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Some alternative fuels for C.I. engines

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■ **ABSTRACT :** Today the diesel engine is a very important prime mover, being used in buses, trucks, locomotives, tractors, pump sets and other stationary industrial applications, small and medium electric power generation and marine propulsion. These wide fields of global usage of diesel engines lead to ever increasing demand of petroleum derived fuels. Today the world is facing three critical problems: high fuel prices, climatic changes, and air pollution. These and other environmental disasters have brought about demands for alternative fuels and energy sources that are convenient, environmentally friendly and economically viable. In recent years, the prominence to conserve petroleum based fuels has provided the motivation for several studies on the development and testing of alternate fuels in diesel engine. This study takes a critical look on the review of already existing alternative fuels that produce less emission or no emission at all. The advantages of the alternative fuels are highlighted and exhaustively discussed. The engine performance and emission characteristics are also discussed.

■ **KEY WORDS :** C.I. engines, Alternative fuels, Environmental characteristics, Performance characteristics, Emission characteristics

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The engines are extensively used worldwide for transportation, decentralized power generation, agricultural applications and industrial sectors because of their high fuel conversion efficiency, ruggedness and relatively easy operation (Chauhan *et al.*, 2009). These wide fields of global usage of diesel engines lead to ever increasing demand of petroleum derived fuels. Fossil fuels are exhaustible sources of energy and hence an over reliability on these fuels is not sustainable in long run. Besides, the rising crude oil prices and increasing pollution due to excessive use of these engines is another grey area. The increased demand on energy associated with fossil fuel has resulted in problems such as high prices, supply depletion and emissions, which in recent years have been the main factors encouraging an increased focus on alternative fuels (Anonymous, 2005). Exhaust emissions of diesel engines, particularly soot, oxides of nitrogen and carbon monoxide are extremely harmful to natural environment and living beings (Yao *et al.*, 2008). The projections upto 2020 demonstrate the increased demand of fossil fuels upto three times that will boost the pollution levels in terms of airborne pathogens (*i.e.* infections, particles and chemicals), greenhouse effect in context of local, territorial and global spectrum (Gill *et al.*, 2011). These and other environmental disasters have brought about demands for alternative fuels and energy sources that are convenient, environmentally friendly and economically viable (Bamgboye and Oniya, 2012). Recently, much attention has been focused to the

development of cleaner alternative fuels for reducing air pollution and for reducing the dependence on fossil fuels (Zhang *et al*., 2010).Therefore, it became a global issue to develop such clean fuel which is technically feasible, domestically available and environmentally acceptable (Bouaid *et al*., 2009 and Han *et al*., 2009).

Alternative fuels, known as non-conventional or advanced fuels, are any materials or substances that can be used as fuels, other than conventional fuels like; fossil fuels (petroleum (oil) and coal). The term 'alternative fuel' refers to such energy carriers that are not of crude oil origin, have, respectively high heating value and their combustion causes lower pollution of the natural environment. The U.S. Department of energy defines alternative fuel, as fuel that is essentially non-petroleum and yields energy security and environmental benefits (Akande *et al*., 2013).

Types of alternative fuels :

Alternative fuels or alternatives can broadly be considered in two categories; those that serves as replacement for conventional fuels such as liquefied petroleum gas (LPG), compressed natural gas, liquefied natural gas (LNG), Di-methyl ether (DME), hydrogen, (H_2); and those that are blended with conventional fuels, examples being alcohols (E85, M85) or bio fuels.

- Alcohol fuels
  - Methanol
  - Ethanol
- Conventional natural gas
  - Liquefied natural gas (LNG)
  - Compressed natural gas (CNG)
- Renewable natural gas
- Liquefied petroleum gas
- Vegetable oils
  - Straight vegetable oils
  - Waste vegetable oils
- Biodiesel
- Hydrogen
- Fuel cells
- Di methyl ether
- GTL
- Solar fuel

A brief description of promising alternative fuels :

The alternative fuels under consideration are: Alcohols (Methanol and Ethanol), Conventional natural gas {Compressed natural gas (CNG), Renewable natural gas, Liquefied natural gas (LNG) and liquefied petroleum gas (LPG)}, vegetable oils, hydrogen.

Alcohols :

Methanol and ethanol are the alcohols considered to be potential transportation alternative fuels. Methanol and ethanol are both liquid and have several physical and combustion properties similar to gasoline and diesel fuels hence they make good substituted as alternative fuels. These properties are similar enough so that the same basic engine and fuel system technologies can be used for methanol and ethanol as for gasoline and diesel fuel. Methanol and ethanol have basic advantages compared to conventional petrol and diesel fuels in that their emissions are less reactive in the atmosphere producing smaller amount of ozone, the harmful component of smog.

Methanol :

What it is: Methanol (CH_3OH) is an alcohol fuel. As engine fuels, ethanol and methanol have similar chemical and physical characteristics.

How it is produced: It is produced from natural gas in production plants with 60% total energy efficiency. The currently preferred process of producing methanol is steam reformation of natural gas. In this process, any sulfur present in natural gas is first removed. Next, the natural gas is reacted with steam in the presence of a catalyst under high heat and pressure to form carbon monoxide (CO) and hydrogen. These elements are then put through the methanol production catalyst to make methanol. Methanol can be made with any renewable resources containing carbon such as seaweed, waste wood and garbage.

Environmental characteristic: Emissions from M-85 vehicles are slightly lower than in gasoline powered vehicles. Smog-forming emissions are generally 30-50 per cent lower; NOx and hydrocarbons emissions from M-85 vehicles are similar to slightly lower. However, CO emissions are usually equal or slightly higher than in gasoline vehicles.

Ethanol

What it is: It's a cheap non-petroleum based fuel. As with methanol, E-85 is the primary ethanol alternative fuel. The use of ethanol in vehicles is not a new

innovation. In the 1880s, Henry Ford built one of his first automobiles to run on ethanol.

How is it produced: It can be produced by fermentation of vegetables and plant materials. In India, its main source is molasses - a byproduct of sugarcane. It's done in three stages 1. Extraction of juice from sugarcane 2.Fermentation of the juice 3.Distillation.

Environmental characteristics: It has approximately 30-50% fewer smog forming emissions than a gasoline vehicle. Air toxics are also reduced by about 50 per cent when compared to gasoline. As with all internal combustion engines, vehicles using ethanol emit minor amounts of aldehydes. This is resolved by installing advanced catalytic converters on the vehicles. Major problem with ethanol is the corrosion. Ethanol driven vehicles require lines, hoses and valves to be resistant to the corrosion that alcohol can induce. Alcohol corrodes lead-plated fuel tanks; magnesium, copper, lead, zinc, and aluminum parts; and some synthetic gaskets.

Engine performance and emission characteristics: For an agriculture country like India, ethanol has been projected as a possible solution to the energy crisis because of large cellulosic biomass and sugarcane available for its production. The ethanol-diesel blends, often called E-diesel, rely on additive packages (emulsifiers) to form stable solutions of ethanol in diesel fuel, so that fuel can be used in existing equipment with minimal changes. The combustion characteristics of Ethanol diesel micro emulsions indicate that ethanol in micro emulsified form can be satisfactorily used in existing diesel engines. Cetane improvers need to be added to keep the cetane number greater than 40 and emulsifiers should be added as a proactive measure for preventing phase separation.

When alcohol is blended with diesel, it reduces cetane rating and energy content of blend. On the other hand, these blends give smoke free operation and reduction in NO_X emission (Premkartikkumar *et al.*, 2015). Anhydrous alcohols can combine with hydrocarbon fuels in any proportion (Havemann *et al.*, 1953). But such blends have very low water tolerance. Hence, the blend is required to be pre-heated to 35^0 C. Diesohol reduces NOX emission and smoke level considerably. Kiani *et al.* (2010) tested engine using blends of ethanol under varying engine speed and at constant engine loads of 25, 50, 70% and full load and reported lower CO and HC emissions and higher CO_2 and NOx emissions. The results also supported by Wen *et al.* (2010) and Costa and Sodre (2010).

Conventional natural gas - LNG and CNG :

What it is: Natural gas is a mixture of hydrocarbons - mainly methane (CH_4). The interest of natural gas as an alternate fuel stems mainly from its clean burning qualities, its domestic resources base, and its commercial availability to end-users. It can be stored on a vehicle either in a compressed gaseous state (CNG) or in a liquefied state (LNG).

How it is produced: Natural gas is primarily extracted from gas wells or in conjunction with crude oil production.

Environmental characteristics: Natural gas has low CO emissions, virtually no PM (particulate matter) emissions, and reduced volatile organic compounds. Per unit of energy, natural gas contains less carbon than any other fossil fuel, leading to lower CO_2 emissions per vehicle mile traveled.

Engine performance and emission characteristics: Compared to liquid hydrocarbon and other fuels natural gas contain less energy per unit volume. As discussed earlier, natural gas used for transportation fuels can either be CNG or LNG. Natural gas mixes readily with air and has a high octane rating which makes it a very good "spark-ignition engine fuel". It has a high ignition temperature that makes it unsuitable for use in compression-ignition engines. Methane barely participates in the atmospheric reactions that produce ozone though it does contribute to global warning when released to the atmosphere. Because of its high hydrogen to carbon ratio (4:1), methane produces about 10% less CO_2 than combustion of equivalent petrol or diesel fuel. Compressed natural gas is one of the commonly used alternative fuels in automobiles and power generations. It is used in dual fuel mode. Dual-fuel operation which utilizes diesel as a pilot fuel as a source of ignition for natural gas proves to be an excellent substitute for conventional diesel fuel with its superior engine performance and exhaust emission characteristics. Ramjee *et al.* (2013) studied the performance and emission characteristics of compression ignition (CI) engine using compressed natural gas (CNG). The engine performance is better on CNG compared to pure diesel upto engine loads of about 75.67%. The emission of unburnt hydro carbons for dual fuel was less compared to

diesel fuel.

Liquified petroleum gas – LPG :

What it is: Liquefied petroleum gas (LPG) consists of various hydrocarbons, mainly propane, propylene, butane, and butylenes in various mixtures. The main constituent, in most of the cases, is propane.

How it is produced: LPG is a byproduct of natural gas processing and petroleum refining.

Environmental characteristics: The LPG run vehicles have lower emission of reactive hydrocarbons (about one-third less), NOx (20 %less), and CO (60 % less) than gasoline vehicles.

Engine performance and emission characteristics: The low cetane number of LPG makes it difficult to be used in large proportions in compression ignition engines, mainly due to high cyclic variation. Hence it can be used in the CI engine in the dual fuel mode only. LPG dual fuel engines are modified diesel engines which use primary fuel as LPG and secondary fuel as diesel. LPG dual fuel engines have a good thermal efficiency at high output but the performance is less during part load conditions due to the poor utilization of charges. This problem can be overcome by varying factors such as pilot fuel quantity, injection timing, composition of the gaseous fuel and intake charge conditions, for improving the performance, combustion and emissions of dual fuel engines. From the studies it is shown that the use of LPG in diesel engine is one of the capable methods to reduce the PM and NOx emissions but at same time at part load condition there is a drop in efficiency and power output with respect to diesel operation.

Renewable natural gas or biogas :

Biogas is a methane rich flammable gas that results from the decomposition of organic waste material. Biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste and plant materials. It is also called as 'Marsh gas". It is a type of biofuel. This type of biogas comprises primarily methane and carbon dioxide.

How it is produced: Biogas is produced by extracting chemical energy from organic materials in a sealed container called a digester. The generation of biogas is the concept of Anaerobic Digestion (AD), also called biological gasification. It is a naturally occurring, microbial process that converts organic matter to methane (CH_4) and carbon dioxide (CO_2). The chemical reaction takes place in the presence of methanogenic bacteria with water an essential medium in the absence of oxygen to produce methane.

Biogas cannot be directly used in automobiles as it contains some other gases like CO_2, H_2S and water vapor. For use of biogas as a vehicle fuel, it is first upgraded by removing impurities like CO_2, H_2S and water vapor.

Engine performance and emission characteristics: RNG or biogas generally has a high self-ignition temperature hence; it cannot be directly used in a CI engine. So it is useful in dual fuel engines. Being a clean fuel biogas causes clean combustion and recesses contamination of engine oil. The uses of biogas reduce the CO_2 addition to the atmosphere as CO2 produced in combustion is less due to the low carbon to hydrogen ratio in biogas. Drop of CO, in biogas for dual fueling increases the thermal efficiency. Sorathia and Yadav (2012) tested diesel-biogas as dual fuel and found it offer similar energetic performance as petroleum diesel fuel. In addition to this, the exergetic performance parameters usually follow similar trends according to the energetic performance parameters. The diesel-biogas dual fuel mode produced lower energy conversion efficiency; which was offset by large replacement of diesel and induction air by biogas. The exhaust gas temperature was found to increase with the increasing proportion of bio-gas. The exhaust gas temperature was lower than that in diesel oil fuelling at all test speeds, especially at the low speed range. The CO_2 increases as the Brake power of the engine is increases; this is due to the increase of carbon content in the biogas. Bio-gas premixed charge diesel-biogas dual fuelling for the engine produced almost no performance deterioration at all test speeds.

Hydrogen (H_2) :

What it is: Hydrogen gas (H_2). Hydrogen has many characteristics that make it the "ultimate" alternative fuel to fossil energy fuels. Hydrogen can be combusted directly in internal combustion engines or it can be used in fuel cells to produce electricity with high efficiency (30%-50% over the typical load range).

How it is produced: Hydrogen can be produced from a number of different sources, including natural gas, water, methanol etc. Two methods are generally

used to produce hydrogen: (1) Electrolysis (2) Synthesis gas production from steam reforming or partial oxidation. Hydrogen is currently produced in large quantities via steam reforming of hydro carbons over a Ni catalyst at 1472º F. This process produces a syngas that must be further processed to produce high purity hydrogen. The syngas conditioning required for steam reforming is similar to that required for a biomass gasification-derived syngas; however, tars and particulates are not as much of a concern. Hydrogen is produced from biomass via. gasification. Gasification is a process in which coal or biomass is converted into gaseous components by applying heat under pressure and in the presence of air/ oxygen and steam. A subsequent series of chemical reactions produces a synthesis gas, which is then reacted with steam to produce a gas stream with an increased hydrogen concentration that then can be separated and purified.

Environmental characteristics: When combusted (oxidized), only water vapor is produced. When burned in an internal combustion engine, small amounts of nitrogen oxides and small amounts of unburned hydrocarbons and carbon monoxide are produced, due to the use of engine lubricants.

Engine performance and emission characteristics: When hydrogen is oxidized in fuel cells, the only emission is water vapor. When combusted in internal combustion engine (ICE), water vapor is the major emission, though, some oxides of nitrogen may be formed if combustion temperatures are high enough. Therefore, the use of hydrogen as a transportation vehicle fuel would result in few or no emission that would contribute to Ozone formation. The major drawback to using hydrogen as a fuel is the storage medium compared to all other fuels as hydrogen has the lowest energy storage density. Hydrogen can be stored as a compressed gas at pressure of 20.68 MPa similar to CNG, liquefied or stored in metal hydride (which absorbs hydrogen when cooled and release it when heated, and at a temperature of –252.9°C). When hydrogen is validated in fuel cell, the only significant emission is water vapor, when combusted in I.C.E. (Spark or diesel) some oxides of nitrogen and peroxides may be produced. None of the toxic emissions typical of petroleum fuels are present (Swain *et al.*, 1983).

Like CNG or propane vehicles, hydrogen vehicles should not produce evaporative emission since fuel system would be closed. According to study conducted by (Murugesan *et al.*, 2009) on a hydrogen-enriched air-inducted diesel (dual fuel) engine system at flow rates of 4lpm, 6lpm and 8lpm, the following conclusions are drawn: The brake thermal efficiency (BTE) increased and brake specific fuel consumption (BSFC) decreased for hydrogen flow rate of 8lpm as compared to diesel and lower volume flow rate of hydrogen. The hydrocarbon (HC) and carbon monoxide (CO) decreased and the oxides of nitrogen (NOx) increased for higher volume flow rate of hydrogen compared to diesel and lower volume flow rate of hydrogen. The heat release rate and cylinder pressure increased for higher volume flow rate of hydrogen compared to diesel and lower volume flow rate of hydrogen.

On the whole it can be concluded that hydrogen-enriched diesel engines perform well and emit less pollution compared to neat diesel fuel. Hence, hydrogen enrichment in a CI engine can be regarded as an eco-friendly alternative fuel to sole diesel.

Biodiesel :

What it is: Biodiesel is nothing but fatty acid ethyl or methyl ester made from edible and non edible oil and animal fats. The main commodity sources for biodiesel in India can be non edible oil obtained from plant species such as *Jatropha curcus* (Ratanjyot), *Pongamia pinnata* (Karanj), *Calophyllum inophyllum* (Nagchampa), *Hevcabra siliensis* (Rubber) etc.

How it is produced: The esterified version of the vegetable oils has been given the generic label of "Bio-diesel" which has much improved characteristics of fuels. The production process, called transesterification, converts oils and fats into chemicals called long-chain mono alkyl esters, which is called biodiesel when used as a fuel. These chemicals are also referred to as fatty acid methyl esters.

Environmental characteristics: Biodiesel has no aromatic content and only trace amounts of sulfur. In vehicle tests, it has lower emissions of carbon monoxide, soot, and polycyclic aromatic hydrocarbons than conventional diesel. With adjustments in the injection engine timing, it is possible to reduce the NOx emissions.

How is biodiesel used? :

Pure biodiesel (B100) is normally "blended" with petroleum diesel for use in engines. Biodiesel blends are

designated by the per cent biodiesel they contain:

B5 - 5% biodiesel and 95% petroleum diesel :

B20 (most common blend)- 20% biodiesel and 80% petroleum diesel.

Engine performance and emission characteristics: All existing C.I. engines can use B5 biodiesel/diesel blend right now; most of them run well with B20. The combustion of bio-diesel has reported to emit lesser pollutants compared to diesel as it has no sulphur content and shows decreasing emissions of CO, CO_2, HC, soot and aromatics (Forson *et al.*, 2004). Biodiesel is an environment friendly fuel produced less amount of harmful gasses during combustion. It does not require an existing engine modification. (Nwafor, 2003) used Jatropha oil in proportion of 97.4:2.6%; 80:20% and 50:50% blends of diesel and Jatropha oil by volume in CI engine. It was found that carbon dioxide emissions were similar for all fuel blends. The test further showed increase in brake thermal efficiency and brake power and reduction of specific fuel consumption for Jatropha oil and its blends with diesel fuel. But the most significant conclusion from the study is that the 97.4% and 2.6% diesel and Jatropha fuel blend produce maximum value of the brake power and brake thermal efficiency as well as minimum value of the specific fuel consumption. D97.4: B2.6 fuel blend yielded the highest cetane number and even better engine performance than the diesel fuels. It was suggested that Jatropha oil could be used as an ignition accelerator additive for diesel fuel. The performance of rapeseed oil blends in a diesel engine was investigated by Nwafor (2003). The experimental result showed that a mixing ratio of 30% and 70% diesel rapeseed ratio was practically optimal in ensuring relatively high thermal efficiency of engine. Knocking problem encountered at light loads was attributed to the longer ignition delays due to the low cylinder temperature. Operation with vegetable fuel oil offered a net reduction in HC emissions compared with base line results. The 50:50 blends competed favourably with diesel oil and offer a reasonable substitute for diesel fuels. Biodiesel provides significant lubricity (Cetane) improvement over petroleum diesel fuel thus increasing engine life.

Conclusion :

From this critical review, various alternative fuels are found to produce less emission in vehicles. So, the air pollution problem and energy security issue could be seriously addressed by not only producing but also utilizing in road transport sector such as buses, cars, trucks and motorcycles etc. The various types of alternative fuels have been discussed in detail and the advantages over the traditional transportation fuel have been stated hence a better replacement for diesel engines. Who knows where we will be in the future. We could see new engine technology, or another type of alternative fuel discovered. In any case, we need to keep working on the identified alternative fuels and overcome their disadvantages.

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