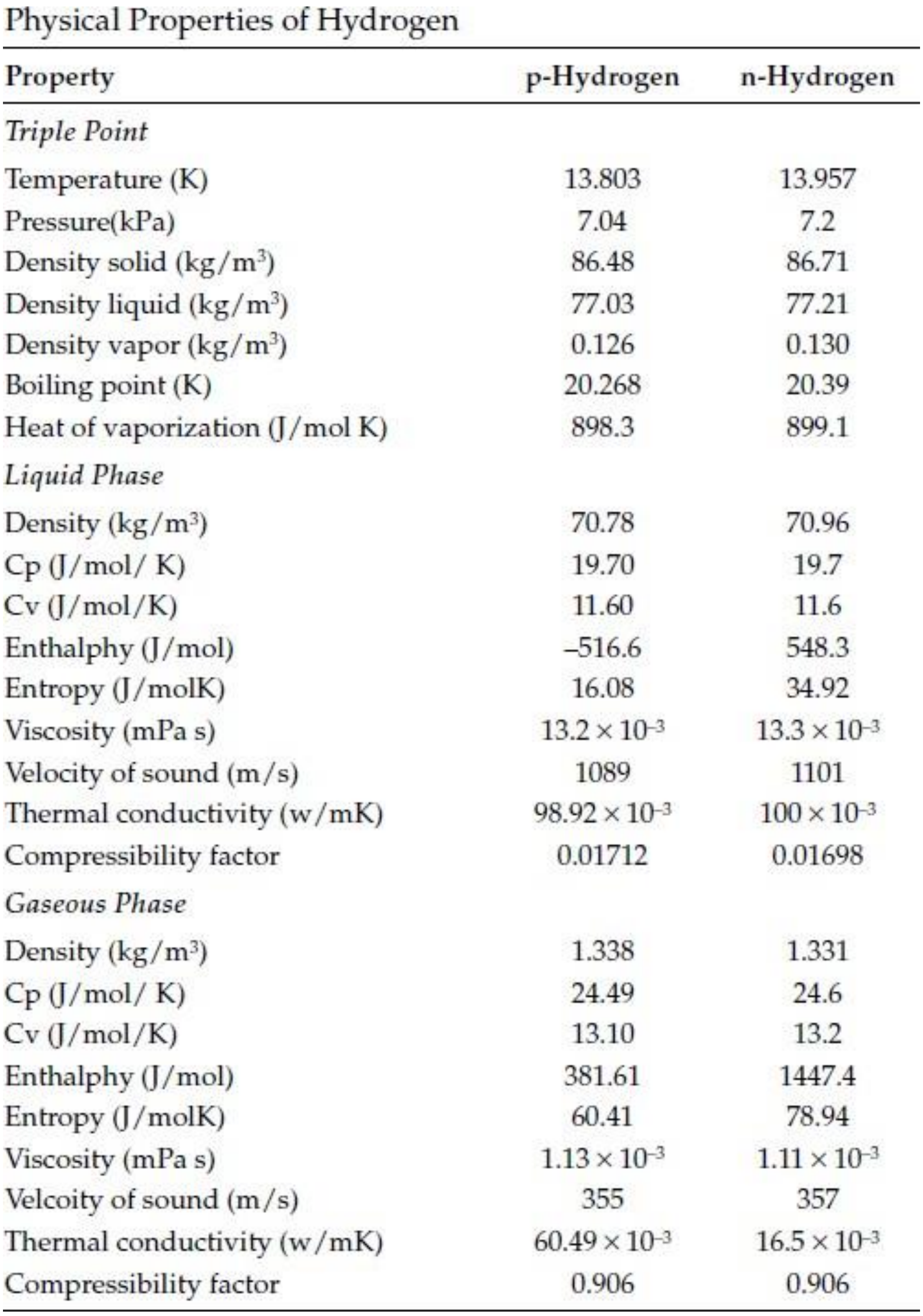
- Thus, the biomass of certain plants with a high content of carbohydrates could be considered as a very promising substrate for **biohydrogen** production. The maximum theoretical hydrogen yield is 4 moles per mole of utilized carbohydrates, expressed as glucose equivalents when carbohydrates are used as substrates

Hydrogen Properties

Physical Properties

- Hydrogen is a clean fuel. Hydrogen is the lightest element and has one proton and one electron. Hydrogen with atomic weight 1.00797 and atomic number 1 is the first element in the periodic table. Three isotopes of hydrogen are hydrogen, deuterium, and tritium, respectively.
- Hydrogen is colorless, odorless, tasteless, and is about 14 times lighter than air. It diffuses in air at a faster rate than any other gases.
- A stream of hydrogen from a leak is invisible in daylight.
- Hydrogen has a very low density of about 0.09 kg/m^3 20ºC. The liquid density of hydrogen is 70.03 kg/m^3. Higher cylinder capacity is required to store sufficient amounts of hydrogen for the operation of a vehicle.
- Moreover, as the energy density reduces, the power output also decreases. On cooling, hydrogen condenses to liquid at –253ºC and to solid at –259ºC. Hydrogen in gaseous form has a heat capacity of 14.4 kJ/kgK
- Hydrogen engines will not face any starting problems as it has a very low boiling point.
- Expansion ratio is the ratio of the volume at which a gas or liquid is stored to the volume of the gas or liquid at atmospheric pressure and temperatures. Hydrogen's expansion ratio is 1:848; that is, gaseous hydrogen occupies a volume of 848 times more than at a liquid state.
- When hydrogen is stored as a high-pressure gas at 250 bar and atmospheric temperature, its expansion ratio to atmosphere is 1:240. This necessitates that a large volume of hydrogen is required to be carried for adequate running of a vehicle.

Table 3.1



Physical Properties of Hydrogen

Property	p-Hydrogen	n-Hydrogen
Triple Point		
Temperature (K)	13.803	13.957
Pressure(kPa)	7.04	7.2
Density solid (kg/m^3)	86.48	86.71
Density liquid (kg/m^3)	77.03	77.21
Density vapor (kg/m^3)	0.126	0.130
Boiling point (K)	20.268	20.39
Heat of vaporization (J/mol K)	898.3	899.1
Liquid Phase		
Density (kg/m^3)	70.78	70.96
Cp (J/mol/ K)	19.70	19.7
Cv (J/mol/K)	11.60	11.6
Enthalphy (J/mol)	–516.6	548.3
Entropy (J/molK)	16.08	34.92
Viscosity (mPa s)	13.2×10^{-3}	13.3×10^{-3}
Velocity of sound (m/s)	1089	1101
Thermal conductivity (w/mK)	98.92×10^{-3}	100×10^{-3}
Compressibility factor	0.01712	0.01698
Gaseous Phase		
Density (kg/m^3)	1.338	1.331
Cp (J/mol/ K)	24.49	24.6
Cv (J/mol/K)	13.10	13.2
Enthalphy (J/mol)	381.61	1447.4
Entropy (J/molK)	60.41	78.94
Viscosity (mPa s)	1.13×10^{-3}	1.11×10^{-3}
Velcoity of sound (m/s)	355	357
Thermal conductivity (w/mK)	60.49×10^{-3}	16.5×10^{-3}
Compressibility factor	0.906	0.906

Chemical Properties

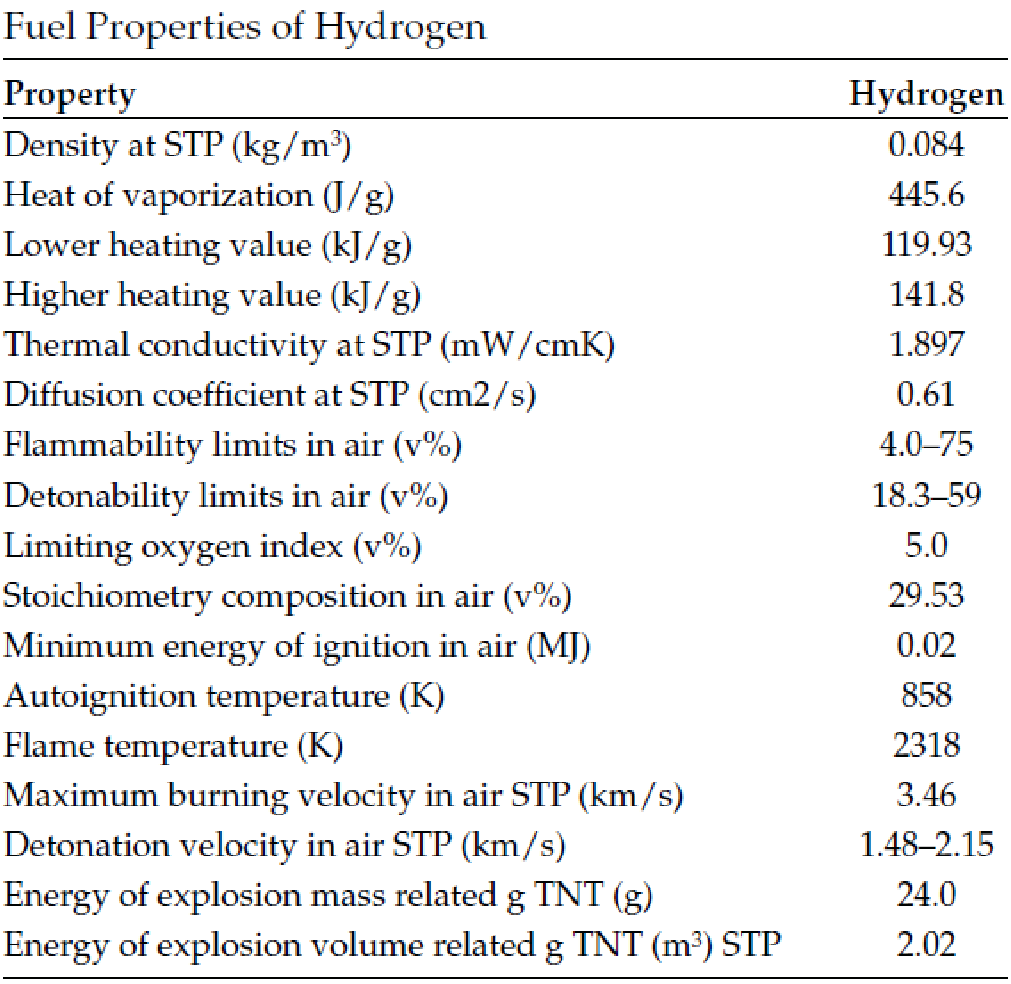
- Hydrogen atoms are chemically very reactive. When a small amount of ignition energy in the form of spark is provided to the hydrogen–air mixtures, the molecules react with air in the atmosphere very actively and release significant amounts of heat and water vapor.
- At room temperatures these reactions are very slow, but is accelerated by catalysts such as platinum and spark. Very high temperatures (>5000 K) are needed to dissociate hydrogen molecules into atomic hydrogen completely. Hydrogen is

considered an energy carrier to store and transmit energy from primary energy sources.

Fuel Properties

- Hydrogen is a suitable gaseous fuel for SI and CI. The fuel properties of hydrogen are given in Table.
- The self ignition temperature of hydrogen is very high and best suited for SI engines. This temperature plays an important role in storage pressure of hydrogen because as pressure of the hydrogen inside the cylinder increases, temperature will also increase.
- The higher self ignition temperature of hydrogen allows the use of larger compression ratios without causing premature ignition.
- It is well known that as the compression ratio of the engine increases its thermal efficiency will also increase. Hydrogen can be ignited at its low ignition energy of 0.02 mJ as compared to 0.24 mJ for gasoline and 0.28 mJ for methane at stoichiometric.

Table 3.2



Fuel Properties of Hydrogen

Property	Hydrogen
Density at STP (kg/m^3)	0.084
Heat of vaporization (J/g)	445.6
Lower heating value (kJ/g)	119.93
Higher heating value (kJ/g)	141.8
Thermal conductivity at STP (mW/cmK)	1.897
Diffusion coefficient at STP (cm2/s)	0.61
Flammability limits in air (v%)	4.0–75
Detonability limits in air (v%)	18.3–59
Limiting oxygen index (v%)	5.0
Stoichiometry composition in air (v%)	29.53
Minimum energy of ignition in air (MJ)	0.02
Autoignition temperature (K)	858
Flame temperature (K)	2318
Maximum burning velocity in air STP (km/s)	3.46
Detonation velocity in air STP (km/s)	1.48–2.15
Energy of explosion mass related g TNT (g)	24.0
Energy of explosion volume related g TNT (m^3) STP	2.02

Minimum Ignition Energy

- Minimum energy required for ignition is the order of magnitude less than that required for gasoline. The minimum ignition energy is a function of equivalence ratio. At the equivalence ratio nearer to 1, minimum ignition energy for hydrogen–air mixtures is very low.
- As very little energy is required for the combustion of hydrogen, any hydrogen–air mixture can be ignited due to wide limits of flammability of hydrogen. The hot spots in the combustion chamber may cause premature ignition in the combustion chamber and flash back also.

Flame Speed

- The flame velocity of hydrogen–air mixtures is a function of equivalence ratio. Hydrogen has a very high flame speed of 1.85 m/s as compared to 0.42 for gasoline and 0.38 for diesel.

Flame Temperature

- Flame temperature of hydrogen–air mixtures is about 2207ºC as compared to 1917ºC for methane and 2307ºC for gasoline . But the rapid combustion allows very little heat loss to surroundings and hence high, instantaneous, local temperatures are produced that leads to formation of high nitric oxides.

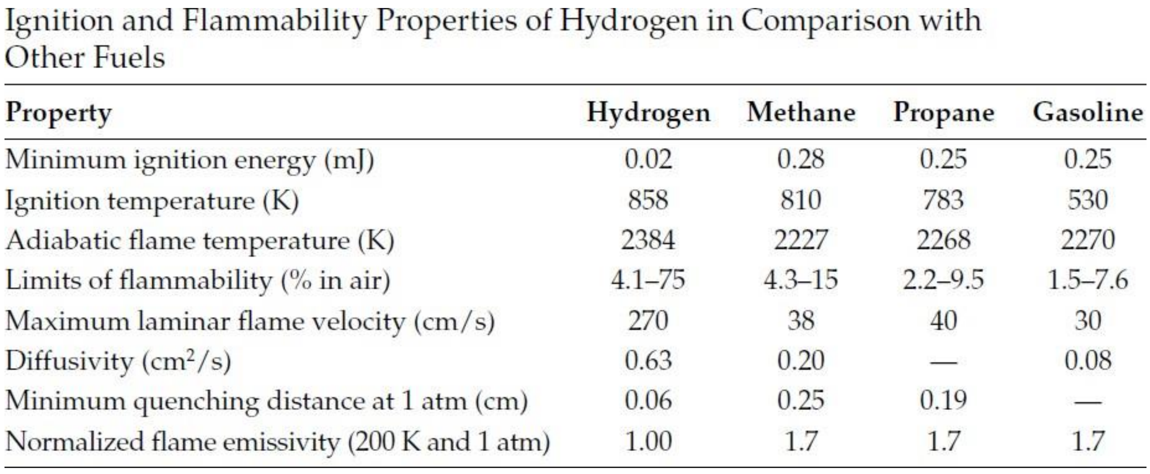
Diffusivity

- Diffusivity of hydrogen in air is much higher than gasoline or diesel. The higher diffusivity helps in formation of homogeneous mixtures of hydrogen and air. Moreover, if there is any leakage of hydrogen from the cylinder, it will disperse quickly in the atmosphere and hence form lean mixtures and reduces the risk of sudden firing.
- The hydrogen molecules are smaller than other gases and hence it can diffuse through many materials considered air tight or impermeable to other gases. Leakage of liquid hydrogen evaporates quickly as its boiling point is very low (–253ºC).
- In the case of leakage of hydrogen, buoyancy and diffusion effects in the air are often overshadowed by the presence of air currents from a slight ambient wind and very slow vehicle motion. In general, these serve to disperse the leaked hydrogen more quickly.

Flammability

- Flammability limits are the range that the engine can operate over the wide range of air–fuel mixtures. Hydrogen–air mixtures are flammable in the broad range, –4–75% concentration, whereas gasoline flammability range is less than 10.
- In the hydrogen–air mixture, 4% hydrogen can provide combustion mixtures whereas the stoichiometric air–fuel ratio is 29.5%.
- At stoichiometric conditions, hydrogen displaces about 30% of the combustion chamber, compared to about 1–2% for gasoline. This reduces the volumetric efficiency of the engine as well as power developed. As hydrogen has a wide flammability range, the hydrogen engine can work in the A/F range of 34:1–180:1.

Table 3.3



Ignition and Flammability Properties of Hydrogen in Comparison with Other Fuels

Property	Hydrogen	Methane	Propane	Gasoline
Minimum ignition energy (mJ)	0.02	0.28	0.25	0.25
Ignition temperature (K)	858	810	783	530
Adiabatic flame temperature (K)	2384	2227	2268	2270
Limits of flammability (% in air)	4.1–75	4.3–15	2.2–9.5	1.5–7.6
Maximum laminar flame velocity (cm/s)	270	38	40	30
Diffusivity (cm^2/s)	0.63	0.20	—	0.08
Minimum quenching distance at 1 atm (cm)	0.06	0.25	0.19	—
Normalized flame emissivity (200 K and 1 atm)	1.00	1.7	1.7	1.7

Hydrogen Embrittlement

Owing to hydrogen embrittlement, the mechanical properties of metallic and nonmetallic materials of hydrogen systems may degrade and fail resulting in leaks.

Hydrogen embrittlement depends upon surrounding temperature and pressure, concentration and exposure time to hydrogen, strength and quality of material, physical and mechanical properties, surface conditions, and so on.

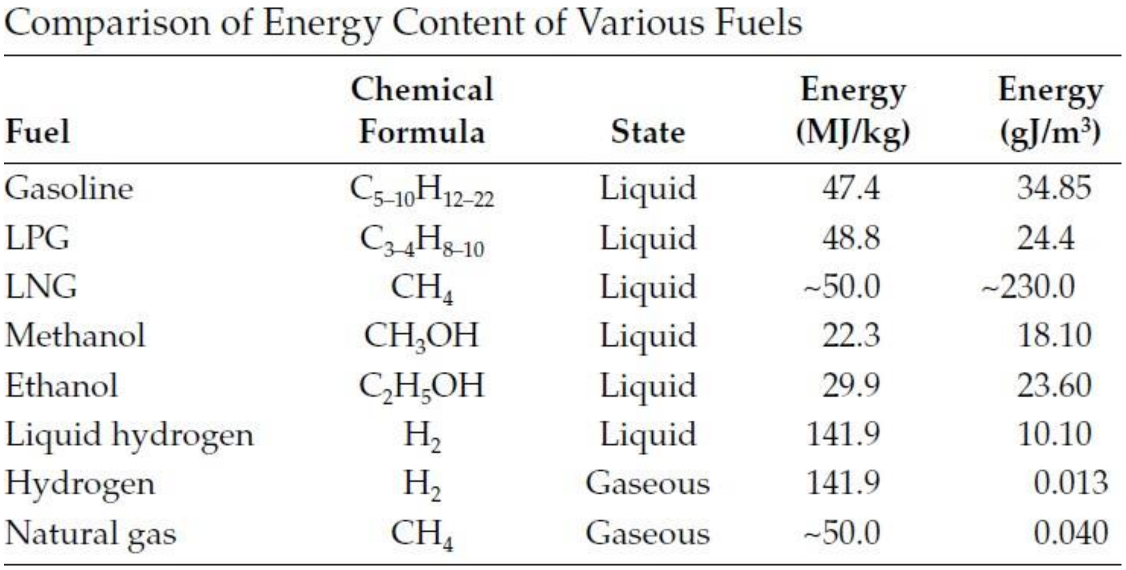
Control of hydrogen embritlement can be achieved by oxide coating, removing stress concentration, additives to hydrogen, selection of alloy materials, and so on.

The internal and environmental hydrogen embrittlement maximizes in the temperature range of between –73 and 27ºC whereas hydrogen reaction embrittlement occurs at temperatures above room temperature

Calorific Value

Calorific value of hydrogen in comparison with other fuels is depicted in Table Hydrogen contains about 2.75 times the energy as compared to that of gasoline on a mass basis. However, on volume basis it is of low energy content.

Table 3.4



Comparison of Energy Content of Various Fuels

Fuel	Chemical Formula	State	Energy (MJ/kg)	Energy (gJ/m^3)
Gasoline	$C_{5-10}H_{12-22}$	Liquid	47.4	34.85
LPG	$C_{3-4}H_{8-10}$	Liquid	48.8	24.4
LNG	CH_4	Liquid	~50.0	~230.0
Methanol	CH_3OH	Liquid	22.3	18.10
Ethanol	C_2H_5OH	Liquid	29.9	23.60
Liquid hydrogen	H_2	Liquid	141.9	10.10
Hydrogen	H_2	Gaseous	141.9	0.013
Natural gas	CH_4	Gaseous	~50.0	0.040

Hydrogen Safety

Hydrogen related technology is a potential future energy option with the potential to limit the increasing global climate problem and the greenhouse effect. However, increasing safety requirements have to be fulfilled to minimize industrial risks and to harmonize the safety culture also in the field of transportation.

The hazards related with Gaseous Hydrogen because of its properties are given below

1. **Physical properties**

- Lighter than air, odorless and colorless gas
- Low viscosity (leaks easily)
- Highly diffusive

2. Pressure

- High-pressure storage can result in pressure rupture, flying debris
- High-pressure gas jet impingement on body can cut bare skin
- Oxygen displacement in confined spaces

3. Chemical

- Flammable, with nonluminous flame, no toxic combustion products
- Explosive, 4–74% by volume can deflagrate (typically only a modest over pressure, ~a few psi in open areas) can also detonate (high over pressure shock wave, ~several atmospheres)

- Low ignition energy, 0.02–1 mJ spark to ignite a deflagration
- Modest autoignition temperature, 574ºC

4. Temperature

- Could be stored at room temperature

5. Materials issues

- Embrittlement of metal and plastics

6. Toxicological

- Asphyxiation in confined spaces
- No other toxic concern effects

The hazards related with liquid hydrogen because of its properties are given below.

1. Physical properties

- ❖ Odorless, colorless, cannot easily be odorized since odorants will freeze out at cryogenic temperatures
- ❖ Boil off gas quickly warms and then is lighter than air
- ❖ Flow-induced static charge generation
- ❖ Boil off vent rate from storage tanks/fuel tanks is typical to maintain cold temperature in tank
- ❖ Liquefies quickly, easily boils by heat transfer into the 20 K liquid
- ❖ Rapid phase transition from liquid to gas can cause pressure explosions
- ❖ Liquid quickly contaminates itself by condensing gases from air contact

2. Pressure

- Stored under modest pressure to suppress boiling

3. Chemical

- Evolved gas is cold, otherwise the same concerns as gaseous hydrogen

4. Temperature

- Cryogenic burns, especially eyes
- Lung damage by cold vapor inhalation
- Possible hypothermia working near these systems
- Condensation of air near LH $_2$ systems if insulation allows heat leak paths; can lead to oxygen rich zones near systems

5. Materials issues

- Mechanical stresses generated by thermal contraction
- Embrittlement of metal
- Mild steels susceptible to cracking at cryogenic temperatures

- Materials have low specific heats at cryogenic temperatures, easy heat transfer

6. Toxicological issues

- Asphyxiation in confined spaces
- Frostbite from acute exposure
- Hypothermia possible from long exposure
- No other toxic concerns

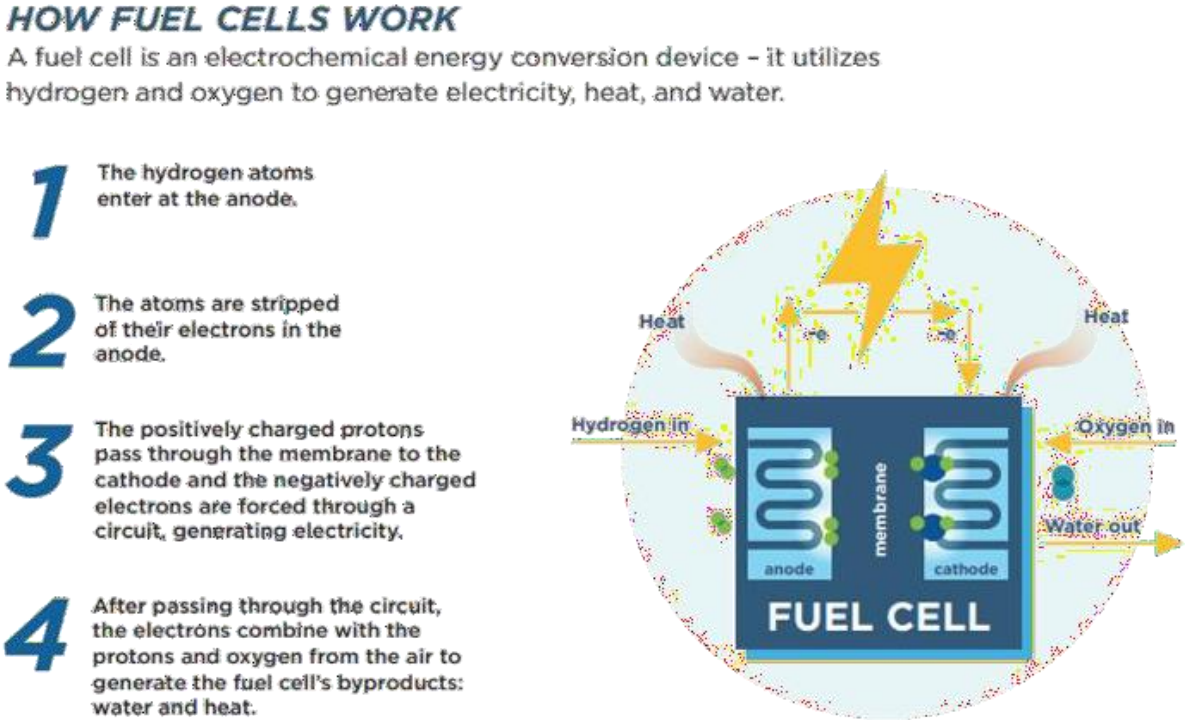
From the list, the **hazard due high-pressure, for gaseous storage**, and **rapid phase transition from liquid to gas**, in cases of liquid storage, seems the most dangerous scenario for the transport sector due to the fact that these hazards develop into the ultimate scenario of fire and explosions. These issues are of particular importance for the risk related to hydrogen storage when vessel rupture, in general and especially in the tunnels, and mitigation measures and tests are highly studied.

Worldwide projects, related to Hydrogen Safety Issues such as: HYSAFE, IEA Task 19–Hydrogen Safety, are studying these hazards

Hydrogen Fuel cell

- A fuel cell is a device that generates electricity through an electrochemical reaction, not combustion.
- In a fuel cell, hydrogen and oxygen are combined to generate electricity, heat, and water.
- Fuel cells are used today in a range of applications, from providing power to homes and businesses, keeping critical facilities like hospitals, grocery stores, and data centers up and running, and moving a variety of vehicles including cars, buses, trucks, forklifts, trains, and more.
- Fuel cell systems are a clean, efficient, reliable, and quiet source of power. Fuel cells do not need to be periodically recharged like batteries, but instead continue to produce electricity as long as a fuel source is provided.
- A fuel cell is composed of an anode, cathode, and an electrolyte membrane.
- A typical fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode.
- At the anode site, a catalyst splits the hydrogen molecules into electrons and protons. The protons pass through the porous electrolyte membrane, while the electrons are forced through a circuit, generating an electric current and excess heat.

- At the cathode, the protons, electrons, and oxygen combine to produce water molecules. As there are no moving parts, fuel cells operate silently and with extremely high reliability.



HOW FUEL CELLS WORK

A fuel cell is an electrochemical energy conversion device – it utilizes hydrogen and oxygen to generate electricity, heat, and water.

1 The hydrogen atoms enter at the anode.

2 The atoms are stripped of their electrons in the anode.

3 The positively charged protons pass through the membrane to the cathode and the negatively charged electrons are forced through a circuit, generating electricity.

4 After passing through the circuit, the electrons combine with the protons and oxygen from the air to generate the fuel cell's byproducts: water and heat.

Fig 3.2

Hydrogen in Spark Ignition Engines

Hydrogen can be used in SI engines in three ways: manifold induction, direct injection of hydrogen into the cylinders, and as a supplement to gasoline.

1. Manifold induction

Hydrogen can be inducted into the engine through carburetion. The engine was able to operate smoothly within the equivalence range of 0.4–0.8 without frequent symptoms of backfire.

This method allows quality governing, ultra-lean operation, high thermal efficiency, and low exhaust emissions in the equivalence range of 0.3–0.5.

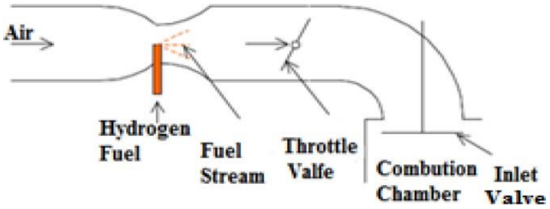


Fig 3.3

- These carburetted versions of the engine systems, apart from developing low power outputs (as compared to the gasoline-fueled engines) also exhibited severe operational combustion-related problems such as backfire, preignition, combustion knock, and rapid rate of pressure rise .
- Hydrogen fuel has a higher brake thermal efficiency and can even operate at lower engine loads with better efficiency (Figure). It can be noticed that brake thermal efficiency is improved to about 31% with hydrogen-fueled engines compared to gasoline fueled engines.
- Traces of CO and HC emissions presented in hydrogen-fueled engines are due to the evaporating and burning of lubricating oil film on the cylinder walls.
- Short time of combustion produces lower exhaust gas temperature for hydrogen. Significant decreases in NO_x emissions are observed with hydrogen operations (Figure).
- Carburetor systems do not require the hydrogen supply to be under high-pressure like other fuel delivery systems.
- Gasoline engines fitted with carburetors can be easily converted to operate on neat hydrogen or blends of gasoline/hydrogen.
- Carburetor engines are more susceptible to preignition and backfire. Moreover, the accumulation of hydrogen/air mixtures within the intake manifold aggravates the effects of preignition.

2. Port injection

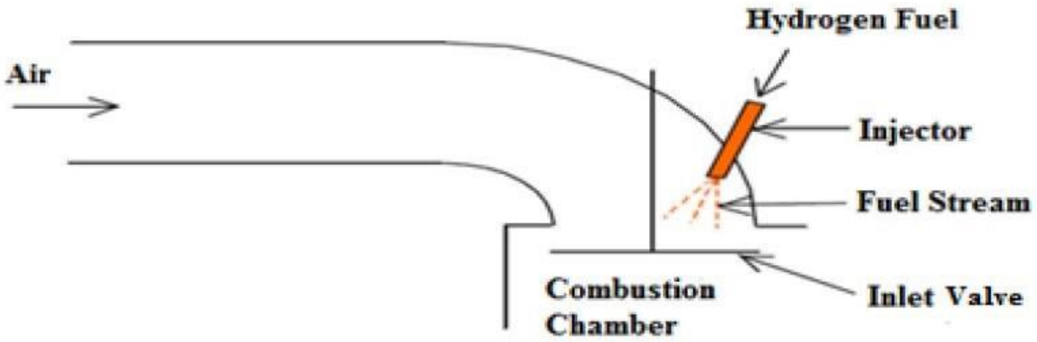


Fig 3.4

- ❖ The port injection fuel-delivery system injects fuel directly into the intake manifold at each intake port, rather than drawing fuel in at a central point.

- Air enters at the beginning of the intake stroke to dilute the hot residual gases and cool any hot spots in the combustion chamber, and hydrogen is injected into the manifold after the beginning of the intake stroke.
- Since less gas (hydrogen or air) is in the manifold at any one time, the probability for premature ignition is reduced. This method reduces the risk of backfire also.
- The inlet supply pressure for port injection is higher than for carbureted systems, but less than for direct injection systems.
- Currently, electronic fuel injection (EFI) systems meters the hydrogen to each cylinder. Each cylinder is fitted with individual fuel injectors.
- Combustion of lean hydrogen–air mixtures with fuel-to-air equivalence ratios of less than 0.5 ($\lambda > 2$) results in extremely low NO^x emissions. Due to the excess air available in the combustion chamber, the combustion temperatures do not exceed the NO_x critical value of approximately 1800 K
- Exceeding the NO_x critical equivalence ratio results in an exponential increase in oxides of nitrogen emissions, which peaks around a fuel-to-air equivalence ratio of 0.75 ($\lambda \sim 1.3$).
- At stoichiometric conditions, the NO^x emissions are at around 1/3rd of the peak value
- theoretical power density of port fuel injected hydrogen engines is higher than gasoline engines.

3. Hydrogen Direct injection

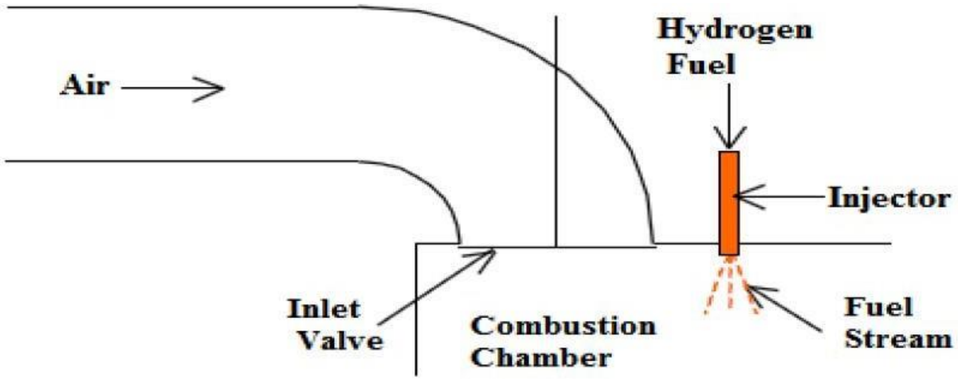


Fig 3.5

- Hydrogen direct injection (DI) system was developed to achieve near zero emission with an increase in power.
- Latest model hydrogen engines use direct injection systems for fuel-delivery purposes. Early injection generally refers to any hydrogen DI during the early

compression stroke shortly after intake valve closing, whereas late DI refers to strategies with the injection late in the compression stroke generally ending just before spark timing.

- In order to avoid displacement of a fresh charge by hydrogen of low density, the start of injection even for early injection is usually set after intake valve closing. During fuel injection, the inlet valve is closed completely thereby avoiding premature ignition during the suction stroke.
- The DI fuel system requires higher fuel rail pressure than other fuel systems.

Preignition Problems in Hydrogen engines

- In hydrogen engines, premature ignition is a problem because of its lower ignition energy, wider flammability range, and shorter quenching distance.
- Premature ignition occurs when the fuel mixture in the combustion chamber ignited before ignition by the spark plug and results in an inefficient rough running engine.
- If the premature ignition occurs near the fuel intake valve the resultant flame travels back into the induction system thus causing backfire.
- Crankcase oil enters into the combustion chamber through blow-by and in suspended form, or in the crevices just above the top piston ring, and acts as a hot spot that may contribute to preignition
- Preignition in hydrogen vehicles, can be avoided by
- Injecting cold exhaust gases into the cylinder
- Injecting cold gaseous hydrogen
- Injecting water into the cylinder
- Increasing the compression ratio
- Using lean burn carburetor

Hydrogen in Compression Ignition Engines

Hydrogen can be used in CI engines in two ways: dual fuel mode and surface ignition.

Dual Fuel Mode Operation

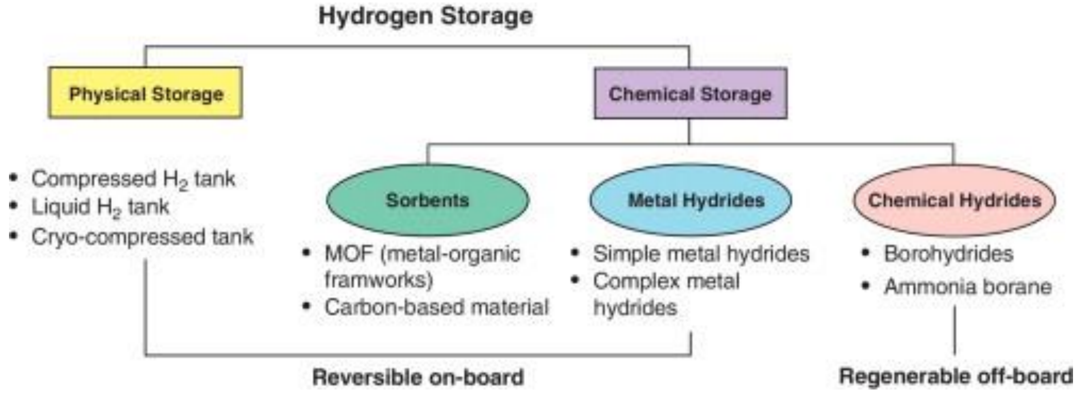
- In this method, hydrogen is inducted into the combustion chamber along with fresh air and compressed and then ignited by a spray of injected liquid fuel (diesel).
- It has been reported by the investigators that hydrogen-fueled diesel combustion could be achieved to a limited extent because of the autoignition characteristics of the fuel.

- The problems associated with this method are: when an insufficient quantity of fuel is injected then incomplete combustion will occur and when hydrogen-gas mixture becomes rich combustion becomes uncontrollable.
- An excessive introduction of the preliminary fuel may cause autoignition by itself thus giving rise to rough combustion. About 30% hydrogen can be replaced by this method. Introduction of a higher percentage of hydrogen leads to uncontrolled pressure rise.
- Hydrogen-fueled diesel engines can produce higher power than an ordinary diesel engine with reduction in NO_x and nil smoke emissions.

Direct injection

- In this method, hydrogen is directly introduced into the cylinder at the end of compression. The gas impinges on the glow plug in the combustion chamber and hence surface ignition burning of fuel occurs.
- Moreover, it is possible to introduce lean hydrogen–air during intake of an engine and then inject the bulk of hydrogen toward the end of compression. The advantage of this method is that surface ignition is not dependant on the compression ratio for ignition. Literature shows that a very small difference in brake thermal efficiency was observed in the compression ratio 12–18.
- With hydrogen directly injected into the combustion chamber in a CI engine, the power output would be approximately double that of the same engine operated in the premixed mode.
- The use of hydrogen DI in a diesel engine has given a higher power to weight ratio when compared to conventional diesel-fueled operation, with the peak power being approximately 14% higher. The power output of such an engine would also be higher than that of a gasoline engine, since the stoichiometric heat of combustion per standard kilogram of air is higher for hydrogen (approximately 3.37 MJ for hydrogen compared with 2.83 MJ for gasoline).

HYDROGEN STORAGE



- A major obstacle for the development of hydrogen powered fuel cell vehicles is the lack of safe, light weight and energy efficient means for on-board hydrogen storage. During the last fifteen years, significant effort has been made to develop effective hydrogen storage methods, including hydrogen tank, sorbents and metal/chemical hydrides

Compressed Gas

- The most commonly used method for hydrogen storage in fuel cell vehicles is compressed hydrogen tanks.
- The most important consideration for compressed gas is the material composing the tank. It must be lightweight, inexpensive and sufficiently strong to meet the required stress, strain and safety specifications
- In addition, thermal conductivity of the material must be high enough to manage exothermic heat during filling the tank.
- Accounting for these requirements, carbon fiber reinforced plastic (CFRP) is promising as material for the compressed gas tank. The CFRP tanks are lightweight and durable, however, they have relatively low thermal conductivity which requires further improvement
- The CFRP (Type IV, made from carbon fiber with a polymer liner) tanks are estimated to provide 5.2 and 5.5 wt% H2 for 700 and 350 bar, respectively
- The volumetric capacity (18 and 28 g H2/L for 350 and 700 bar, respectively) and the cost of tanks, however, are still challenges

Cryo-compressed H2

- Cryo-compressed H2, combines compression and cryogenic storage
- The volumetric density of hydrogen can be increased by pressurizing LH2 at 20 K

from 70 g/L at 1 bar to 87 g/L at 240 bar, which reduces the requirement for expensive carbon fiber composite.

- In addition, it can decrease evaporative loss of hydrogen as well as extend the dormancy period in insulated pressure vessels.
- Cryo-compressed tanks (276 bar, 20 K) are estimated to provide 5.8 wt% and 43 g H2/L.

Metal Hydrides

- Some metal hydrides have the potential for reversible on-board hydrogen storage and release hydrogen at the relatively low temperatures and pressures required for fuel cells.
- For example, $LaNi_5H_6$ can release hydrogen under PEM fuel cell operating conditions (1–10 atm and 25–100degC), but its gravimetric capacity is too low (1.4 wt%) and its cost too high for vehicular applications
- As compared to conventional metal hydrides, complex metal hydrides offer the potential to improve gravimetric hydrogen capacity. By introducing titanium dopants, sodium alanate ($NaAlH_4$) can store and release hydrogen reversibly at modest temperature (150 degC). However, complex metal hydrides still provide relatively low hydrogen.

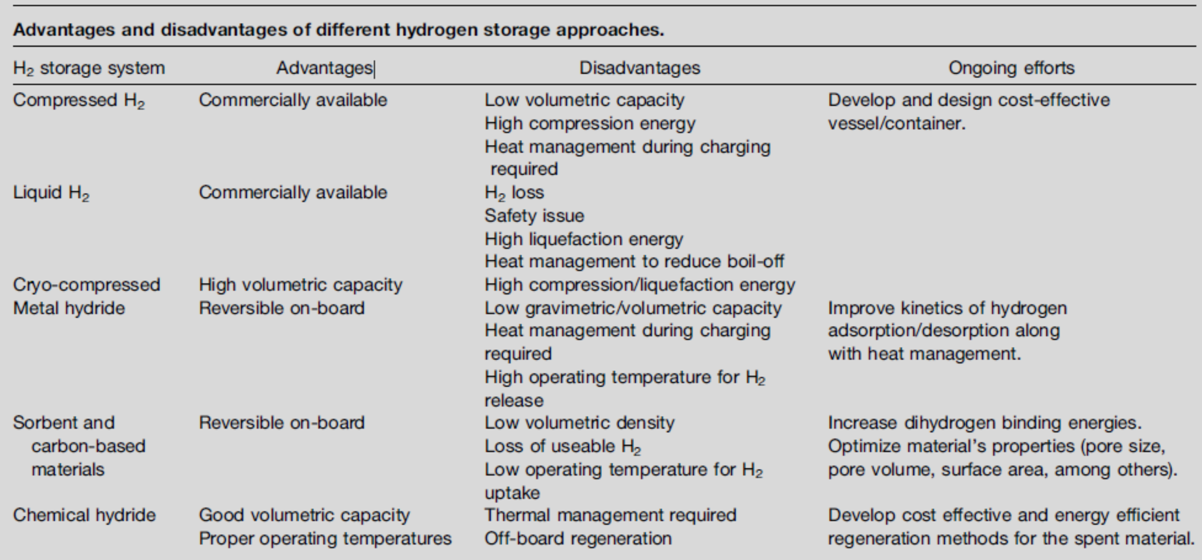
Chemical Hydrides

- As compared to metal hydrides, chemical hydrides offer higher energy densities since they contain lighter elements.
- In addition, they can release hydrogen under relatively mild operating conditions. The dehydrogenation reactions, however, are irreversible, so the resulting products have to be regenerated off-board the vehicle .
- Sodium borohydride ($NaBH_4$) can provide relatively high theoretical hydrogen yield (10.8 wt%) via hydrolysis reaction which proceeds in an aqueous medium with a catalyst
- A $NaBH_4$- based system has been estimated to possess system gravimetric and volumetric capacities of 4.5 wt% and 36 g/L, respectively

$$NaBH_4 + 2H_2O \rightarrow NaBO_2 + 4H_2$$

- There are a number of boron-hydrogen compounds that have high hydrogen content. Ammonia borane (AB, NH_3BH_3) has high material capacity (19.6 wt% H2), where the hydrogen can be released by either hydrolysis or thermolysis.

$$NH_3BH_3 + 3H_2O \rightarrow B(OH)_3 + NH_3 + 3H_2$$



Advantages and disadvantages of different hydrogen storage approaches.

H_2 storage system	Advantages	Disadvantages	Ongoing efforts
Compressed H_2	Commercially available	Low volumetric capacity High compression energy Heat management during charging required	Develop and design cost-effective vessel/container.
Liquid H_2	Commercially available	H_2 loss Safety issue High liquefaction energy Heat management to reduce boil-off	
Cryo-compressed	High volumetric capacity	High compression/liquefaction energy	
Metal hydride	Reversible on-board	Low gravimetric/volumetric capacity Heat management during charging required High operating temperature for H_2 release	Improve kinetics of hydrogen adsorption/desorption along with heat management.
Sorbent and carbon-based materials	Reversible on-board	Low volumetric density Loss of useable H_2 Low operating temperature for H_2 uptake	Increase dihydrogen binding energies. Optimize material's properties (pore size, pore volume, surface area, among others).
Chemical hydride	Good volumetric capacity Proper operating temperatures	Thermal management required Off-board regeneration	Develop cost effective and energy efficient regeneration methods for the spent material.

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SCHOOL OF MECHANICAL
DEPARTMENT OF AUTOMOBILE

UNIT – IV – Alternate Fuels and Energy systems – SAUA3013

Potential of LPG

- Liquefied petroleum gas (LPG), a mixture of propane (C_3H_8) and butane (C_4H_{10}) gas, is a popular fuel for internal combustion engines.
- This popularity comes from many features of the fuel such as its high octane number for spark ignited engines, comparable to gasoline heating value that ensures similar power output.
- Other features include the possibility of transport and storage of LPG in liquid state because of relatively low pressure of saturated vapor in normal temperature range, better exhaust gas composition, and lower cost per energy unit in comparison with gasoline.
- The last feature is a reason of rapidly growing popularity of gas fuel in the world.
- The above mentioned features of LPG also give the possibility to applying this fuel to compression ignition engines with relatively low- compression ratio as the heating value of stoichiometric mixture of diesel oil and air is similar to the heating value of LPG–air mixture and it gives the possibility to obtain the same power output from the engine fueled with diesel oil and LPG.
- Also, the high octane number allows compressing of the propane–butane with air in CI engines with low-compression ratio without apprehension of self-ignition appearance and enables non knocking combustion of the mixture.
- This is in addition to improved exhaust gas composition and lower cost per energy unit from LPG in comparison with diesel oil.

LPG Production

- LPG is formed naturally, interspersed with deposits of petroleum and natural gas.
- Natural gas contains LPG, water vapor, and other impurities that must be removed before it can be transported in pipelines as a salable product.
- LPG can be produced from natural gas purification or from crude oil refining.
- It consists of hydrocarbons that are vapors, rather than liquids, at normal temperatures and pressures, but that turn to liquid at moderate pressures; its main constituent is propane, and it is sometimes referred to by that name.

Natural gas and Oil extraction

- When natural gas and crude oil are drawn from the earth, a mixture of several different gases and liquids are in fact extracted, with LPG typically accounting for roughly 5% of the whole. Before natural gas and oil can be transported or used, the gases that make up LPG, which are slightly heavier than methane, are separated out.

Crude Oil refining

- The process of refining oil is complex and involves many stages. LPG is produced from oil at several of these stages including atmospheric distillation, reforming, cracking, and others. It is produced because the gases of which it is composed (butane and propane) are trapped inside the crude oil. In order to stabilize the crude oil before pipeline or tanker distribution, these "associated" or natural gases are further processed into LPG.

Properties of LPG

- While LPG is stored as a liquefied gas under pressure at ambient temperature, it is usually used in the liquid form for internal combustion engines, being directly injected into the engine by the fuel injection system.
- The term "LPG" covers a range of mixtures of propane and butane stored as liquids under pressure, but it is propane that is mostly used to fuel vehicles.
- An LPG-derived refinery can differ from its refinery counterpart. However, whether refinery or natural gas origin, a mixture of liquefied saturated and unsaturated hydrocarbons in the range of C3–C4 is considered boiling.

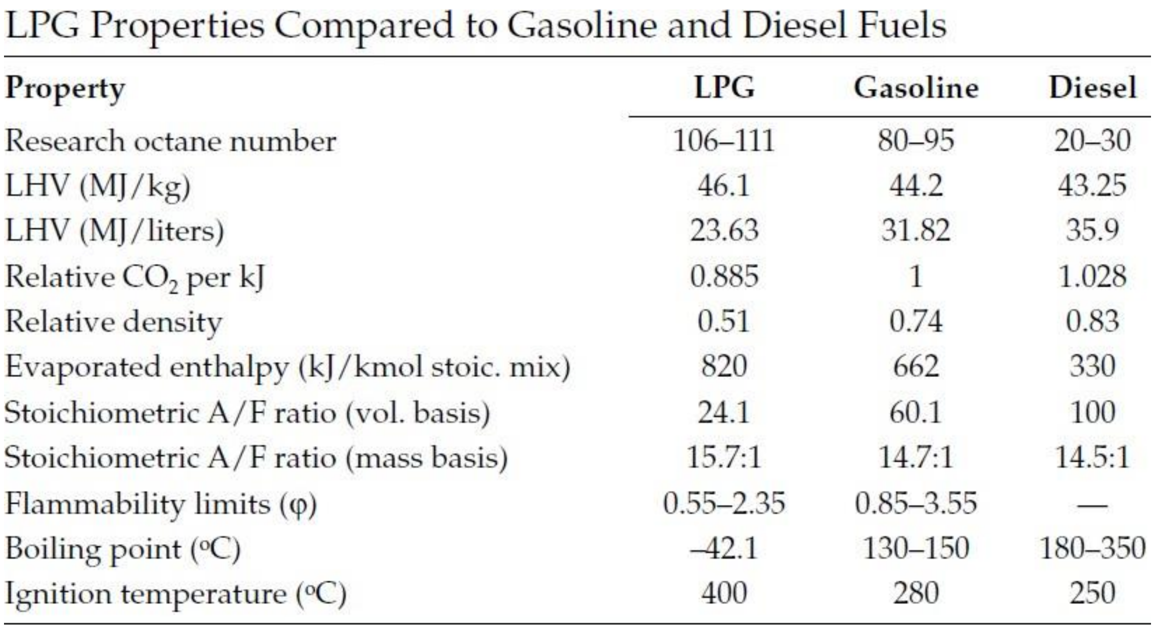
Commercially, LPG is sold to domestic and industrial customers in four grades

1) LPG propane consisting mainly of propane and/or propylene
2) LPG butane consisting mainly of n-butane, isobutene, and/or butylenes
3) LPG mixture consisting of C3 and C4 hydrocarbons
4) High purity propane containing about 95% propane

- LPG and petrol have many similar properties and the good practices appropriate for work on petrol vehicles apply equally to LPG vehicles.
- The viscosity of liquid LPG (0.15 centi Poise at 15.6ºC) is much lower than water (1 centi Poise). The value for LPG vapor at atmospheric pressure of 15.5ºC is about 0.08 centi Poise.
- The flash point of propane is very low, in line with its very low freezing and boiling points. The autoignition temperature of propane is nearly twice as high as that of gasoline providing more safety when exposed to hot surfaces.
- The stoichiometric air–fuel ratio for propane is only slightly higher than that of gasoline. As liquid, propane is about 68% of the weight of gasoline.
- Its boiling point is very low, which is typical of lower molecular weight hydrocarbons.
- Its vapor pressure is much higher than that of gasoline at 100ºF.

- The net calorific value of LPG on mass basis is higher but its net calorific value on volume basis lower than that of gasoline and diesel.
- The main difference is that LPG vaporizes more rapidly than petrol, so, as LPG is stored in the fuel tank and associated fuel lines at elevated pressure (up to 10 bar g), any leakage will immediately vaporize and disperse.
- LPG vapor is highly flammable and mixtures in air of between 2 and 10% will readily ignite and explode.
- The rapid expansion resulting from the conversion of liquid propane into a vapor causes severe cooling of the gas. Anyone exposed to a vapor cloud or in contact with metal surfaces may receive cold burns.
- LP gases are 1.5–2 times heavier than air. Leaking LPG will sink to ground level rather than rise to the atmosphere whereas natural gas or hydrogen goes up.
- The octane rating of propane is higher than that of gasoline. Hence, higher compression ratios engines can be used to take advantage of the higher octane number.
- The sulfur content in the LPG is much lower than gasoline and has an advantage of low-sulfur emissions and improved catalyst efficiency.

Table 4.1



LPG Properties Compared to Gasoline and Diesel Fuels

Property	LPG	Gasoline	Diesel
Research octane number	106–111	80–95	20–30
LHV (MJ/kg)	46.1	44.2	43.25
LHV (MJ/liters)	23.63	31.82	35.9
Relative CO_2 per kJ	0.885	1	1.028
Relative density	0.51	0.74	0.83
Evaporated enthalpy (kJ/kmol stoic. mix)	820	662	330
Stoichiometric A/F ratio (vol. basis)	24.1	60.1	100
Stoichiometric A/F ratio (mass basis)	15.7:1	14.7:1	14.5:1
Flammability limits (φ)	0.55–2.35	0.85–3.55	—
Boiling point (°C)	–42.1	130–150	180–350
Ignition temperature (°C)	400	280	250

Engine Tests

- LPG is commonly used in both types of engines. The gasoline engines can be equipped with retrofit devices that enable them to run on LPG as well as gasoline.
- The gasoline engines can be converted to dedicated LPG fueled engines.

- In both cases, vehicles have similar characteristics in terms of fuel system and storage systems.
- In diesel engines dual fuel mode operation, LPG is inducted into the engine as a mixture of LPG + air.

What is an LPG Conversion?

- An LPG conversion is taking a normal petrol powered vehicle and adding a secondary LPG vehicle fuel system.
- Almost all vehicles fuelled by petrol are convertible to LPG vehicle operation at a reasonable cost.
- These dual-fuel LPG systems allow an LPG vehicle to operate on either LPG or petrol.
- The petrol tank still remains in the LPG vehicle.
- The driver can switch from gas to petrol or vice-versa.
- The driver is typically provided with a switch and can select which fuel they choose to use.
- Having two fuel tanks can double an LPG vehicle's range.
- With both the petrol and LPG tanks filled, dual fuel LPG vehicle cruising ranges of 1000km or more are not unusual.

Advantages of LPG Engines

- Autogas engines have lower running costs.
- LPG is typically less expensive than petrol or diesel.
- Engine oil and spark plugs need changing less often with LPG vehicles, for reduced service costs.
- Environmental benefits of LPG vehicles include reduced particulate, CO2 and NOx emissions.
- Octane ratings over 100 allows for higher compression ratios, which can increase power output.

Four Types of LPG Vehicle Intake Systems

1. LPG Converter-and-Mixer Systems

- Converter-and-mixer systems are the oldest style, dating back decades and still widely used.
- The liquid fuel converts into vapour and is then mixed with air before going into the intake manifold.

2. LPG Vapour Phase Injection (VPI)

- Vapour phase injection (VPI) systems use a converter-and-mixer system.
- The gas exits the converter under pressure and is injected into the intake manifold.
- Electrically controlled injectors improve the metering of fuel to the engine, fuel economy and power, and reduce emissions.
- This has been the most popular type of LPG vehicle system in recent years.

3. LPG Liquid Phase Injection (LPI)

- Liquid phase injection (LPI) systems inject liquid directly into the intake manifold.
- That is where it vaporises, not using a converter.
- The system works by pumping LPG at high pressure from the LPG vehicle tank to the engine inlet manifold via a set of liquid LPG injectors.
- The injectors spray the liquid LPG into the intake manifold.
- The fuel vaporising in the intake manifold cools and increases the density of the intake air.
- This substantially increases power output, improves fuel economy and has lower emission, when compared to VPI systems.

4. LPG Liquid Phase Direct Injection (LPDI)

- Liquid phase direct injection (LPDI) are the most advanced systems.
- Liquid LPG is injected directly into the combustion chamber.
- The LPG instantly vaporises, cooling the combustion chamber fuel-air mixture during the compression stroke.
- This provides further performance and emission improvements.
- This cooling effect increases the density of the air-fuel mixture.
- So, power and torque are maintained with fewer CO_2 emissions.
- The effect is like intercooling on turbocharged cars.
- An Electronic Control Unit (ECU) controls the various components of the liquid injection system, including the injectors.
- LPG injection signal optimises the flow and LPG injection timing.
- The ECU is calibrated to the specific vehicle and engine

Environmental Benefits of LPG Vehicle Engines

- Using LPG in vehicles creates appreciably less carbon dioxide (CO_2) than unleaded petrol.
- CO_2 is the primary greenhouse gas causing long term climate change.
- When examined from a “Well to Wheel” perspective, the CO_2 benefit is even greater
- This includes emissions associated with the processing and transportation, as well as

use.

- Diesel CO_2 emissions are 29.2% higher than LPG vehicles whilst petrol is 26.8% higher than LPG.
- LPG cars and LPG vehicles also produce 95% less ozone and smog causing NOx than diesel engines.
- The dirty black smoke that we see coming from diesel vehicles is fine particulate matter.
- These fine particles may be deeply inhaled into the lung, carrying with them a collection of hazardous compounds.
- Experts at the World Health Organisation (WHO) say diesel engine exhaust fumes are carcinogenic
- One of the key environmental advantages of LPG Autogas vehicles over diesel, as well as petrol, is the near-absence of particulate matter (PM) emissions.

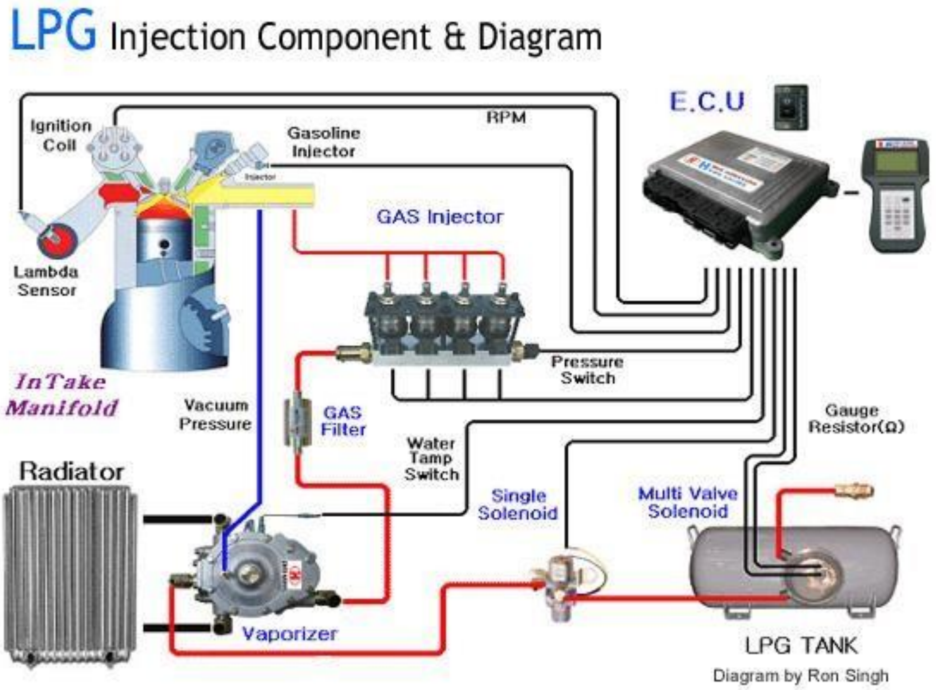


Fig 4.1

LPG in gasoline engine Applications

- LPG is an environmentally friendly fuel for SI engines that has potential emission advantages over gasoline. LPG is liquefied under pressure and compressed and stored in steel tanks under pressure that varies from 1.03 to 1.24 MPa.

Experience shows that LPG has some advantages over gasoline due to the following:

- LPG produces lower exhaust emissions than gasoline
- It reduces engine maintenance
- It offers faster cold starting
- It provides overall lower operational costs
  - On the other hand, LPG displaces 15–20% greater volume than gasoline. Thus the power output decreases by 5–10%. This reduction can reach up to 30% at very lean conditions.
  - Propane has lower density and stoichiometric fuel–air ratio than gasoline, and thus, it could reduce the specific fuel consumption and exhaust emissions.
  - propane can be used at higher compression ratios due to its higher octane number, and as a consequence of this property, engine performance; that is, engine power and thermal efficiency, would be improved.
  - The most important drawback of this fuel is that it reduces the engine volumetric efficiency and consequently the fresh charge mass, which is mainly due to its rising inlet temperature and its entering the intake system in the gaseous state. This problem can be removed by cooling; that is, offsetting the heat in the inlet manifold.
  - The maximum cylinder pressures and temperatures predicted for LPG are higher. This may cause some damages on engine structural elements.

LPG in Diesel engine Applications

- The use of LPG as a main fuel in diesel engines that uses the liquid diesel as a pilot fuel is also increasing worldwide.
- Gaseous fuels, namely LPG and CNG are recognized as clean fuels possessing significant environmental benefits compared to conventional liquid fuels as well as their relatively increased availability at attractive prices.
- In dual fuel engines, gaseous fuel is usually inducted with the intake air through the inlet manifold. They are mixed and compressed as in a conventional diesel engine. A small amount of liquid diesel fuel, called the pilot, is injected near the end of the compression stroke, which initiates the combustion of the gas–air mixture. Diesel fuel autoignites and creates ignition sources for the surrounding gaseous fuel mixture.
- It has a high octane number and therefore it is suitable for engines with relatively high compressions ratios.

- Moreover, it mixes uniformly with air, resulting in efficient combustion and substantial reduction of emissions in the exhaust gas. Further, the exhaust smoke density of dual fuel engines is much lower than for diesel engines.

Some disadvantages of the two fuels currently prevent them from achieving widespread use.

- Gaseous fuel has a lower energy density relative to gasoline, so vehicles have to carry large gaseous fuel tanks in order to obtain acceptable mileage range.
- Large tanks occupy a lot of useful space and their additional weight requires significant power. The volume of gaseous fuels displaces some portion of intake air in the engine resulting in a loss of power and torque.

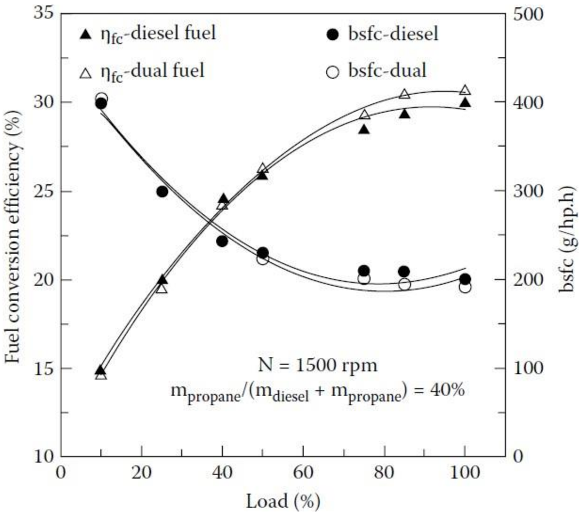


Fig 4.2

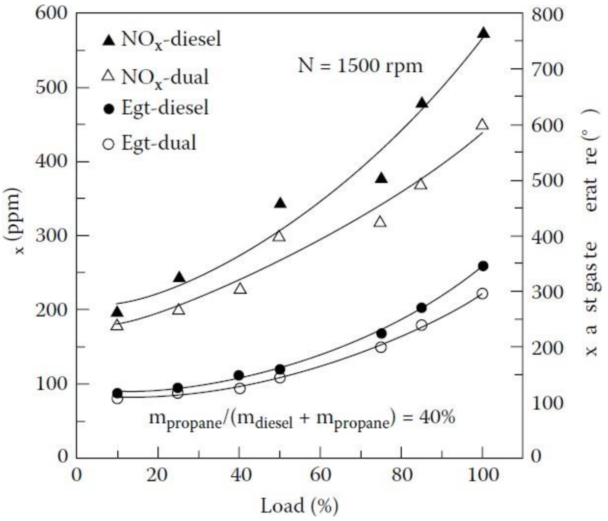


Fig 4.3

LPG Merits and Demerits

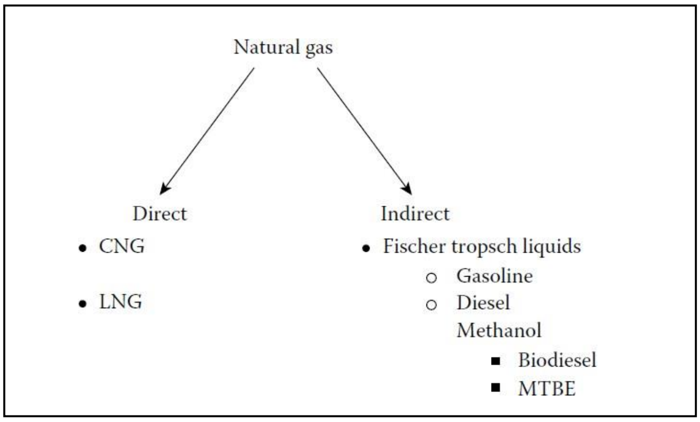
- LPG is made up of two major ingredients, namely propane and butane. The percentage of the two depends upon the season, as a higher percentage of propane is kept in winter and the same for butane in summer.
- It is a nonrenewable fossil fuel that is prepared in a liquid state under certain conditions.
- With more and more people buying vehicles running on LPG, most of the gas stations provide refueling systems for LPG-run cars.
- LPG turns out to be a lot cheaper and efficient in comparison to petrol and diesel. After petrol and diesel, LPG is the third most extensively used fuel for transportation over the world.
- The LPG-fitted cars are very popular in countries such as Japan, Italy, Canada, and Austria.
- Today, the LPG kits that are available in the market offer dual fueled or bi-fueled systems. Automatic and manual switching to LPG from petrol or diesel or vice versa is available.
- Using LPG increases the fuel efficiency of the vehicle as LPG has a high octane value.
- It causes less corrosion of the engine because less water is vaporized, however, not everybody is aware of the safety risks and conservation issues that surround it.
- Being a flammable gas, LPG is potentially hazardous.
- The major disadvantage of using LPG in a vehicle is that because it does not use lead or any other substitute for combustion, it damages the valves, resulting in a decrease of the life of the engine.
- Moreover, as it is a low-density energy fuel, in comparison to petrol or diesel, LPG is consumed more but because of the subsidized rates available, it proves to be a lot cheaper.
- Further, LPG is not recommended for mountains or any kind of rough terrain as it does not provide power and torque to the vehicle, as with other fuels.
- Using LPG means the vehicle drives 20% less than with other sources of fuel, resulting in more frequent refueling.
- In contrast to petrol or diesel vehicles, starting is always a problem with LPG driven vehicles under 32ºF (cold conditions), because at lower temperatures it has a lower vapor pressure.

- It is considered to be eco-friendly as it reduces the emission of carbon dioxide by more than 40%.
- The use of LPG in cars is growing day by day, so in future a gradual increase in its consumption can be seen.
- Also the lack of many refilling stations is another drawback that needs to be improved in future with the availability of the fuel itself.
- The other disadvantage is that a small amount of trunk space of the vehicle may be lost in order to make room for the LPG tank.

Natural Gas

- Compressed Natural Gas (CNG) was successfully applied to over 1,000,000 vehicles in many parts of the world such as Argentina, Russia, and Italy and is gaining increasing acceptance particularly for transport vehicles such as taxis, buses, and garbage tippers.
- Natural gas is a natural hydrocarbon energy formed in the earth's crust by millions of years of biological action on organic matter. It occurs along with oil deep in the earth's crust and is recovered from wells under very high pressure.
- Natural gas is difficult to store or transport because of its physical nature and needs high pressures and/ or low temperatures to increase the bulk density, whereas oil is readily stored in large, relatively simple, and cheap tanks and then transported in huge tankers.
- Natural gas reaches the public for use for transportation through pipelines, liquefied natural gas (LNG), gas to liquids (GTL), converted as electricity, CNG, and in metal hydrates
- Natural gas can be utilized for transport or automotive purposes in two ways: Direct and indirect applications. The applications of NG are depicted in Figure

Applications of natural gas.

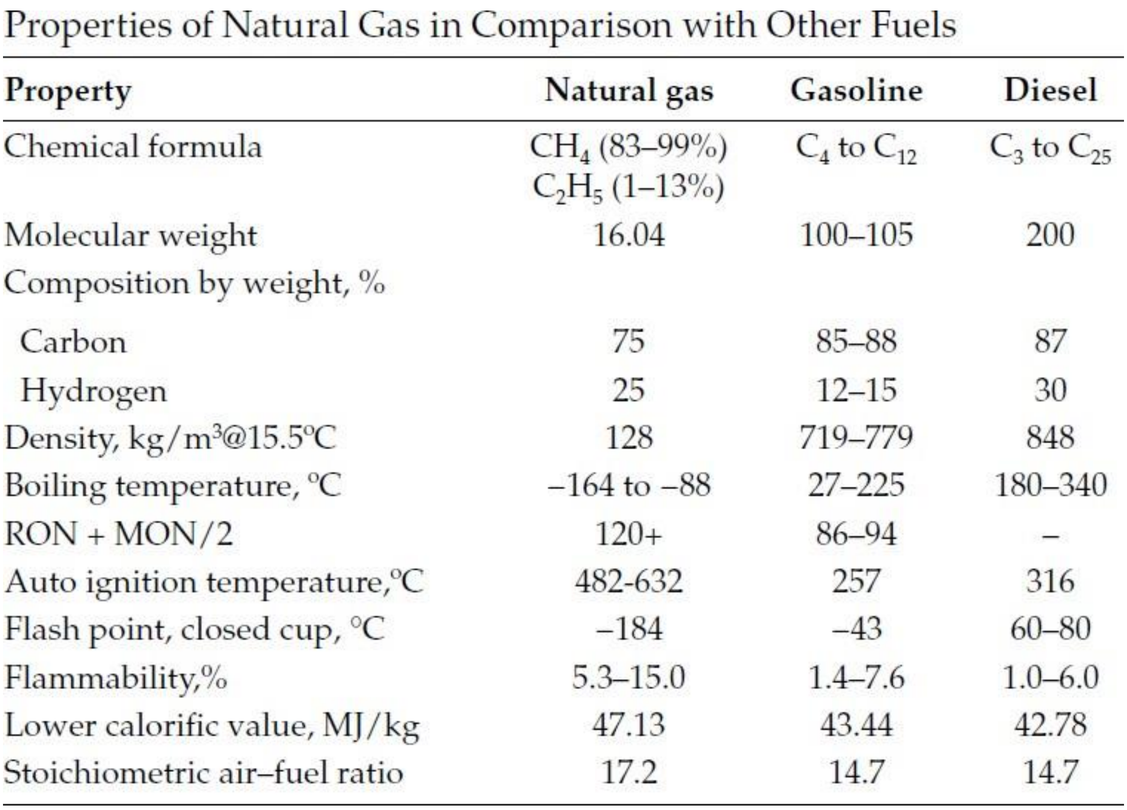


Natural Gas Properties

- Natural gas is composed primarily of methane (CH_4; > 80%) but has other HC compounds in small amounts (e.g., propane, butanes, and pentanes).
- It is a cleaner burning fuel than that of gasoline and diesel as they are more complex mixers of HC and other compounds.
- However, NG also contains active compounds, such as sulfur, and inert compounds such as nitrogen and CO_2.
- Excess amounts of higher hydrocarbons must be removed to prevent them from condensing under the high pressures in the gas transmission network.
- These hydrocarbons are valuable feedstock for gasoline/LPG production. The mixer of minor components varies from plant to plant depending on the source and processing of gas.
- In order to ensure consistent combustion behavior natural gas specification limits the percentage of propane, butane, and higher hydrocarbons, and the heating value by volume
- Natural gas is in gaseous state and its low boiling point presents problems in storage.
- Natural gas is stored in cylinders in CNG at high pressure in the range of 15–25 bar or as a liquid at very low temperatures (–170ºC and 70–210 bar) usually called LNG. The properties of CNG in comparison with other fuels are shown in Table
- Natural gas is high-octane fuel (>100 octane number), which is more suitable for spark ignition engines or specially designed gas engines with higher compression ratios.
- Typical compression ratios for gas engines are in the range of 10:1–13:1. At higher compression ratios, higher thermal efficiencies can be achieved.
- Due to its low-cetane number, in general, for satisfactory use in a diesel cycle engine it must be used in conjunction with a high-cetane fuel to provide ignition in dual fuel mode operation.
- Natural gas has a very high-autoignition temperature than that of gasoline/ diesel. CNG is likely to be safer than gasoline or diesel, since its low density, high-ignition temperature (540ºC) and high-flammability limits give the gas a high-dispersal rate and make it less likely to ignite.
- The minimum spark energy required for methane ignition is much higher than that required for other petroleum products.

- Hence, NG engines require high-performance ignition systems that can generate more than three times the energy required by gasoline engines (30–40 mJ).
- It also has a wider flammability range that allows the engine to operate lean mixtures also.
- However, there is a marginal reduction in engine performance as the gas enters the engine through the intake manifold—it reduces the engine volumetric efficiency.
- Moreover, methane combustion is very slow in nature

Table 4.2



Properties of Natural Gas in Comparison with Other Fuels

Property	Natural gas	Gasoline	Diesel
Chemical formula	CH_4 (83–99%) C_2H_5 (1–13%)	C_4 to C_{12}	C_3 to C_{25}
Molecular weight	16.04	100–105	200
Composition by weight, %			
Carbon	75	85–88	87
Hydrogen	25	12–15	30
Density, kg/m^3@15.5°C	128	719–779	848
Boiling temperature, °C	−164 to −88	27–225	180–340
RON + MON/2	120+	86–94	–
Auto ignition temperature,°C	482-632	257	316
Flash point, closed cup, °C	−184	−43	60–80
Flammability,%	5.3–15.0	1.4–7.6	1.0–6.0
Lower calorific value, MJ/kg	47.13	43.44	42.78
Stoichiometric air–fuel ratio	17.2	14.7	14.7

- Natural gas provides mass heating values around 10% higher than conventional fuels. But lower-calorific values as compared to liquid fuel on a volume basis.
- The calorific value of gas reduces with increasing inert gas compounds. The stoichiometric ratio of gas varies from 14 to 17 depending on the gas.
- Natural gas contains 75% carbon by weight whereas gasoline/diesel fuels have 86–88%, hence less CO_2 emissions with NG.
- Moreover, under rich-mixture conditions, CO is lower for methane than conventional fuels. As the combustion reaction is slow with NGs, it reduces the NO_x emissions as well.

CNG Storage

- Natural gas is used in automobiles; hence it is necessary to store the NG in compact form in order to reduce the weight of the vehicle.
- There are four types of vehicles in the market: dedicated fuel systems, dual-fuel modes, after-market conversions, and hybrid electric systems. Storage systems for these of vehicles are classified into three types: liquefied gas, compressed gas, and adsorbed gas.
- **Liquefied gas systems** are generally used for storing NG for long hauling vehicles like trains, buses, and trucks.
- For passenger cars, NG is stored in cylinders in compressed form. Natural gas is **compressed to about 200 bar** and is stored in cylinders of capacity ranging from 20 to 100 liters.
- However, regulations require that cylinders to be capable of handling pressures of 600 bar in case of accidental exposure to fire.
- Cylindrical and conformable shaped storage tanks are used for storing the CNG. Conformable shaped tanks are preferred for on board storage of CNG
- The low-energy density of CNG also causes storage problems onboard vehicles, along with the issue of heavy pressurized storage cylinders necessary to store the gaseous fuel.
- Cylinders are made of steel, high-strength aluminum, aluminum wound with fiberglass, or resin composites of glass or carbon fiber.
- **Adsorbent NG** is the latest technology to store natural gas. Activated charcoal or metallic oxides are used as storage materials. The advantages of adsorbent technologies include mass storage capacity and use of lower pressures (30–40 bar). This reduces the costs associated with compression and storage
- Among the various options to store natural gas, storing NG in compressed gas cylinders is preferred by the automotive industry because of its space optimization in vehicles and to use the existing infrastructure.

CNG Safety

- Compressed natural gas has some excellent physical, chemical, and combustion characteristics that make it a safe engine fuel.
- The safety aspects of CNG fueled engine operations are generally superior to those of engines fueled with conventional fuels such as gasoline or other alternative fuels.

- Natural gas or methane is a nontoxic gas that is lighter than air. This means that it will not puddle (like gasoline) or sink to the ground like propane, which is heavier than air. Instead, NG will rise and dissipate in the atmosphere
- Natural gas is compressed and stored in metallic cylinders. The safety of the cylinders depends upon its strength and the conductive nature of metallic cylinders.
- Fuel tanks/cylinders must meet all the safety regulations in the country of use and be tested at regular intervals. All fuel tubes, connectors, pressure switches, indicators, regulators, and so on, and associated equipment must also be of appropriate design and should comply with safety regulations.
- NG should be free from impurities like sulfur and water and so on, or have acceptable levels of purity.
- Presence of water may cause tank corrosion problems and reduce the strength of the material.
- Heating of gas cylinders would increase the pressure inside the cylinder. If the increase in pressure is very high, it may cause an explosion of the cylinder if the pressure relief valve is not functioning.
- Currently, cylinders are made of special materials that at high pressures will not fragment, instead a crack will develop and release the gas very slowly.
- Natural gas has a relatively high flammability limit as compared to the other fuels. For continuous flame propagation, natural gas requires a minimum of 5% by volume as compared to around merely 2% for propane and 1% for gasoline vapor. Hence, it is safer than other conventional fuels.
- The dispersion rate of methane is much higher than gasoline. Hence, if there is any leakage of CNG from cylinders, gas will be discharged at a very high velocity jet into the surrounding area, aiding greatly in the rapid dispersion of fuel
- CNG has a higher autoignition temperature than gasoline.
- The minimum energy required for ignition of a fuel–air mixture within the flammability range is relatively high for methane gas mixtures.
- CNG powered vehicles stored in domestic garages present a risk of explosion. Small leaks of CNG will tend to rise toward the roof-space of a garage, as the density of CNG is only 60% of that of air. Thus a small leak will accumulate by the fluorescence light fitting, and this may present a source of ignition.

- For domestic CNG powered vehicles, it would be prudent either to park the vehicle outside at all times, or to make sure that the garage is ventilated at both low and high levels to ensure adequate natural ventilation.

Engine Tests

- CNG can be used in engines as sole fuel or bi-fuel operation.
- Bi-fuel engines are Otto cycle (spark ignited) that run on *either* NG *or* gasoline. The gasoline vehicles can be converted for CNG/gasoline operation; that is, the engine uses either CNG or gasoline for its operation.
- Dedicated NG engines are Otto cycle (spark ignited); that is, operated only on NG. They tend to be optimized; that is, they have a compression ratio designed to take advantage of the 130 octane of NG, and have been designed to take into consideration the combustion characteristics of the fuel so that the engine is very low polluting.

Natural gas in SI engines

- Engine is operated separately either with gasoline or CNG using an electronically controlled solenoid actuated valve system. CNG was stored under a maximum pressure of 200 bars.
- Before entering into the carburetor, CNG passes through the three-stage conversion kit. The conversion kit supplies CNG to the engine carburetor at approximately atmospheric pressure (~0.8 bar).

The CNG operation increases NO_x emissions by 33% and reduces the HC emissions by 50%. Moreover, CNG produced much less concentration of CO (80%) and CO_2 (20%) emissions compared to gasoline.

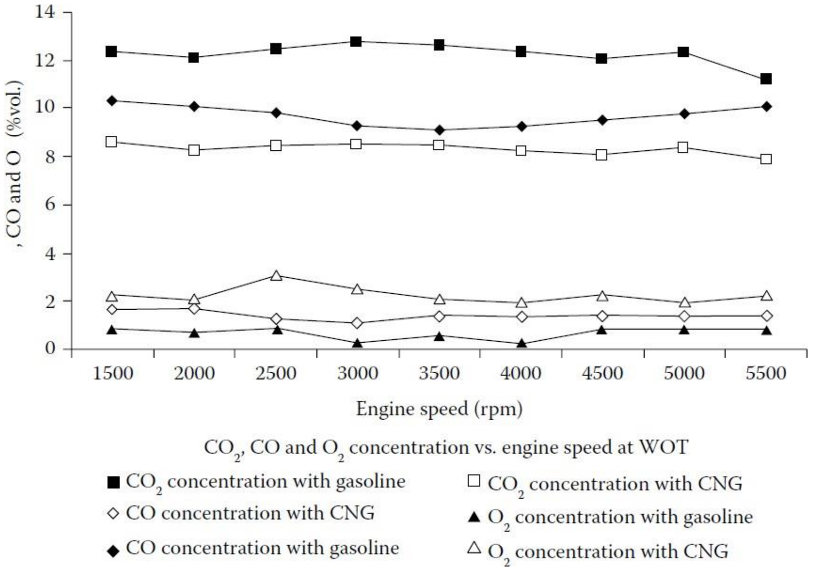


Fig 4.4

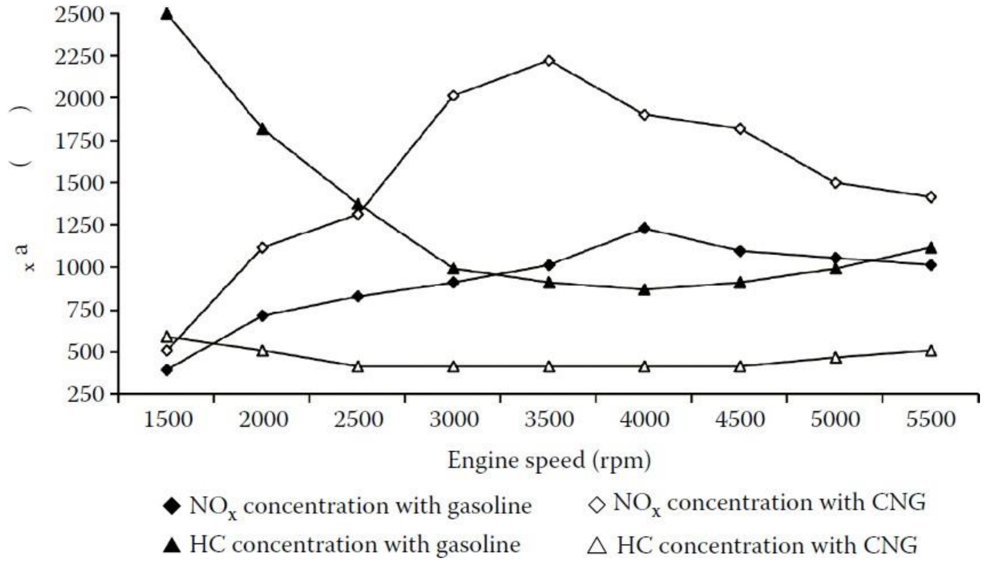


Fig 4.5

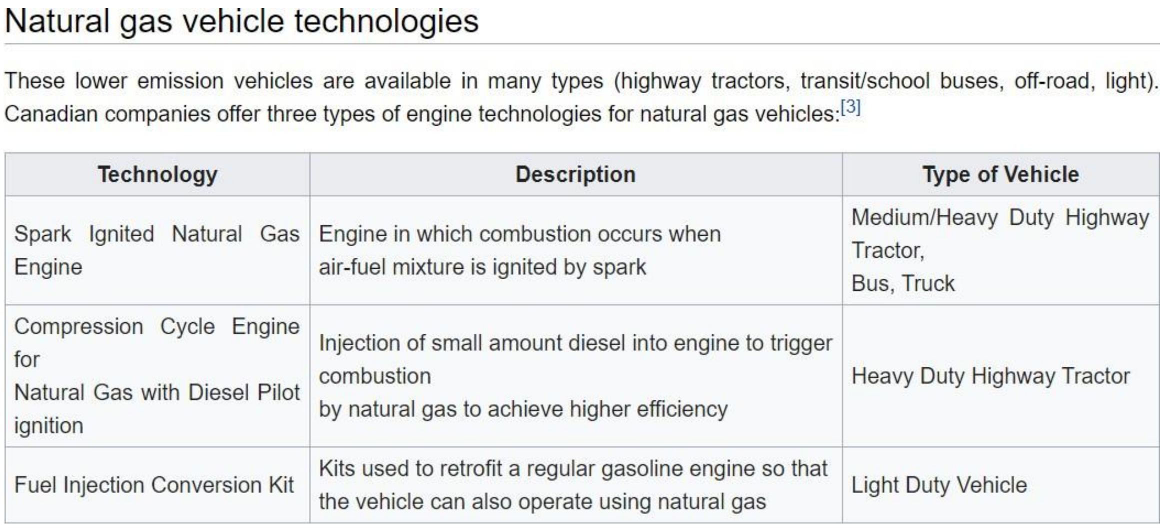
Natural gas in CI engines

- Dual fuel NG engines are based upon diesel technology. Diesel engines can be converted as dual-fuel engines, in that diesel is injected through the injectors and NG is carbureted along with fresh intake air and enters into the engine through the intake manifold.
- These engines also can operate on 100% diesel fuel. When the engine runs at idle, it tends to operate on 100% diesel.
- As the vehicle begins to move to full load performance, an increasing amount of NG replaces the diesel fuel to 80% or more. Dual-fuel NG replaces 80–90% diesel that reduces about 25% CO2.
- Natural gas is injected into the combustion chamber shortly before the end of the compression stroke, a diesel pilot that precedes the NG injection provides the ignition source.
- Varying the fuel composition has a significant impact on emissions. The influence of fuel composition varies strongly with combustion timing.

How Do Natural Gas Vehicles Work?

- Compressed natural gas (CNG) vehicles operate much like gasoline-powered vehicles with spark-ignited internal combustion engines.
- Natural gas is stored in a fuel tank, or cylinder, typically at the back of the vehicle. The CNG fuel system transfers high-pressure gas from the fuel tank through the fuel lines, where a pressure regulator reduces the pressure to a level compatible with the engine fuel injection system. Finally, the fuel is introduced into the intake manifold or

combustion chamber, where it is mixed with air and then compressed and ignited by a spark plug



Natural gas vehicle technologies

These lower emission vehicles are available in many types (highway tractors, transit/school buses, off-road, light). Canadian companies offer three types of engine technologies for natural gas vehicles:[3]

Technology	Description	Type of Vehicle
Spark Ignited Natural Gas Engine	Engine in which combustion occurs when air-fuel mixture is ignited by spark	Medium/Heavy Duty Highway Tractor, Bus, Truck
Compression Cycle Engine for Natural Gas with Diesel Pilot ignition	Injection of small amount diesel into engine to trigger combustion by natural gas to achieve higher efficiency	Heavy Duty Highway Tractor
Fuel Injection Conversion Kit	Kits used to retrofit a regular gasoline engine so that the vehicle can also operate using natural gas	Light Duty Vehicle

CNG Advantages

1. **Environmental**: CNG vehicles produce far less of all regulated pollutants compared to gasoline or diesel vehicles, including NOx and particulate matter. Natural gas has a low C/H ratio and hence lower CO and HC emissions. CNG vehicles produce far less unregulated air toxics and greenhouse gases. Due to proper combustion of gas–air mixtures, reduced unburned HC emissions will reduce the environmental pollution of visible photochemical smoke.
2. **Energy security:** NG usage reduces the consumption of gasoline and diesel fuel.
3. **Operating cost:** NG is cheaper at the pump than gasoline and diesel fuel.
4. **Distribution efficiency/safety:** Natural gas has a higher ignition temperature than gasoline or diesel. Natural gas is lighter than air and hence disperses quickly in the event of leakage of fuel. This is the safest and most efficient energy distribution system. The explosive limit of NG–air mixtures is higher than diesel–air mixtures. For continuous flame propagation, NG requires a minimum of 5% by volume as compared to around merely 2% for propane and 1% for gasoline vapor. Hence, it is safer than other conventional fuels.
5. **Flexibility:** CNG vehicles can be produced as dedicated and bi-fuel versions. Dedicated vehicles are most appropriate where vehicles tend to operate in an area where NG fueling is available. Bi-fuel vehicles have both NG and gasoline storage tanks on board, can operate on either fuel at the flip of a switch. Bi-fuel vehicles are

most appropriate where the driver may need to travel to areas not currently served by NG stations. Compared to other fuels it is also economical and environmentally friendly.

Challenges for CNG

1. **Fueling:** NG refueling process is slow. Low-volumetric efficiency of engine and low-energy density result in low-engine performance.
2. **Vehicle cost:** NG vehicles cost more than comparable gasoline or diesel models because of its low-production volumes and the greater cost of fuel storage tanks
3. **Driving range:** Compared to a volumetric gallon of gasoline or diesel fuel, there is less energy in an energy gallon equivalent of NG (both CNG and LNG). Therefore, the driving range of vehicles operating on NG is less. Natural gas vehicles need pressurized fuel storage tanks. The present storage capacity has a range of about 150 km.
4. On-board NG fuel tanks are larger than comparable gasoline or diesel fuel tanks. There are inconsistent NG fuel properties around the world.

Introduction to Biogas Technology

Biogas : It's a mixture of gas produced by the microorganisms during the anaerobic fermentation of biodegradable materials. Anaerobic fermentation is a biochemical process in which particular kinds of bacteria digest biomass in an oxygen-free environment resulting in production of CH4, CO2, H2 and traces of other gases along with decomposed mass.

Properties of Biogas: Biogas is a mixture of different components and the composition varies depending upon the characteristics of feed materials, amount of degradation, etc. Biogas predominantly consists of 50 to 70 per cent methane, 30 to 40 per cent carbon dioxide and low amount of other gases. Methane is a combustible gas. The energy content of biogas depends on the amount of methane it contains. Methane content varies from about 50 percent to 70 percent.

Microbiology of biogas production: The production of biogas from organic material under anaerobic condition involves sequence of microbial reactions. During the process complex organic molecule present in the biomass are broken down to sugar, alcohols, pesticides and amino acids by acid producing bacteria. The resultant products are then used to produce methane by another category of bacteria. The biogas production process involves three stages namely:

i. Hydrolysis
ii. Acid formation and
iii. Methane formation

The process of degradation of organic material in every step is done by range of bacteria, which are specialized in reduction of intermediate products formed. The different process involved in production of biogas is given in the figure. The efficiency of the digestion depends how far the digestion happens in these three stages. Better the digestion, shorter the retention time and efficient gas production.

Hydrolysis: The complex organic molecules like fats, starches and proteins which are water insoluble contained in cellulosic biomass are broken down into simple compounds with the help of enzymes secreted by bacteria. This stage is also known as polymer breakdown stage (polymer to monomer). The major end product is glucose which is a simple product.

Acid formation: The resultant product (monomers) obtained in hydrolysis stage serve as input for acid formation stage bacteria. Products produced in previous stage are fermented under anaerobic conditions to form different acids. The major products produced at the end of this stage are acetic acid, propionic acid, butyric acid and ethanol.

Methane formation: The acetic acid produced in the previous stages is converted into methane and carbon dioxide by a group of microorganism called “Methanogens”. In other words, it is process of production of methane by methanogens. They are obligatory anaerobic and very sensitive to environmental changes. Methanogens utilise the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. It is these components that make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pH’s and occurs between pH 6.5 and pH 8. Major reactions occurring in this stage is given below:

$CH_3COOH \longrightarrow CH_4 + CO_2$

Acetic acid Methane Carbon dioxide

$2CH_3CH_2OH \quad CO_2 \longrightarrow CH_4 + 2CH_3COOH$

Ethanol + Carbon dioxide Methane Acetic acid

$CO_2 + 4\,H_2 \longrightarrow CH_4 + 2\,H_2O$

Carbon dioxide Hydrogen Methane Water

The process of biogas formation through different stages is depicted in figure.

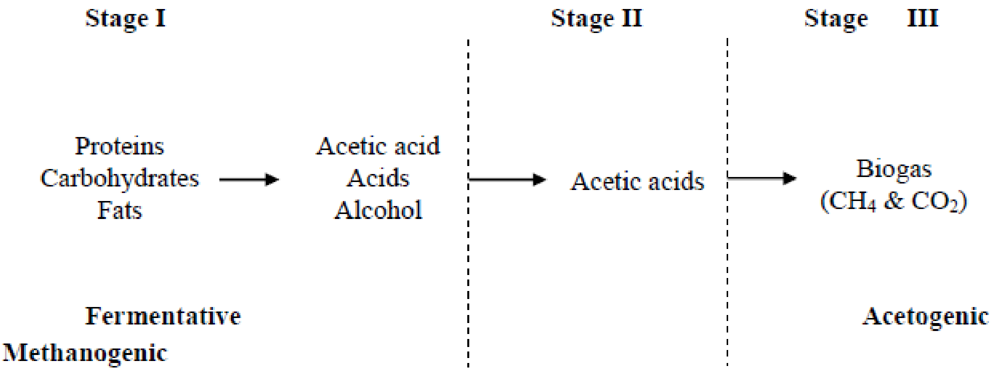


Figure: Stages of biogas formation

Fig 4.6

Biogas plant and its components:

A physical structure designed to carry out anaerobic digestion of organic materials is called "Biogas plant". Following are the components of biogas plants:

Mixing tank	:	Cow dung is collected from the shed and mixed with the water in equal proportion (1:1) to make a homogenous mixture (slurry) in the mixing tank
Feed inlet pipe/tank	:	The homogenous slurry is let into the digester through this inlet pipe (KVIC biogas plants)/tank (Janatha biogas plants)
Digester	:	The fed slurry is subjected to anaerobic fermentation with the help of microorganisms inside the digester.
Gas holder	:	As a result of anaerobic fermentation, gas produced is stored in gas holder (Drum in the case of KVIC and in dome in the case of fixed dome biogas plants)
Slurry outlet tank/pipe	:	The digested slurry is let out from the digester through slurry outlet pipe (KVIC biogas plants)/tank (Janatha biogas plants)
Gas outlet pipe	:	Stored gas is released and conveyed through the gas outlet pipe present at the top of gas holder.

Classification of biogas plants

Based on the nature of feeding, biogas plants would be broadly divided into 3 types and they are as follows

i. **Batch type:** The organic waste materials to be digested under anaerobic condition are charged only once into a reactor-digester. The feeding is between intervals, the plant is emptied once the process of digestion is complete. Retention time usually varies from 30 to 50 days. The gas production in it is intermittent. These plants are well suited for fibrous materials. This type of plant needs addition of fermented slurry to start the digestion process and it not economical to maintain which are considered to be the major draw backs.

ii. **Semi continuous:** A predetermined quantity of feed material mixed with water is charged into the digester from one side at specified interval of time; (say once a day) and the digested material (effluent) equivalent to the volume of the feed, flows out of the digester from the other side (outlet).

iii. **Continuous type:** The feed material is continuously charged to the digester with simultaneous discharge of the digested material (effluent). The main features of this type of plants are continuous gas production, requires small digestion area, lesser period for digestion, less maintenance, etc.

The biogas plants used in the villages are of semi continuous type employing animal dung and other biomass as the feed stock for biogas production. So the classification of semi-continuous type biogas plant is explained below.

i. Floating drum type – KVIC model
ii. Fixed dome type model – Deenbandhu model

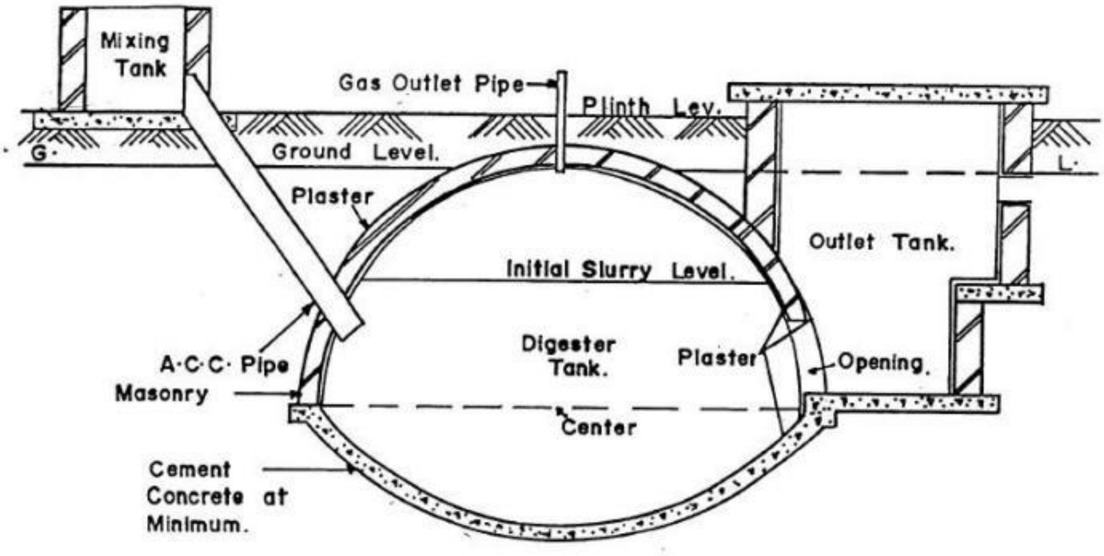


Fig 4.7 Fixed Dome Type

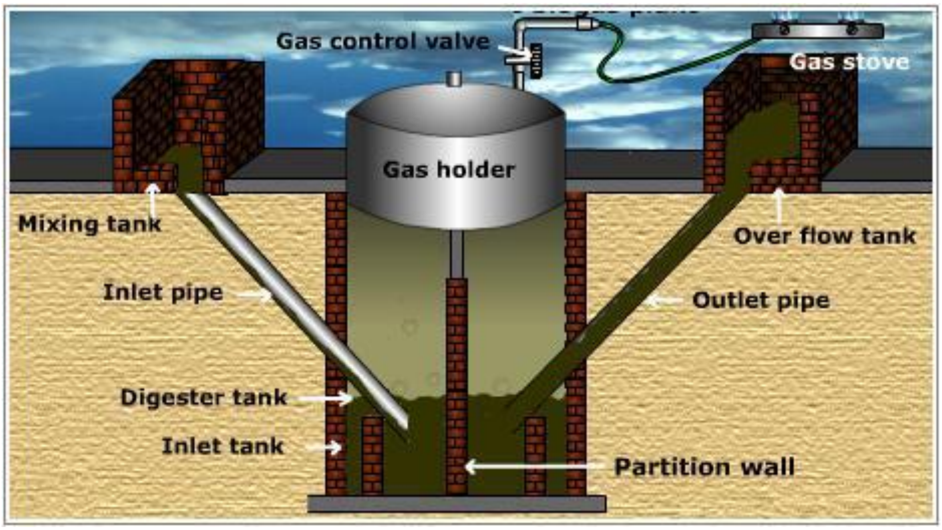


Fig 4.8 Floating Dome Type

Floating drum type (Constant pressure)

In this type of plants digester is made of bricks and is of circular in shape. It is constructed typically underground to lessen the heat loss from the plant. Partition wall is constructed (dividing the digester into two parts) for higher size capacity plants to avoid the short-circuiting of digested slurry with the fresh feed. Separate gasholder is fabricated and fixed to store the gas produced during digestion besides acting as an anaerobic seal for the process. As the volume of gas production increases drum starts to rise and if the stored gas is withdrawn the level of drum drops to lower level. Scum formed in the digester can be broken with the help of drum rotation both clockwise and anticlockwise. Central guide frame is provided to hold the gasholder and to allow it to move vertically during gas production. The drum is made up of mild steel and it constitutes around 60 per cent of overall plant costs. Salient features of this type of plants include weight of drum helps to discharge the gas produced at constant pressure, volume of gas storage can be judged visually.

Small masonry tanks are constructed for mixing of cow dung, water and to discharge the slurry out of the digester. Concrete pipes are provided to convey the raw and digested slurry in and out of the digester. Gas outlet pipe is provided at top of the drum to let the gas out of drum. KVIC floating drum model is predominantly used in India and fig shows the schematic diagram of it.

Advantages:

i. Higher gas production per cum of the digester volume is achieved.
ii. Floating drum has welded braces, which help in breaking the scum by rotation.
iii. No problem of gas leakage.

iv. Constant gas pressure.

Disadvantages

i. It has higher cost, as cost is dependent on steel and cement
ii. Heat is lost through the metal gasholder.
iii. Gasholder required painting once or twice a year, depending on the humidity of the location.
iv. Flexible pipe joining the gasholder to the main gas pipe requires maintenance, as ultraviolet rays in the sun damage it.

Fixed dome biogas plants (Constant volume)

To reduce the cost of biogas plants, researchers has designed fixed dome plants in which dome act as gasholder in place of high cost drum. Gasholder and digester constructed as single unit. The digesters of such plants are completely underground to maintain a perfect environment for anaerobic fermentation to take place besides avoiding cracking of dome due to difference in temperature and moisture.

Advantages

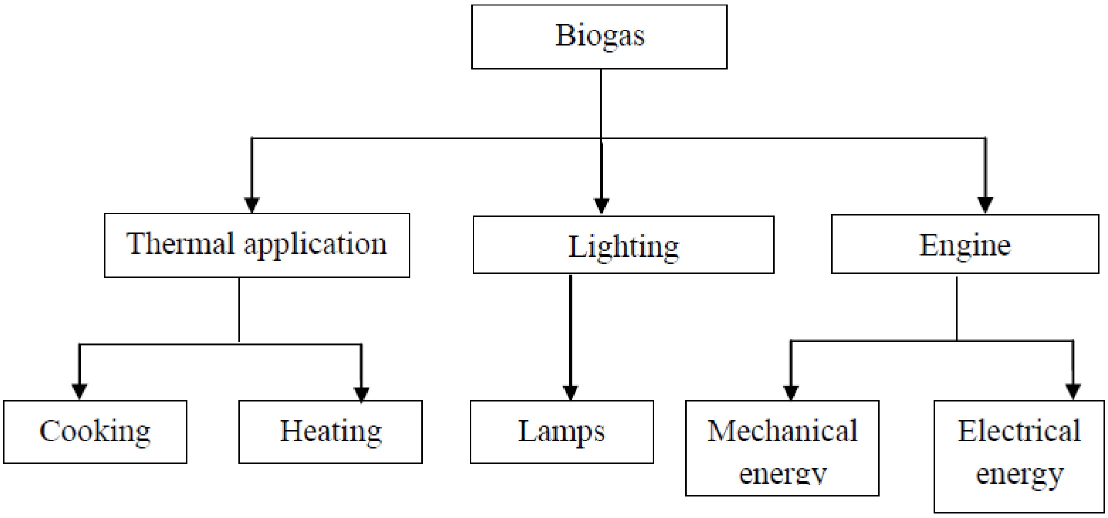
i. It has low cost compare to floating drum type, as it uses only cement and no steel.
ii. It has non-corrosion trouble.
iii. It this type heat insulation is better as construction is beneath the ground.
iv. Temperature will be constant.
v. Cattle and human excreta and long fibrous stalks can be fed.
vi. No maintenance.

Disadvantages:

i. This type of plant needs the services of skilled masons, who are rather scarce in rural areas.
ii. Gas production per cum of the digester volume is also less.
iii. Scum formation is a problem as no stirring arrangement
iv. It has variable gas pressure

Uses of biogas

Biogas serves as a suitable alternate fuel for satisfying the energy needs of human society. It can be used for production of power, for cooking, lighting, etc. Figure explains the flow chart of different applications of biogas.



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ELECTRIC VEHICLES

WHY ELECTRIC MOBILITY

- The world is transitioning to cleaner mobility options with the aim at improving air quality, reducing carbon emissions and reducing dependency on fossil fuels.
- By their virtue of being energy efficient and clean (zero or significantly lower tailpipe emissions), in comparison to similar Internal Combustion Engine Vehicles (ICEVs), EVs have emerged a popular clean mobility choice and have the potential to reduce carbon emissions and other criteria pollutants.
- As the EVs are powered fully or partially by batteries, they can also help reduce dependence on imported fossil fuels and address energy security concerns for India.

WHAT IS ELECTRIC VEHICLE

Electric Vehicles (EVs) use one or more electric motors or traction motors for propulsion. An electric vehicle may source its power from off-vehicle on-board battery, or other sources such as solar panels or electric generators. Based on the degree of electrification of the propulsion system, the EVs can be classified into

1) Battery Electric Vehicle (BEV)
2) Hybrid Electric Vehicle (HEV)
3) Plug-in Hybrid Electric Vehicle (PHEV)
4) Fuel Cell Electric Vehicle (FCEV))

1. Battery Electric Vehicle (BEV)

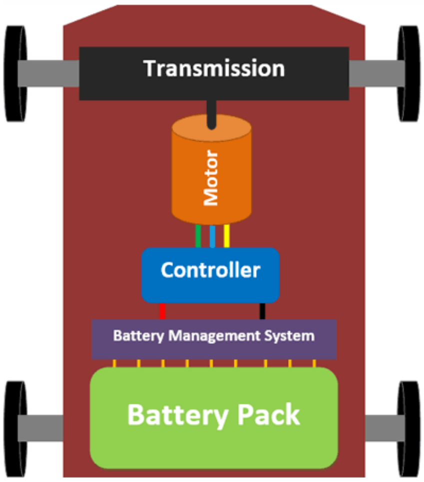

Fig 5.1

The Engine of a conventional IC Engine Car is replaced by an electrical Motor and the fuel tank is replaced by the Battery Pack. Of all the components only the Battery Pack and Motor alone contributes to about more than 50% of the total cars weight and the price.

Battery Pack, Battery Management System (BMS) Controller, Motor and the Transmission unit forms the major components in an EV.

EV Batteries

Batteries are the fuel source for Electric Cars. The complete battery anarchy consists of the Cell, Battery Module and Battery Pack.

Cell :

The cell refers to a single battery. There many different sizes and shapes for a cell based on the chemistry. Most commonly used chemistry is the **Lead-Acid Batteries and Lithium Batteries**. These batteries are available in many different shapes like cylindrical, Coin, Prismatic and Flat type few of which are shown below.

The voltage rating of the cells (per cell) will be anywhere from 3.7V for a lithium batteries and a maximum of 12V for Lead-Acid batteries. This voltage is not enough to run an electric car.

Battery Module

A single lithium cell voltage and Ah rating is not enough to drive an EV, so these cells are connected in series and parallel configuration to increase the resulting system voltage. This pack is called as a module.

Battery Pack

Once the system Voltage and Ah rating is obtained by combining various modules in series and parallel configuration this set-up should be placed inside the EV. So, once the battery modulus is ready it should be connected to the BMS and a cooling system for safe operation of battery. The complete set-up is kept in a steel casing to prevent mechanical damage. This complete arrangement along with the BMS, cooling system casing and the battery modules all together is called as a Battery Pack of a car.

Battery Management System (BMS)

- A BMS is like the brain or caretaker of batteries
- Every BMS measures only three vital parameters of the battery which are the Voltage, current and Temperate of the cell.
- It constantly compares these values with safety limits and disconnects the load if they exceed the threshold values.

- Apart from safety purpose the BMS is also used for some computational purpose, like measuring the SOC and SOH of a battery.
- **SOC** stands for **Sate of Charge** and SOH stands for **State of health**.
- **SOC** tells you how far you can drive before recharge and
- **SOH** tells you when it’s time to replace your batteries

Electric Vehicle Motors

- While batteries are the fuel tanks of an EV, the motors are the Engines of them. There are many types of Motors used in EV and the one used for Scooters and bikes is totally different form the one that is used in cars.
- Let’s have a quick look on the commonly used ones that are BLDC motors, Brushed DC motors and AC Induction Motor.

BLDC Motors:

- BLDC Motors have been the choice for EV’s from its origin in 1900. Even today it is commonly used in Electric cycles and scooters.
- stands for Brush Less DC motor, these motors have a constant torque and fast response making it suitable for automotive applications.
- Apart from EV’s these motors are also used in wipers, power windows etc.

The BLDC motor for EV can again be classified into the following two types

BLDC Hub Motors

- In BLDC Hub type motor, the rotor of the magnet is the wheel itself, meaning there is no need of coupling arrangement since the rim of the wheel forms the motor. These motors are also called as the BLDC out runner motor.
- Advantage of this type of motor is that there is less mechanical loss and since there is no transmission unit cost and weight is reduced. Downside is that we cannot have gear ratio of high power motors due to size limitations. A BLDC hub motor of scooter is shown below. Almost all electric cycles and scooters you find on road uses such type of motors.

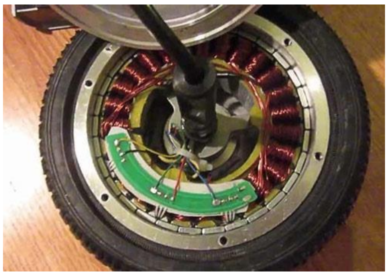

Fig 5.2

BLDC In-runner Motors:

Another type of BLDC motors are the In-runner types. They are used in applications where a transmission unit is required. They are normally coupled along with a differential for 3-wheeled or 4-wheeled EVs. These motors look like normal motors with a shaft and the shaft rotates when the motor is powered. An In-runner type Motor of an E-rickshaw coupled with differential is shown below.

Fig 5.3

Brushed DC motors:

- The Brushed DC motor also known as DC series motor was the preferable choice for all old Electric cars.
- These motors provide a lot of torque which could easily give a sporty feel to the EV. The pull/pick-up of the EV would be almost at par with an average conventional car that these motors were used by drag racers during then.
- But now after 2008, these motors are not much in use any longer the reason is DC motors cannot provide a constant torque under a varying load. Meaning cursing or climbing a hill with the car will be difficult.
- Also DC motors cannot start without a load that is it cannot self start due to its high initial current which might damage the motor itself. Today these motors are used in Golf carts commonly a picture of the same is shown below

Fig 5.4

AC Induction Motors:

- Most Modern day Electric cars like **the Tesla uses an AC Induction motor**. The Tesla model S for instance uses a 3-phase AC Induction Motor.
- The reason why these motors are selected is that they do not have permanent magnets within them and thus low cost. It also has good life since there are no magnets, magnets would lose their tendency in day course.
- The downside of the motor would be that it is hard to control the speed and torque of the motor and advanced circuitries are required.

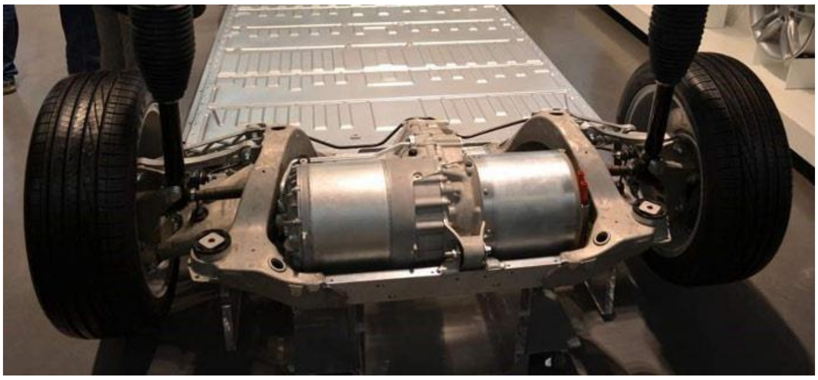

Fig 5.5

Controller

- From a basic bi-cycle till a *Tesla Roadster* every EV has its own controller that converts the DC voltage from the Battery to a suitable level for the Motors to run.
- It also controls the speed of the motor.
- The controller gets all the inputs from the user like the amount of throttle (acceleration), breaks pressure, driving mode etc and controls the speed of the motor accordingly. If motors are considered to the muscle of a car, controller is its brain.
- A controller is often a generic term and it might include other circuits like a DC-DC converter, Speed controller, Inverter etc.
- The DC-DC converter is used to power all the peripherals of the car like the infotainment system, Headlights and other low level electronic devices.
- Apart from this the controller also takes care of regenerative braking. It is the process of converting kinetic energy into electric energy.
- That is when the EV runs down a slope the motor are rotating freely due to the kinetic energy, at this situation the motors can be made to act as a generator so that the power thus obtained can be used to charge the batteries.

EV Chargers

- Another important component in an EV which requires advancement is the Chargers. An average E-Car takes a minimum of 5 hours to get charge that combined with its very low mileage becomes a disaster.
- It gets plugged into the AC mains and converts the AC to DC to charge the batteries. But there are more to add to it. Charging is a process in which the batteries and charger should coexist you cannot push current inside a battery if the battery is not ready to accept it.

2. The Hybrid Electric Vehicle (HEV)

- The term hybrid vehicle refers to a vehicle with at least two sources of power.
- A hybrid-electric vehicle indicates that one source of power is provided by an electric motor.
- The other source of motive power can come from a number of different technologies, but is typically provided by an internal combustion engine designed to run on either gasoline or diesel fuel.

This hybrid drivetrain concept can be implemented by different configurations as follows:

- Series configuration
- Parallel configuration
- Series-parallel configuration
- Complex configuration

- series hybrid is to couple the ICE with the generator to produce electricity for pure electric propulsion.
- parallel hybrid is to couple both the ICE and electric motor with the transmission via the same drive shaft to propel the vehicle
- Series-Parallel System configuration incorporates the features of both the series and parallel HEVs. However, this configuration needs an additional electric machine and a planetary gear unit making the control complex.
- The complex hybrid is similar to the series-parallel hybrid since the generator and electric motor is both electric machines. However, the key difference is due to the bi-directional power flow of the electric motor in complex hybrid and the unidirectional power flow of the generator in the series-parallel hybrid

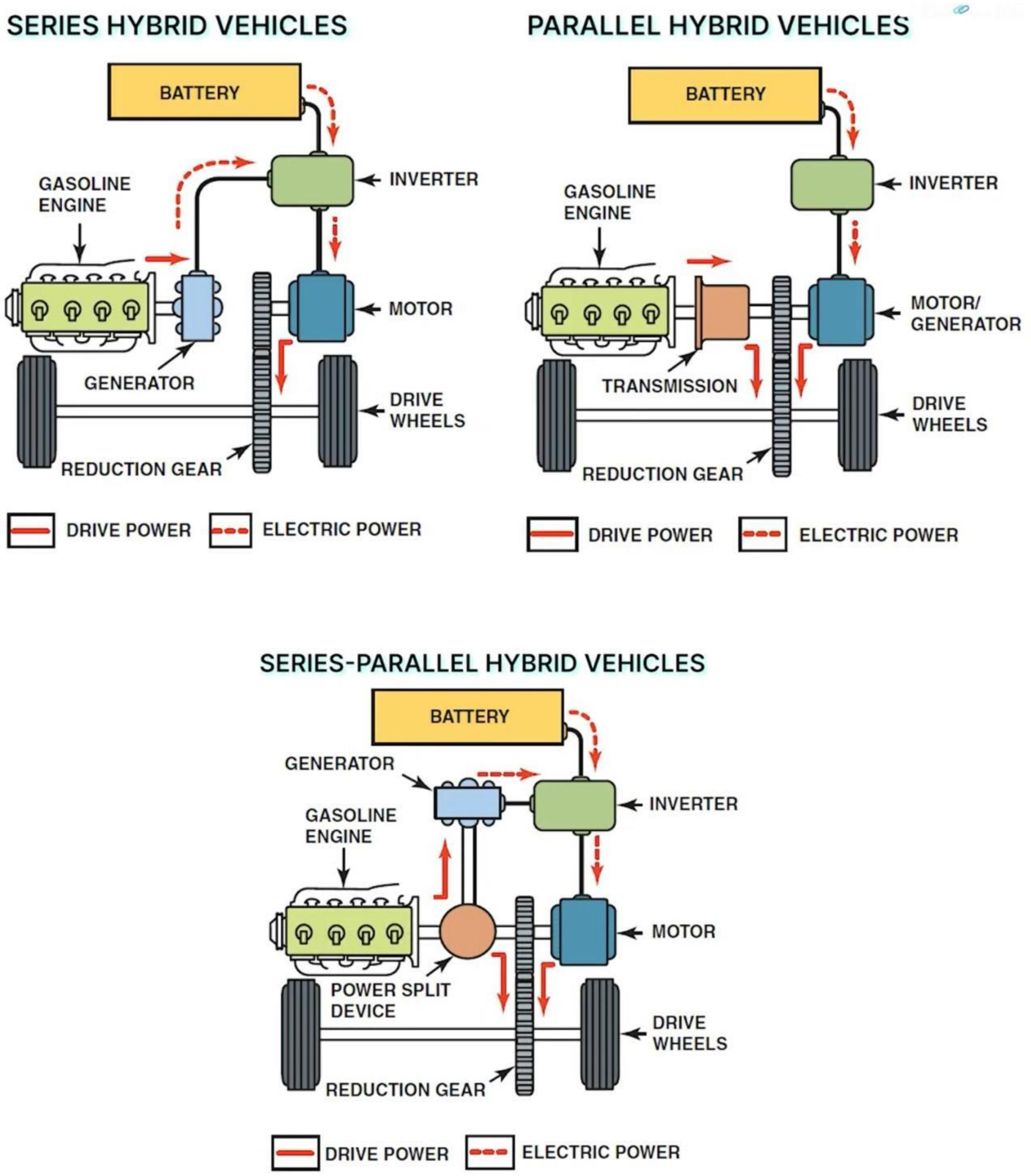

Fig 5.6

Series Hybrid System:

❖ In case of series hybrid system (Figure 4a) the mechanical output is first converted into electricity using a generator.

❖ The converted electricity either charges the battery or can bypass the battery to propel the wheels via the motor and mechanical transmission.

❖ Conceptually, it is an ICE assisted Electric Vehicle (EV). The advantages of series hybrid drivetrains are:

❑ mechanical decoupling between the ICE and driven wheels allows the IC engine operating at its very narrow optimal region

- ❑ nearly ideal torque-speed characteristics of electric motor make multi-gear transmission unnecessary.

However, a series hybrid drivetrain has the following disadvantages:

- ❑ the energy is converted twice (mechanical to electrical and then to mechanical) and this reduces the overall efficiency.
- ❑ Two electric machines are needed and a big traction motor is required because it is the only torque source of the driven wheels.
- ❑ The series hybrid drivetrain is used in heavy commercial vehicles, military vehicles and buses. The reason is that large vehicles have enough space for the bulky engine/generator system.

Parallel Hybrid System:

- ❖ The parallel HEV (Figure 4b) allows both ICE and electric motor (EM) to deliver power to drive the wheels.
- ❖ Since both the ICE and EM are coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by ICE alone, by EM only or by both ICE and EM.
- ❖ The EM can be used as a generator to charge the battery by regenerative braking or absorbing power from the ICE when its output is greater than that required to drive the wheels.
- ❖ The advantages of the parallel hybrid drivetrain are:
- ➢ both engine and electric motor directly supply torques to the driven wheels and no energy form conversion occurs, hence energy loss is less
- ➢ Compactness due to no need of the generator and smaller traction motor.

The drawbacks of parallel hybrid drivetrains are:

- ➢ Mechanical coupling between the engines and the driven wheels, thus the engine operating points cannot be fixed in a narrow speed region.
- ➢ The mechanical configuration and the control strategy are complex compared to series hybrid drivetrain.

Due to its compact characteristics, small vehicles use parallel configuration. Most passenger cars employ this configuration.

3. Plug-In Hybrid Electric Vehicle (PHEV)

- ❖ The PHEV concept arose to extend the all-electric range of HEVs .

- It uses both an ICE and an electrical power train, like a HEV, but the difference between them is that the PHEV uses electric propulsion as the main driving force, so these vehicles require a bigger battery capacity than HEVs.
- PHEVs start in ‘all electric’ mode, runs on electricity and when the batteries are low in charge, it calls on the ICE to provide a boost or to charge up the battery pack. The ICE is used here to extend the range.
- PHEVs can charge their batteries directly from the grid (which HEVs cannot); they also have the facility to utilize regenerative braking.
- PHEVs’ ability to run solely on electricity for most of the makes its carbon footprint smaller than the HEVs.
- They consume less fuel as well and thus reduce the associated cost.
- The vehicle market is now quite populated with these, Chevrolet Volt and Toyota Prius sales show their popularity as well.

4. Fuel Cell Electric Vehicle (FCEV)

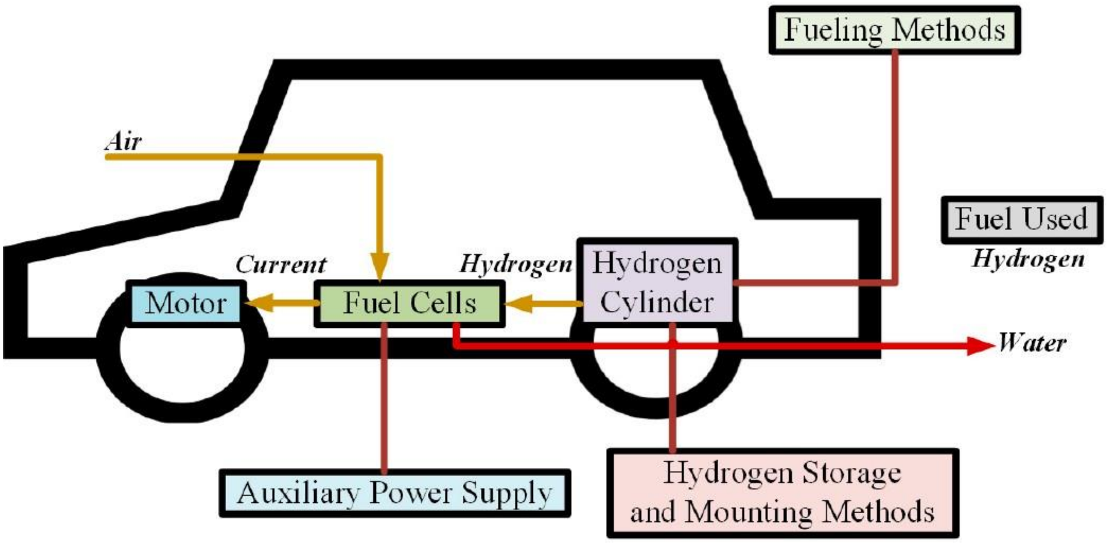

Fig 5.7

- FCEVs also go by the name Fuel Cell Vehicle (FCV). They got the name because the heart of such vehicles is fuel cells that use chemical reactions to produce electricity.
- Hydrogen is the fuel of choice for FCVs to carry out this reaction, so they are often called ‘hydrogen fuel cell vehicles’.
- FCVs carry the hydrogen in special high pressure tanks, another ingredient for the power generating process is oxygen, which it acquires from the air sucked in from the environment.

- Electricity generated from the fuel cells goes to an electric motor which drives the wheels. Excess energy is stored in storage systems like batteries or super capacitors

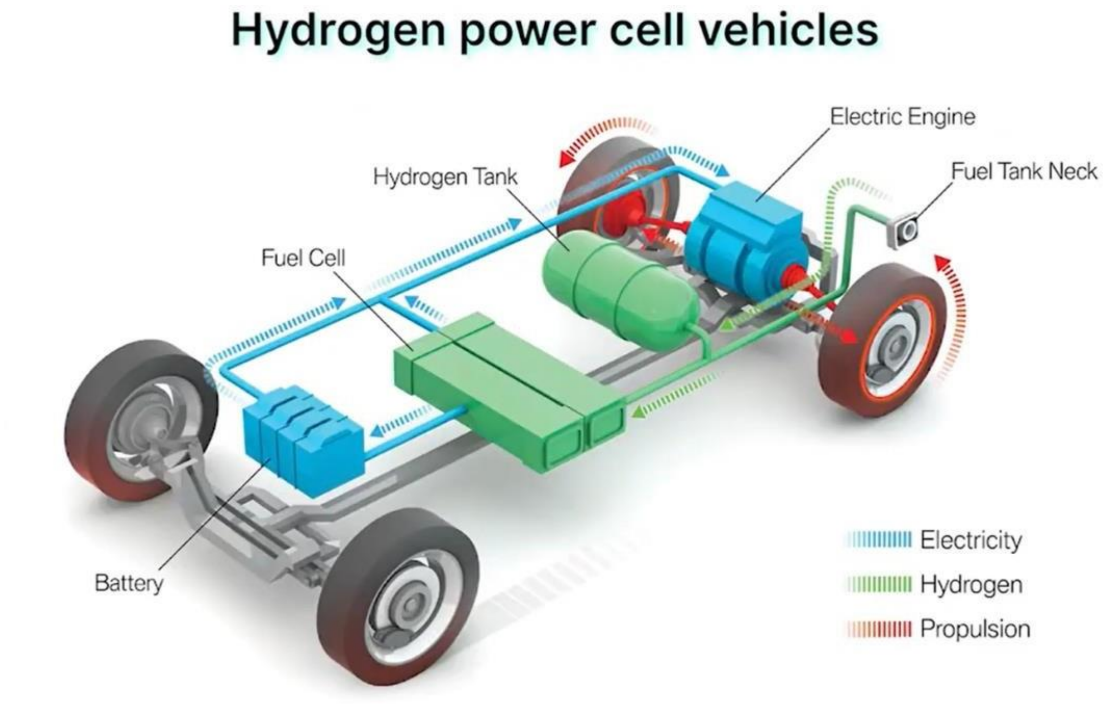

Fig 5.8

- FCVs only produce water as a byproduct of its power generating process which is ejected out of the car through the tailpipes.
- An advantage of such vehicles is they can produce their own electricity which emits no carbon, enabling it to reduce its carbon footprint further than any other EV.
- Another major advantage of these are, and maybe the most important one right now, refilling these vehicles takes the same amount of time required to fill a conventional vehicle at a gas pump. This makes adoption of these vehicles more likely in the near future.
- A major current obstacle in adopting this technology is the scarcity of hydrogen fuel stations, but then again, BEV or PHEV charging stations were not a common scenario even a few years back.
- another disadvantage which is the high cost of fuel cells, that cost more than $200 per kW, which is far greater than ICE (less than $50 per kW).
- There are also concerns regarding safety in case of flammable hydrogen leaking out of the tanks.
- If these obstacles were eliminated, FCVs could really represent the future of cars.

Requirement of Electric Vehicle Batteries

The batteries should have

1) A stable voltage output over a good depth of discharge
2) High energy capacity for the given battery weight and size
3) High peak power output per unit mass and volume
4) High energy efficiency
5) Able to function with wide ranges of operating temperatures
6) Good charge retention on open-circuit stand
7) Ability to accept fast recharge
8) Ability to withstand overcharge and over discharge
9) Reliable in operation
10) Maintenance free
11) Rugged and resistant to abuse
12) Safe both in use and accident conditions
13) Made of readily available and inexpensive materials with environmental friendliness
14) Efficient reclamation of materials at the end of service life

The various types of batteries for automotive applications are classified as follows:

1.Lead–acid batteries

2. Nickel-based batteries
   a. Nickel–iron battery
   b. Nickel–zinc battery
   c. Nickel–cadmium battery
   d. Nickel-metal hydride battery

3. Lithium-based batteries
   a. Lithium-solid polymer battery
   b. Lithium-ion battery

4. Other types

a. Sodium–sulfur battery

b. Sodium–nickel chloride battery

c. Aluminum–air battery

d. Zinc–air battery

Solar Electric Vehicles

A solar vehicle is an EV powered by solar energy obtained from solar panels on the surface of the vehicle. Photovoltaic (PV) cells convert the sun's energy directly into electrical energy.

PVCs are the components in solar paneling that convert the sun’s energy to electricity. A solar array is the combination of various PV cells.

Design of Solar Vehicles

Designing solar vehicles is a multistage process where many parts need to be carefully designed and assembled. The various stages and steps involved are:

1) Designing chassis and basic framework
2) Designing and selection of suspension, braking system, and steering system
3) Designing and selecting motor and electric drive train
4) Selecting motor controller
5) Designing solar array with PV cells
6) Selecting proper batteries
7) Selecting electrical systems and instruments to display speed, load, temperature, and so on.

Various factors to be considered during the design are:

1) Efficient PV cells
2) Good aerodynamic structure
3) Use efficient long running durable batteries
4) High performance motor
5) Light weight (200–350 kg)
6) Reliable chassis

Advantages

- Electric vehicle with more advantages of no noise, no pollution, saving energy and reduce carbon dioxide emissions is to power-driven vehicle with a motor drive wheels moving.
- Solar electric vehicle can make to reduce our greenhouse gas emissions and other pollution. All advantages of solar electric vehicle make research and application of solar electric vehicle as a “hot spot” of automotive industry and the trend of future cars.
- Solar electric vehicle is made of PV panels, battery, electric motor, vehicle controller and vehicle body.
- Solar electric vehicle drives using dual-mode of PV and battery hybrid. It can be achieved PV-driven and battery-driven independently.
- In good sunny conditions, the full charge endurance of solar electric vehicle can be increased about 35% substantially compared with no PV panels.

- Solar electric vehicle can achieve low-carbon, energy saving, environmental protection and true zero-emissions for the future of human life

Solar electric vehicle

SEV is made of PV panels, battery, electric motor, vehicle controller and vehicle body. PV panels are installed on the top of vehicle or on the sides of the vehicle body. PV panels and vehicle batteries are connected through the vehicle controller. PV panels can not only directly charge the batteries, but also directly supply power to the motor. The important role of the vehicle controller is to manage the operation of vehicle and the distribution of electricity

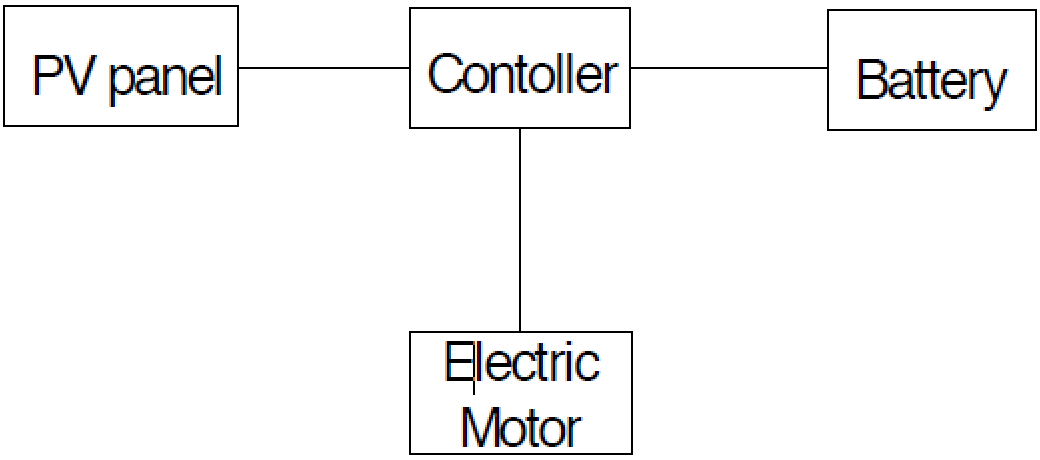

Fig 5.9

Applications of Electric Vehicles

Depending on the special requirements of a particular operation in specific industries, the following are some of the varieties of materials handling equipment :

1) Electric truck for use in steel plant soaking pit
2) Electric truck for frame and channel handling and mounting stud planter and stud puller in aluminum industries
3) Fork-lift truck for bale handling
4) Electric truck for batch trolleys in textile industries
5) Electric truck for die handling and for use as an order picker
6) Electric truck for inter-bay movements
7) Electric locomotive for mines
8) Electric tow truck for handling passenger luggage at airports
9) Electric vehicle for passenger movement at airports

Benefits of Electric Vehicles

1. Electric vehicles do not emit greenhouse emissions and toxic exhaust gases. The EVs are zero emission vehicles if the energy required to operate the vehicle (i.e., charging of battery) is produced from renewable energy sources or onboard hydrogen fuel cells.
2. Electric motor is much more efficient than conventional internal combustion engines.
3. Electric vehicles are noiseless.
4. Electric vehicles reduce the dependency of fossil fuels if they run on alternative fuels.

Challenges of Electric Vehicles

1) The cost of EVs is high as compared to contemporary gasoline and diesel cars. Recharging time of the batteries is high and research is going on to reduce the recharge time. It takes hours to recharge the batteries, which is more than the refueling time of gasoline and diesel vehicles.
2) Driving range of the EVs depending on the power of the batteries. To date the driving range is limited and is around 100 miles in one recharging.
3) Limited seating space availability as increase in the space will increase load of the passengers affecting the driving range as increased load puts stress on the battery performance and life.
4) Less customer acceptance and satisfaction. This is a marketing challenge as it will be a difficult task to change customer perception with so many limitations of EVs and when other options that are far better than EVs are available in the market.