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ALTERNATE FUELS FOR COMPRESSION IGNITION ENGINES

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Abstract— **In this paper an alternative fuels for IC Engines is discussed. The objective of this paper is to provide a means of renewable fuels utilization. India is an agricultural based country and it has an abundant potential of bio fuels and to be utilized in IC engines. These fuels give high efficiency and low emissions will lead to establishing a path for their utilization. The increasing industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels. The country like India is not having petroleum resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum from Gulf countries in Asia. Hence, it is necessary to look for alternate fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc. This paper reviews the production, characterization and current status of bio alcohol and biodiesel. The use of biodiesel in conventional diesel engines has result in substantial reduction in emission of unburned hydrocarbons, carbon monoxide and particulate matter. This review focuses on performance and emission of biodiesel in CI engines, combustion analysis, wear performance on long-term engine usage, and economic feasibility. The test results of alcohol blends of 15 % and 20% with mineral diesel has been shown at different load conditions in figures 1 and 2 respectively.** ***The results of performance tests are compared with various blends of castor oil biodiesel with that of neat diesel. The result indicates that at blend B20%, highest Brake thermal efficiency and lowest Brake Specific Fuel Consumption ,while for blend B 20, the Lowest fuel consumption is obtained.***

Keywords— CI Engine, Blends, Efficiency , and brake specific fuel consumption

I. INTRODUCTION

The spectrum of renewable biofuels is very wide, and they can be classifi ed in many ways. In energy production, solid biomass used in boiler applications is still the dominating fuel source, but liquid biofuels are becoming increasingly popular and clearly have potential for use in, for example, large medium-speed diesel engines, in both power plant and marine applications. Liquid biofuels can be vegetable based or, alternatively, can originate from animal fats. These can be either crude biofuels or biofuels that have gone through further processing in order to remove undesired compounds and to achieve a better quality and recommends that crude biofuels be utilized as such, and not mixed with. Bio diesel is made from animal fats or vegetable oils. The renewable sources that come from plants such as soyabeen, sun flowers, corn, olive, peanut, palm, coconut, canola, sesame, cotton seed etc. Systematic propagation and processing of seeds is very important in view of large scale commercial production of bio fuels. Biodiesel is methyl or ethyl ester of fatty acid made from virgin or used vegetable oils (both edible and non-edible) and animal fat. The main resources for biodiesel production can be non-edible oils obtained from plant species such as polang, kusum, neem, sal, linseed, castor, baigaba, Jatropha, curcas, Karanj etc are native to India. Biodiesel can be blended in any proportion with mineral diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition (diesel) engine, and essentially require very little or no engine modifications because biodiesel has properties similar to mineral diesel. It can be stored just like mineral diesel and hence does not require separate infrastructure. The use of biodiesel in conventional diesel engines has result in substantial reduction in emission of unburned hydrocarbons, carbon monoxide and particulate matter.

The major disadvantage of gasoline is more likely to explode and burn accidentally, gum would form on storage surfaces, and carbon deposits would form in combustion chamber. Ethanol is one of the possible fuels for diesel replacement in compression ignition (CI) engines also. The application of ethanol as a supplementary CI engine fuel may reduce environmental pollution, strengthen agricultural economy, create job opportunities, reduce diesel fuel requirements, and thus contribute in conserving a major commercial energy source. Ethanol was first suggested as an automotive fuel in USA in the 1930s, but was widely used only after 1970. Nowadays, ethanol is used as fuel, mainly in Brazil, and as a gasoline additive for octane number enhancement and improved combustion in USA, Canada and India. As gasoline prices increase and emission regulations become more stringent, ethanol could be given more attention as a renewable fuel or gasoline additive. Ethanol is made from renewable resources like biomass from locally grown crops and even waste products such as waste paper, grass and tree trimmings etc. Ethanol is an alternative transportation fuel since it has properties, which would allow its use in existing engines with minor hardware modifications. Ethanol has higher octane number than gasoline. A fuel with a higher octane number can endure higher compression ratios before engine starts knocking, thus giving engine an ability to deliver more power efficiently and economically. Ethanol burns cleaner than regular gasoline and produce lesser carbon monoxide, HC and oxides of lead to environmental degradation problems such as soil degradation.

II. LITERATURE SURVEY

Due to gradual depletion of world petroleum reserves and the impact of environmental pollution of increasing exhaust emissions, there is an urgent need for suitable alternative fuels for use in diesel engines. In view of this, vegetable oil is a promising alternative because it has several advantages—it is renewable, environ-friendly and produced easily in rural areas, where there is an acute need for modern forms of energy [1–5]. Therefore, in recent years systematic efforts have been made by several research workers [6–9] to use vegetable oils as fuel in engines. Obviously, the use of non-edible vegetable oils compared to edible oils is very significant because of the tremendous demand for edible oils as food and they are far too expensive to be used as fuel at present. From previous studies [10–12], it is evident that there are various problems associated with vegetable oils being used as fuel in compression ignition (C.I.) engines, mainly caused by their high viscosity. The high viscosity is due to the large molecular mass and chemical structure of vegetable oils which in turn leads to problems in pumping, combustion and atomization in the injector systems of a diesel engine. Due to the high viscosity, in long term operation, vegetable oils normally introduce the development of gumming, the formation of injector deposits, ring sticking, as well as incompatibility with conventional lubricating oils [13–17]. Therefore, a reduction in viscosity is of prime importance to make vegetable oils a suitable alternative fuel for diesel engines. The problem of high viscosity of vegetable oils has been approached in several ways, such as preheating the oils, blending or dilution with other fuels, trans-esterification and thermal cracking/pyrolysis.

III. PROPERTIES OF BIO FUELS

Ethanol is isomeric with di-methyl-ether (DME) and both ethanol and DME can be expressed by the chemical formula C_2H_6O. The oxygen atom in ethanol possibly induces three hydrogen bonds. Although, they may have the same physical formula, the thermodynamic behavior of ethanol differs significantly from that of DME on account of the stronger molecular association via hydrogen bonds in ethanol. The physical properties of alcohols in comparison to CNG, DME and petroleum fuels are given below.

	Methane	**Methanol**	**Dimethyl Ether(DME)**	**Ethanol**	**Gasoline**	**Diesel**
Formula	CH_4	CH_3OH	CH_3OCH_3	CH_3CH_2OH	C_7H_{16}	$C_{14}H_{30}$
Molecular weight(g/mol)	16.04	32.04	46.07	46.07	100.2	198.4
Density(g/cm^3)	0.00072	0.792	0.661	0.785	0.737	0.856
Normal boiling point ^{0}C	-162	64	-24.9	78	38-204	125-400
LHV(kj/kg)	47.79	19.99	28.62	26.87	43.47	41.66
Exergy Mj/Kg	51.76	22.36	30.75	29.4	47.46	46.94
Sulphur content ppm	7-25	0	0	0	~200	~250

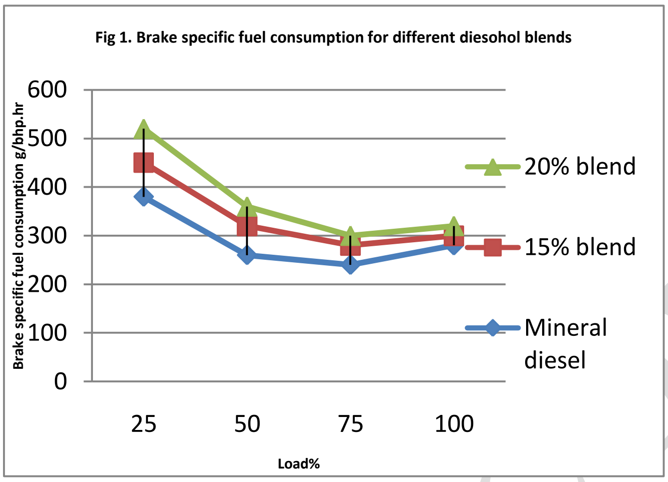
Alcohol fuels, methanol and ethanol have similar physical properties and emission characteristics as that of petroleum fuels. Alcohol's production is cheaper, simple and eco-friendly. This way, alcohol would be a lot cheaper than gasoline fuel. Alcohol can be produced locally, cutting down on fuel transportation costs. Alcohol can be used directly in an engine or it can be blended with gasoline or diesel fuels. Alcohol fuels can be successfully used as IC engine fuels either directly or by preparing biodiesel. The transesterification process utilizes methanol or ethanol and vegetable oils as the process inputs. This route of utilizing alcohol as a diesel engine fuel is definitely a superior route as the toxic emissions (aldehydes) are drastically reduced. The problem of corrosion of various engine parts utilizing alcohol as fuel is also solved by way of transesterification. Alcohols have been attracting attention worldwide. Consumer wants a cleaner fuel that can lower the risk of harm to environment and health. Though biofuels remain relatively small in use compared to more traditional energy forms, the scenario is changing rapidly. When factors are coupled with vast agri-resources, new technologies that reduce cost, emphasize on environment and pollution abatement and a strong will from both the government and private entrepreneurs; the markets for biofuels are slowly but surely gaining momentum.

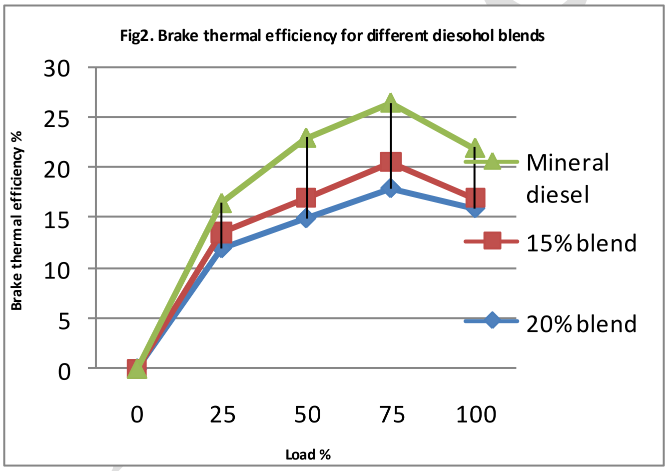
IV. MATERIAL COMATIBILITY STUDIES

The vehicle modification is required for alcohol fueling because its properties are different from those of gasoline. Ethanol has low stoichiometric air–fuel ratio and high heat of vaporization that requires carburetor re-calibration and increased heating of the air–fuel mixture to provide satisfactory drivability. Brazil has most developed technology for the alcohol fueled Otto cycle (4 stroke) internal combustion engines. In the early 1980s, there were more than 3.5 million alcohol-powered automobiles in Brazil. In order to make alcohol engines more practical, functional, durable, and economical, engineers made several changes in the regular gasoline engines. These included the following: Since alcohol does not evaporate as easily as gasoline, the intake manifold had to be redesigned to provide more heating for evaporation. The carburetor was regulated in order to change the air/fuel proportions. The tin and lead coating of the fuel tank was changed to pure tin. The fuel lines (zinc steel alloy) were changed to cadmium brass. The fuel-filtering system was changed and re-dimensioned in order to allow a greater fuel flow rates. In order to take advantage of the alcohol's much higher octane rating, the compression ratio was increased to about 12:1. The valve housings, made of cast-iron, were changed to an iron-cobalt synthetic alloy. This also compensated for the lack of lubrication resulting from the absence of lead in the fuel. The catalytic converters catalyst was changed from palladium and rhodium to palladium and molybdenum, helping further reduce the alcohol engine emissions. The use of ethanol in gasoline engines in the early 1980s resulted in numerous materials compatibility studies, many of which are also applicable to the effect of ethanol–diesel blends in diesel engines and particularly in the fuel injection system. The quality of the ethanol has a strong influence on its corrosive effects. Freshly formulated blends containing pH neutral dry ethanol would be expected to have relatively little corrosive effect. However, if a blend has been standing in a tank for sufficient time to allow the ethanol to absorb moisture from the atmosphere, it may tend to be more corrosive as it passes through the fuel injection system. Corrosion inhibitors have been incorporated in some additive packages used with ethanol–diesel blends. Nonmetallic components have also been affected by ethanol with particular reference to elastomeric components such as seals and O-rings in the fuel injection system.

V. ENGINE PERFORMANCE WITH DIESOHOL BLENDS

Ethanol is one of the possible alternative fuels for partial replacement of mineral diesel in CI engines. The application of ethanol as a supplementary fuel may reduce environmental pollution, strengthen agricultural economy, create job opportunities, reduce diesel requirements, and thus contribute in conserving a major commercial energy source. The researchers analyzed the effect of using different blends of ethanol–diesel (diesohol) on engine power, brake-specific fuel consumption, brake thermal efficiency, exhaust gas temperatures, and lubricating oil temperature. The results indicate no significant power reduction in the engine operation on ethanol–diesel blends (up to 20%) at a 5% level of significance. Brake-specific fuel consumption increased by up to 9% (with ethanol up to 20%) in the blends as compared to mineral diesel. The exhaust gas temperature, lubricating oil temperatures and exhaust emissions (CO and NOx) were lower with operations on ethanol–diesel blends as compared to operation on diesel. Ethanol–diesel blends up to 20% can very well be used in present day constant speed CI engines without any modification. The brake-specific fuel consumption is slightly increased as shown when higher blends of ethanol are used. There is no significant difference in the power produced and the thermal efficiency of the engine as shown in the fig1 and fig2. Exhaust gas temperatures were lower for ethanol–diesel blends than mineral diesel. The engine could be started normally both hot and cold.





The results of the oxygenated blends were compared to those of the base fuel and of a leaded fuel prepare by adding tetra ethyl lead (TEL) to the base fuel. The engine's maximum output and thermal efficiency were evaluated at a variety of operating conditions. In general, the highest exhaust temperature is observed with the base fuel, and the lowest with the leaded fuel. The increase in thermal efficiency means that a larger portion of combustion heat has been converted into work and therefore lower exhaust temperatures can be expected.

A. Regulated and Unregulated emissions from ethanol operated engines

Combustion engine emissions have been shown to be the major contributor to air pollution in urban areas. Vehicle emissions are divided into two groups; regulated and unregulated pollutants. Regulated pollutants are carbon monoxide (CO), nitrogen oxides (NOx), and unburned fuel or partly oxidized HC. The levels of emissions of these pollutants are specified by legislations. Unregulated pollutants include polycyclic aromatic hydrocarbons (PAHs), methane, aldehydes, carbon dioxide, other trace organic emissions and carbon deposits. Carbon deposits increase engine wear, while some of the PAH isomers are known to be carcinogenic and mutagenic. With increase of ethanol content in the fuel blend, acetaldehyde emissions increase. Since acetaldehyde is an intermediate product from the partially oxidized quenched fuel, it is possible that more acetaldehyde emissions are formed from ethanol fueling under some operating conditions. It is also observed that acetaldehyde emissions have close relationship with the engine load and ethanol content in the blend. With increase in load from idling, acetaldehyde emissions gradually decrease to their minima at medium loads, then increase again at high engine loads. High acetaldehyde emissions are attributed to thick quenching layer formed by a large amount of ethanol in the fuel at high loads and also due to low oxidation rate of acetaldehyde at low engine loads due to low combustion temperatures and exhaust gas temperatures. There are other toxic emissions (unregulated), which should be considered to ascertain the impact of ethanol blended fuels such as acetaldehyde, formaldehyde, propionaldehyde and acrolein, benzene, ethylbenzene,1-3 butadiene, acrolein, hexane, toluene, xylene, and fine particulate.

B. Vegetable oils and their utilization as engine fuels

The advantages of using vegetable oils as fuels are: Vegetable oils are liquid fuels from renewable sources. They do not over-burden the environment with emissions. Vegetable oils have potential for making marginal land productive by their property of nitrogen fixation in the soil. Vegetable oil's production requires lesser energy input in production. Vegetable oils have higher energy content than other energy crops like alcohol. Vegetable oil combustion has cleaner emission spectra. But these are not economically feasible yet and need further R&D work for development of on farm processing technology. Due to the rapid decline in crude oil reserves, the use of vegetable oils as diesel fuels is again promoted in many countries. Depending upon climate and soil conditions, different nations are looking into different vegetable oils for diesel fuels. For example, soybean oil in the USA, rapeseed and sunflower oils in Europe, palm oil in Southeast Asia (mainly Malaysia and Indonesia), and coconut oil in Philippines are being considered as substitutes for mineral diesel. An acceptable alternative fuel for engine has to fulfill the environmental and energy security needs without sacrificing operating performance. Vegetable oils can be successfully used in CI engine through engine modifications and fuel modifications. Engine modifications include dual fueling, injection system modification, heated fuel lines etc. Fuel modifications include blending of vegetable oils with diesel, transesterification, cracking/pyrolysis, micro-emulsion, and hydrogenation to reduce polymerization and viscosity. Nevertheless, technologies must be developed for the use of vegetable oils as an alternative diesel fuel that will permit crop production to proceed in an emergency situation. Vegetable oil in its raw form cannot be used in engines. It has to be converted to a more engine-friendly fuel called biodiesel. System design approach has taken care to see that these modified fuels can be utilized in the existing diesel engine without substantial hardware modification. It will be expensive and time-consuming to incorporate even a minor design alteration in the system hardware of a large number of existing engines operating in the rural agricultural sector of any country. In its simplest form, the carbon cycle of vegetable oil consists of the fixation of carbon and the release of oxygen by plants through the process of photosynthesis and then combining of oxygen and carbon to form CO_2 through processes of combustion. Vegetable oils are not suitable as fuel for diesel engines; hence they have to be modified to bring their combustion-related properties closer to those of mineral diesel. This fuel modification is mainly aimed at reducing the viscosity to get rid of flow and combustion-related problems. Considerable efforts have been made to develop vegetable oil derivatives that approximate the properties and performance of HC-based fuels. Vegetable oils can be used through at least four ways:

1. Direct use and blending
2. Micro-emulsions
3. Pyrolysis (thermal cracking)
4. Transesterification.

Direct use and blending
The researchers found that 50% blend of Jatropha oil can be used in diesel engine without any major operational difficulties but further study is required for the long-term durability of the engine. Direct use of vegetable oils and/or the use of blends of the oils have generally been considered to be not satisfactory and impractical for both direct and indirect diesel engines.

Micro-emulsions
To solve the problem of the high viscosity of vegetable oils, micro-emulsions with solvents such as methanol, ethanol and 1-butanol have been investigated. A micro-emulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimension generally in the 1–150 nm range, formed spontaneously from two normally immiscible liquids. They can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. Short term performance of micro-emulsions of aqueous ethanol in soybean oil was nearly as good as that of mineral diesel, in spite of the lower cetane number and energy content.

Pyrolysis (thermal cracking)

Pyrolysis is the conversion of one substance into another by means of heat or by heat in presence of a catalyst. The paralyzed material can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids. Many investigators have studied the pyrolysis of triglycerides to obtain products suitable for diesel engine. Thermal decomposition of triglycerides produces alkanes, alkenes, alkadines, aromatics and carboxylic acids.

Transesterification

In organic chemistry, transesterification is the process of exchanging the alkoxy group of an ester compound by another alcohol. The reactions are often catalyzed by an acid or a base. Transesterification is crucial for producing biodiesel from biolipids. The transesterification process is the reaction of a triglyceride (fat/oil) with a bio-alcohol to form esters and glycerol.

C. Biodiesel as an engine fuel

The best way to use vegetable oil as fuel is to convert it in to biodiesel. Biodiesel is the name of a clean burning mono-alkyl ester-based oxygenated fuel made from natural, renewable sources such as new/used vegetable oils and animal fats. The resulting biodiesel is quite similar to conventional diesel in its main characteristics. Biodiesel contains no petroleum products, but it is compatible with conventional diesel and can be blended in any proportion with mineral diesel to create a stable biodiesel blend. The level of blending with petroleum diesel is referred as Bxx, where xx indicates the amount of biodiesel in the blend (i.e. B10 blend is 10% biodiesel and 90% diesel. It can be used in CI engine with no major modification in the engine hardware.Biodiesel is the product of the process of transesterification. Biodiesel is biodegradable, non-toxic and essentially free from sulfur; it is renewable and can be produced from agriculture and plant resources. Biodiesel is an alternative fuel, which has a correlation with sustainable development, energy conservation, management, efficiency and environmental preservation. Alcohol combines with the triglycerides to form glycerol and esters. A catalyst is usually used to improve the reaction rate and yield.The process of transesterification brings about drastic change in viscosity of vegetable oil. The biodiesel thus produced by this process is totally miscible with mineral diesel in any proportion. Biodiesel viscosity comes very close to that of mineral diesel hence no problems in the existing fuel handling system. Flash point of the biodiesel gets lowered after esterification and the cetane number gets improved. Even lower concentrations of biodiesel act as cetane number improver for biodiesel blend. Calorific value of biodiesel is also found to be very close to mineral diesel. Some typical observations from the engine tests suggested that the thermal efficiency of the engine generally improves, cooling losses and exhaust gas temperature increase, smoke opacity generally gets lower for biodiesel blends. Flash point, density, pour point, cetane number, calorific value of biodiesel comes in very close range to that of mineral diesel. Diesel engine can perform satisfactory for long run on biodiesel without any hardware modifications. Several researchers investigate the different vegetable oil esters and find esters comparable to mineral diesel. Biodiesel has viscosity close to mineral diesel. These vegetable oil esters contain 10–11% oxygen by weight, which may encourage combustion than hydrocarbon-based diesel in an engine. The cetane number of biodiesel is around 50. Biodiesel has lower volumetric heating values (about 10%) than mineral diesel but has a high cetane number and flash point. Due to near absence of sulfur in biodiesel, it helps reduce the problem of acid rain due to transportation fuels. The lack of aromatic hydrocarbon (benzene, toluene etc.) in biodiesel reduces unregulated emissions as well like ketone, benzene etc. Biodiesel is oxygenated fuel (hence more complete combustion) and causes lesser particulate formation and emission. Various studies show that smoke opacity for biodiesel is generally lower. Several experimental investigations are performed on 4-stroke DI diesel engines with vegetable oil methyl esters and found that hydrocarbon emissions are much lower in case of biodiesel compared to diesel. This is also due to oxygenated nature of biodiesel where more oxygen is available for burning and reducing hydrocarbon emissions in the exhaust. Biodiesel is an oxygenated fuel and leads to more complete combustion, hence CO emissions reduce in the exhaust. Ignition delay for ester/diesel blend was shorter than diesel as a fuel. The researchers found that with rapeseed oil methyl ester heat release always takes place in advance as compared to diesel and injection also starts earlier in case of biodiesel as a fuel and average cylinder gas temperature was higher in case of biodiesel as a fuel. The soybean oil methyl ester as a fuel on a indirect injection diesel engine and found that overall combustion characteristics were quite similar as for diesel except shorter ignition delay for soybean methyl ester.

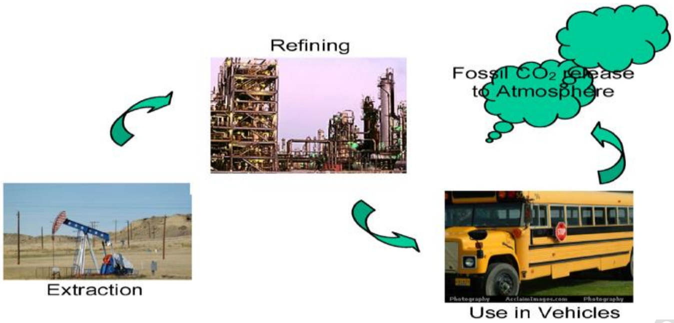


Fig3 Bio diesel CO2 cycle

VI. CONCLUSIONS

Using ethanol as a fuel additive to unleaded gasoline causes an improvement in engine performance and exhaust emissions. Ethanol addition results in an improvement in brake power, brake thermal efficiency, volumetric efficiency and fuel consumption, however the brake specific fuel consumption and equivalence air–fuel ratio decrease because of lower calorific value of the gasohol. Using an ethanol–unleaded gasoline blend leads to a significant reduction in exhaust emissions of CO and HC for all engine speeds. On the other hand, CO_2 emissions increase marginally. Ethanol diesel blends up to 20% can very well be used in present day constant speed CI engines without any hardware modification. Exhaust gas temperatures and lubricating oil temperatures were lower for ethanol diesel blends than mineral diesel. The engine could be started normally both hot and cold. Significant reduction in CO and NOx emission was observed while using ethanol diesel blends. A continuous transesterification process is a method of choice to lower the production cost. Researchers in various countries carried out experimental research using vegetable oils and biodiesel as petroleum fuel substitutes. Vegetable oil methyl esters gave performance and emission characteristics comparable to that of diesel. Esterification is a process, which brings about a change in the molecular structure of the vegetable oil molecules, thus bringing down the levels of viscosity and unsaturation of vegetable oils. The viscosity of vegetable oil gets drastically reduced after esterification. The esterification has been found to be an effective technique to prevent some long-term problems associated with utilization of vegetable oils such as fuel filter plugging, injector coking, formation of carbon deposits in combustion chamber, ring sticking, and contamination of lubricating oils. The experimental investigations revealed that the overall combustion characteristics were quite similar for biodiesel blend (B20) and mineral diesel. However, combustion starts earlier in case of B20. Ignition delay is lower and combustion duration is slightly longer for B20 compared to mineral diesel. Twenty percent blend of rice bran oil methyl ester did not cause any fuel/combustion related problems. This detailed experimental investigation confirms that biodiesel can substitute mineral diesel without any modification in the engine. Hence, biodiesel may be considered as diesel fuel substitutes. The use of biofuels as IC engine fuels can play a vital role in helping the country like India by saving foreign exchange reserves and strengthen the country's agricultural system.

References

[1] Kloptenstem WE. Effect of molecular weights of fatty acid esters on cetane numbers as diesel fuels. J. Am. Oil Chem. Soc. 1988;65:1029–31.

[2] Harrington KJ. Chemical and physical properties of vegetable oil esters and their effect on diesel fuel performance. Biomass 1986;9:1–17.

[3] Masjuki H, Salit. Biofuel as diesel fuel alternative: an overview. J. Energy Heat Mass Transfer 1993;15:293–304.

[4] LePori WA, Engler CR, Johnson LA, Yarbrough CM. Animal fats as alternative diesel fuels, in liquid fuels from renewable resources. Proceedings of an Alternative Energy Conference. American Society of Agricultural Engineers, St Joseph; 1992. pp. 89–98.

[5] Srinivasa Rao P, Gopalakrishnan VK. Vegetable oils and their methylesters as fuels for diesel engines. Ind. J. Technol. 1991;29:292–7.

[6] Masjuki H, Sohif M. Performance evaluation of palm oil diesel blends on small engine. J. Energy Heat Mass Transfer 1991;13:125–33.

[7] Nag A, de Bhattcharya KB. New utilizations of vegetable oils. J. Am. Oil Chem. Soc. 1995;72(12):1391–3.

[8] Takeda Y. Developmental study on jatropha curcas (Sabu dum) oil as a substitute for diesel engine oil in Thailand. J. Agricultural Assoc. China 1982;20:1–9.

[9] Piyaporn K, Narumon J, Kanit K. Survey of seed oils for use as diesel fuels. J. Am. Oil Chem. Soc. 1996;71(4):471–7.

[10] Agarwal AK. Vegetable oils verses diesel fuel: development and use of biodiesel in a compression ignition engine. TIDE 1998;8(3):191–204.

[11] Sinha S, Misra NC. Diesel fuel alternative from vegetable oils. Chem. Engg World 1997;32(10):77–80.

[12] Roger AK, Jaiduk JO. A rapid engine test to measure injector fouling in diesel engines using vegetable oil fuels. J. Am. Oil Chem. Soc. 1985;62(11):1563–4.

[13] Ryan TW, Dodge LG, Callahan TJ. The effects of vegetable oil properties on injection and combustion in two different diesel engines. J. Am. Oil Chem. Soc. 1984;61(10):1610–9.

[14] Korus RA, Jaiduk J, Peterson CL. A rapid engine test to measure injector fouling in diesel engines using vegetable oil fuels. J. Am. Oil Chem. Soc. 1985;62(11):1563–4.

[15] Rewolinski C, Shaffer DL. Sunflower oil diesel fuel: lubrication system contamination. J. Am. Oil Chem. Soc. 1985;61(7):1120–4.

[16] Ziejewski M, Kaufman KR. Laboratory endurance test of a sunflower oil blend in a diesel engine. J. Am. Oil Chem. Soc. 1983;60(8):1567–73.

[17] Pryde EH. Vegetable oil as diesel fuels: overview. Papers from the symposium on vegetable oils as diesel fuels, presented at the 73rd AOCS annual meeting, Toronto, Canada. J. Am. Oil Chem. Soc. 1983;60(8).