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Alternative fuels for I.C. Engines: A review

Suresh Chand Gurjar[1], Harendra Singh[2]
[1, 2] Department of Mechanical Engineering, Institute of Engineering and Technology, Alwar, Rajasthan, India

Abstract
At present the two third of the world energy demand is met by fossil fuels. Limited reserves of fossil fuels and their unequal distribution have resulted the fuel cost to raise several folds. The increased automobile population and industrialization have further increased the fuel demand as a result the world is facing twin crisis of fossil fuel depletion and environmental degradation. Conventional hydrocarbon fuels used by internal combustion engines, are dominating many fields like transportation, agriculture, and power generation which leads to pollutants like HC (hydrocarbons), SO_2 (sulphur oxides) and particulates which are highly harmful to human health. Conventional fuels are obtained from limited reserves which are getting scarce day by day. To go a long way in finding solutions to future fuel needs the answer surely lies in Alternative Fuels.
This paper reviews alternate fuels such as biodiesel, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG), alcohols, hydrogen etc. and certain new fuels like Algae, Ammonia, Liquid Nitrogen, Dimethyl Ether and Diethyl Ether, Acetylene which have a great potential to act as future alternate fuels for IC engines and can play a vital role in mitigating the energy crises.

Keywords: alternate fuels, biodiesel, compressed natural gas (CNG), liquefied petroleum gas (LPG), alcohols, hydrogen, microalgae, ammonia, liquid nitrogen, dimethyl ether, diethyl ether and acetylene

Introduction

An alternative fuel can be defined as any material or substance, other than petroleum, which is consumed to provide energy to power an engine. In light of the dependence of the transportation sector on petroleum (and recent sharp increases in the price of gasoline), it is clear that substitution of petroleum-based fuels (gasoline and diesel) by non-petroleum-based fuels (including alternative fuels such as biodiesels, ethanol, hydrogen, liquefied petroleum gas, methanol, and natural gas) could be a key means of reducing the air pollution. Alternate fuels, known as non-conventional fuels, are any materials that can be used as fuels, other than conventional fuels. Conventional fuels include fossil fuels like petroleum (oil), coal, propane, and natural gas.
Somewell-
knownalternate fuels include biodiesel, alcohols (methanol, ethanol, butanol), hydrogen, non-fossil methane, non fossil natural gas, vegetable oil, and other biomass sources, which have proved themselves to be suitable candidate for use as fuel in IC Engine. Bio fuels are also considered a renewable source. Biodiesel is made from animal fats or vegetable oils, renewable resources that come from plants and can either be mixed with pure diesel to make various proportions, or used alone. Biodiesel releases a smaller number of its pollutants because biodiesel burns both cleaner and more efficiently.
Alcohol fuels i.e., Methanol and Ethanol fuel can be used in internal combustion engines. Ethanol is a good alternate fuel. It can be produced in large quantities at low cost, its high oxygen content improves the combustion characteristics and it reduces the harmful emissions from IC Engines.
Hydrogen is an emission less fuel. The by product of hydrogen burning is water, although some mono-nitrogen oxides NO_x are produced when hydrogen is burned with air. Hydrogen is considered an alternative fuel for two reasons: It is renewable, and it is the most abundant element on the earth. HCNG (or H_2CNG) is a mixture of compressed natural gas and 4-9 percent hydrogen by energy.
Some of the new alternative fuels studied here are Algae, Ammonia, Liquid Nitrogen, Ethers (Dimethyl Ether and Diethyl Ether), and Acetylene.

Biodiesel

Vegetable oils and their derivatives (especially methyl esters) commonly referred as “Biodiesel”, are prominent candidates as alternate Diesel fuel. These oils have advanced from experimental fuels to initial stages of commercialization.
Biodiesel is a diesel replacement fuel that is manufactured from vegetable oils, recycled cooking greases or oils, or animal fats.
Plants produce oils from sunlight and air, and can do so year after year on cropland, thus these oils are renewable. Animal fats are produced when the animal consumes plant oils and other fats, and they too are renewable. Biodiesels which can be used as an alternative diesel fuel are made from the renewable biological sources such as vegetable oils and animal fats. It is biodegradable, non toxic and has low emission profile [1]. Used cooking oils are mostly made from vegetable oils, but may also contain animal fats. Used cooking oils are both recycled and renewable.

Advantages of Biodiesels

1. It is renewable.
2. It is energy efficient.
3. It displaces petroleum derived diesel fuel
4. It can be used in most diesel equipment with no or only minor modifications.
5. It can reduce global warming gas emissions/ Environmental benefits.

Disadvantages of Biodiesels

1. Stability
2. Solvency
3. Material Compatibility
4. In some cases long term operational problems persist.

Alcohols

The alcohols are fuels of the family of the Oxygenates. As is known to all, the alcohol molecule has one or more oxygen, which contributes to the combustion. The alcohols are named accordingly to the basic molecules of hydrocarbon which derives from them: Methanol (CH_3OH); Ethanol (C_2H_5OH); Propanol (C_3H_7OH); Butanol (C_4H_9OH). These alcohols are those of the simplest molecular structure, i.e., Methanol and Ethanol. Methanol is produced by a variety of process, the most common are as follows: Distillation of wood; Distillation of coal; Natural gas and petroleum gas [2] Ethanol is produced mainly from biomass transformation, or bioconversion. It can also be produced by synthesis from petroleum or mineral coal.

Ethanol is produced from bio-mass conversion and solar energy is stored in the plants by the photosynthesis process.

Therefore Ethanol is renewable fuel [3]

Advantages

1. Ethanol works well in internal combustion engines.
2. Ethanol helps combat pollution. E85 vehicles demonstrate a 25% reduction in ozone-forming emissions compared with gasoline.
3. Ethanol has a positive energy balance; that is, the energy content of ethanol is greater than the fossil energy used to produce it and this balance is constantly improving with new technologies.
4. Ethanol enhances the octane properties of gasoline and is used as an oxygenate to reduce CO emissions.
5. Ethanol is the main component in E85, a high-level blend of 85% ethanol and 15% gasoline.

Disadvantages

1. Technology of production needs further improvement
2. Used for other purposes also

Liquefied petroleum gas

Liquefied petroleum gas (also called LPG, GPL, LP Gas, or autogas) is a mixture of hydrocarbon gases (C2-C4) used as a fuel in heating appliances and vehicles, and increasingly replacing chlorofluorocarbons as an aerosol propellant and a refrigerant to reduce damage to the ozone layer, inferring that it is flammable.

Varieties of LPG bought and sold include mixes that are primarily propane, mixes that are primarily butane, and the more common, mixes including both propane (60%) and butane (40%), depending on the season—in winter more propane, in summer more butane. Propylene and butylenes are usually also present in small concentration. A powerful odorant, ethanethiol, is added so that leaks can be detected easily. The international standard is EN 589. In the United States, thiophene or amyl mercaptan are also approved odorants. LPG has been used in C.I. Engine in a HCCI mode using Diethyl ether for ignition purpose [4].

Advantages

1. Low running cost as it is approximately 50% cheap then petrol.
2. When used to power internal combustion engines it burns cleanly with no soot and very few sulfur emissions, posing no ground or water pollution hazards.
3. LPG is non-toxic, non-corrosive, additive-free.
4. Doesn't contain tetra-ethyl lead.
5. Increased lubricating oil life.

Disadvantages

1. However, its energy density is lower than these fuels, resulting in fewer miles per gallon. Approximately 20% reduction per liter due to low density and low energy per volume.
2. As less energy density thus to gain more power, high CR is required.
3. Low volumetric efficiency due to high latent heat of vaporization.
4. Handling has to done at 18 bar.
5. Blending response is poor.

Compressed natural gas

Compressed Natural Gas (CNG) is a fossil fuel substitute for gasoline (petrol), diesel, or propane fuel. Although its combustion does produce greenhouse gases, it is a more environmentally clean alternative to those fuels, and it is much safer than other fuels in the event of a spill (natural gas is lighter than air, but disperses quickly when released).

CNG is made by compressing natural gas (which is mainly composed of methane [CH_4]), to less than 1% of its volume at standard atmospheric pressure. It is stored and distributed in hard containers, at a normal pressure of 200–220 bar (2900–3200 psi), usually in cylindrical or spherical shapes.In response to high fuel prices and environmental concerns, CNG is starting to be used also in light-duty passenger vehicles and pickup trucks, medium-duty delivery trucks, transit and school buses, and trains. CNG's energy density is estimated to be 42% of LNG's (because it is not liquefied), and 25% of diesel's [5].

Advantages

1. PER KG CNG COST < Petrol and Diesel
2. Vehicle maintenance cost lower than other vehicles due to better fuel quality of CNG
3. Clean burning characteristics of CNG
4. increase in spark plug life
5. Reduced number of oil changes

Disadvantages

- Compressed natural gas vehicles require a greater amount of space for fuel storage than conventional gasoline power vehicles.
- Since it is a compressed gas, rather than a liquid like gasoline, CNG takes up more space for each gasoline gallon equivalent (GGE).
- While CNG-powered vehicles are considered to be safer than gasoline-powered vehicles, there are concerns about how best to fight fires involving CNG vehicles.
- Costly operating systems involving
- Being lighter can collect in overhead areas, creating an explosion hazard.

Hydrogen

Hydrogen is "the forever fuel"

- Petroleum reserves are being depleted and prices susceptible to foreign events beyond our control
- Bio fuels, including ethanol, cannot meet the growing demand of transportation fuels
- Hydrogen cannot be depleted
- Hydrogen has the ability to make societies completely energy-independent Hydrogen is used as a sole fuel in S.I.engine. in case of S.I. Engine while using hydrogen it has comparable power with higher efficiency [6]. in C.I

engine hydrogen is generally used in a dual fuel mode with diesel [7].

Advantages

1. "H" is abundant on earth, but usually bound to carbon (such as CH4) or oxygen (H2O) or both (organic matter – "carbohydrates" – C6H12O6)
2. H_2 is not found in nature in large quantities (although there are some underground gas deposits that have relatively high concentrations of H_2)
3. A gas under standard conditions. Liquefies at -253 ^oC
4. Odourless, Colourless, Non toxic or carcinogenic
5. Hydrogen burns more efficiently and creates energy more efficiently than gasoline thus complementary to, and matches electricity very well.

Disadvantages

1. Hydrogen being the smallest and lightest element in nature, it diffuses rapidly to the surroundings to non-combustible proportions
2. It is odorless, and therefore an odorant must be added to enable detection (Odorants must not contaminate hydrides).
3. It is invisible and thus harder to extinguish or to avoid. A flame colorant would make detection easier (Colorants must not contaminate hydrides).

Algae

Harvested algae, like fossil fuel, release CO_2 when burnt but unlike fossil fuel the CO_2 is taken out of the atmosphere by the growing algae. As part of the photosynthesis process algae produce oil and can generate 15 times more oil per acre than other plants used for bio fuels, such as corn and switch grass. Algae can grow in salt water, freshwater or even contaminated water, at sea or in ponds, and on land not suitable for food production.On top of those advantages, algae, should grow even better when fed extra carbon dioxide (the main greenhouse gas) and organic material like sewage. If so, algae could produce bio fuel while cleaning up other problems.

Algae cost more per unit mass (as of 2010, food grade algae costs ~$5000/tonne), due to high capital and operating costs [8], yet are claimed to yield between 10 and 100 times more energy per unit area than other second-generation bio fuel crops. Microalgae are capable of producing large amounts of biomass and usable oil in either high rate algal ponds or photo bioreactors. This oil can then be turned into biodiesel which could be sold for use in automobiles. Regional production of microalgae and processing into bio fuels will provide economic benefits to rural communities [9].

Algae can produce up to 300 times more oil per acre than conventional crops, such as rapeseed, palms, soybeans, or jatropha. As algae have a harvesting cycle of 1–10 days, it permits several harvests in a very short time frame, a differing strategy to yearly crops. Algae can also be grown on land that is not suitable for other established crops, for instance, arid land, land with excessively saline soil, and drought-stricken land. This minimizes the issue of taking away pieces of land from the cultivation of food crops. Algae can grow 20 to 30 times faster than food crops [4]. The obstacle preventing widespread mass production of algae for biofuel production has been the equipment and structures needed to begin growing algae in large quantities. Maximum use of existing agriculture processes and hardware is the goal [10].

Ammonia

It shares with hydrogen the virtue of yielding only water and nitrogen as combustion products when burned in internal combustion engines but avoids the packaging, safety and logistic problems of using hydrogen fuels in motor vehicles. Ammonia can be stored under moderate pressure at ambient temperatures. (Its physical properties are closely similar to those of liquid propane.) It can be packaged in a volume compatible with present automobiles. It is used as a fertilizer in quantities of over 100 million tons per year so that facilities for its storage, safe handling, transportation and distribution are available worldwide. It could be an economical replacement for gasoline if the foreseen costs of air pollution and global warming caused by fossil fuels are included in the economic evaluation.

The drawbacks include, the efficiency will be less than a battery powered vehicle. Pure ammonia is not suitable for use in high-speed engines. Its flame speed is too low. However, ammonia can be doped by environmentally friendly chemical additives, and thus be compatible in high-speed engines. Performance factors such as are influenced by engine speed, spark timing and manifold pressure are not far different with ammonia than with hydrocarbons as long as minimum amounts of hydrogen are inducted as a part of the fuel flow [11].

Liquid Nitrogen

To use liquid nitrogen as a non-polluting fuel, a multiple reheat open Rankine and a closed Brayton cycle are used. Cryogenic Heat Engine is an engine which uses very cold substances to produce useful energy. A unique feature of an cryogenic heat engine is that it operates in an environment at the peak temperature of the power cycle, thus, there is always some heat input to the working fluid during the expansion process. The principle of running the LN Car is like that of steam engine, except there is no combustion involved. Instead liquid nitrogen at 320^{o}F (-196^{o}C) is pressurized and then vaporized in a heat exchanger by ambient temperature of the surroundings air. This heat exchanger is like the radiator of a car but instead of using air to cool water, it uses air to heat and boil liquid nitrogen.

The resulting high pressure nitrogen gas is fed to an engine that operates like a reciprocating steam engine, converting pressure to mechanical power. The only exhaust is nitrogen, which is major constituent of atmosphere. Liquid Nitrogen is the cheapest, widely produced and most common cryogenic liquid. It is mass produced in air liquefaction plants. The liquefaction process is very simple in it normal, atmospheric air is passed through a dust precipitator and pre-cooled using conventional refrigeration techniques. It is then compressed inside large turbo pumps to about 100 atmospheres. Once the air has reached 100 atmospheres and has been cooled to room temperature it is allowed to expand rapidly through a nozzle into an insulted chamber. By running several cycles the temperate of the chamber reaches low enough temperatures the air entering it starts to liquefy. Liquid nitrogen is removed form the chamber by fractional distillation and is stored inside well-insulated Dewar flasks [11]. Liquid nitrogen is inert, colorless, odourless, non-corrosive, non-flammable, and extremely cold.

The principle of running a liquid nitrogen fuelled engine is like that of steam engine, except there is no combustion involved. Instead liquid nitrogen at –320^{o}F (-196^{o}C) is pressurized and then vaporized in a heat exchanger by ambient temperature of the surroundings air. This heat exchanger is like the radiator of a car but instead of using air to cool water, it uses air to heat and boil liquid nitrogen. The resulting high pressure nitrogen gas is fed to an engine that operates like a reciprocating steam engine, converting pressure to mechanical power. The only exhaust is nitrogen, which is major constituent of our atmosphere [12]. Advantages of using liquid nitrogen are-The energy density of liquid nitrogen is relatively low and better than readily available battery systems. They have significant performance and environmental advantages over electric vehicles. A liquid nitrogen car is much lighter and refilling its tank will only 10-15 minutes. The exhaust produced by the car is environmental friendly.

Dimethyl ether and diethyl ether

DME is a pure simple oxygenate having similar physical properties to liquefied petroleum gas (LPG), hereby also referred as synthetic LPG. It condenses at 25 C under atmospheric pressure, or under 5e6 bar at ambient temperature. Therefore, DME can be handled similarly as LPG so existing tankers and receiving terminals of LPG can be easily converted for DME distribution. The production of DME is very similar to that of methanol; DME is produced through gasification of various renewable substances or fossil fuels, i.e. natural gas, coal, biomass or other carbon containing materials. However, the current production technology is costly and relatively energy inefficient. As well, some engine optimization is required to take advantage of the fuel's properties. Conventional fuel injection system has to be modified due to the intrinsic properties of the DME. Diethyl ether (DEE) is also the most similar to DME except for DEE is liquid at the ambient conditions, which makes it attractive for fuel storage and handling. DEE is produced from ethanol by dehydration process so it is a renewable fuel. DEE has several favourable properties, including exceptional cetane number, reasonable energy density, high oxygen content, low auto ignition temperature and high volatility. Therefore, it can be assist to improving of engine performance and reducing the cold starting problem and emissions when using as a pure or an additive in diesel fuel [13]. Consequently, both of DME and DEE are promising alternatives for diesel engines due to suitable fuel properties cited above.

Ismet Sezer [14] conducted a simulation study on both dimethyl ether and diethyl ether. The reformulation of diesel fuel contains the reduction of the sulphur and aromatic contents or the oxygen addition to diesel fuel. A direct injection diesel engine was simulated via thermodynamic cycle model for investigation. Thermodynamic and performance parameters besides emissions determined and compared for diesel, dimethyl ether and diethyl ether fuels at two different states. The results showed that dimethyl ether and diethyl ether presented a lower cylinder temperature and pressure, and thus a lower engine performance than diesel fuel for the equal injection conditions. A commercial suction (naturally-aspirated) direct injection automobile diesel engine was used for the parametric investigation.

Acetylene

Acetylene has a very wide flammability range, and minimum ignition energy is required for ignition since the engine can run in lean mode with higher specific heat ratios leading to increased thermal efficiency. It has higher flame speed and hence faster energy release. High self-ignition temperature of acetylene allows larger compression ratios than diesel engines do. Due to lower ignition energy, high flame speed, wide flammability limits, and short quenching distance lead to premature ignition and also lead to undesirable combustion phenomenon called knock. It shares with hydrogen the virtue of yielding only water and nitrogen as combustion products when burned in internal combustion engines but avoids the packaging, safety and logistic problems of using hydrogen fuels in motor vehicles. Ammonia can be stored under moderate pressure at ambient temperatures. (Its physical properties are closely similar to those of liquid propane.) It can be packaged in a volume compatible with present automobiles. It is used as a fertilizer in quantities of over 100 million tons per year so that facilities for its storage, safe handling, transportation and distribution are available worldwide. It could be an economical replacement for gasoline if the foreseen costs of air pollution and global warming caused by fossil fuels are included in the economic evaluation.Acetylene aspiration results in lower thermal efficiency, reduced Smoke, HC and CO emissions, when compared with baseline diesel operation.

Sole acetylene fuel in HCCI mode showed the results with high thermal efficiencies in a wide range of BMEP. The values of NO_2, smoke are reduced by HCCI combustion, but HC emissions were more compared with base line diesel fuel. The brake thermal efficiency in dual fuel mode was found as lower than diesel operation at full load, as a result of continuous induction of acetylene in the intake. By applying certain techniques like, TMI, TPI the thermal efficiency can be improved with a reduced NO_2 emissions level [15].

Diesel like fuel from waste oils

The lubricating oils can be recycled as lubricating oil, and re-used as fuel or made into diesel-like fuel. Production of diesel-like fuel from waste oils such as industrial and engine waste oils, wood pyrolysis oils, fresh and waste fats and vegetable oils is an excellent way for producing alternative fuel sources. Industrial and engine waste oils, wood pyrolysis oils, fresh and waste fats and vegetable oils have been proposed as pyrolysis raw material to produce gasoline and diesel-like fuels. Characteristics of the DLF, such as density, flash point, viscosity and heating value were tested and found to be close to the values of the diesel fuel used in a study. The lowest flash point, density and sulfur of the fuel samples were obtained by using CaO. The DLF was obtained as 75% of the purified waste engine oilor 60% of waste engine oil [16].

Conclusion

Today, the internal combustion engine fuelled by fossil fuel powers the vast majority of the world's vehicles. However, alternative fuels offer opportunities for significant emission reductions and efficiency increases for certain niche vehicle categories. The different alternative fuels and technologies are in various stages of development and each has unique performance and emission characteristics.

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