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Review Article

A Review on Combustion, Performance and Emission Characteristics of Liquid Alternative Fuels for Diesel Engine

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Abstract

The liquid alternative fuels discussed in the present work include alcohol fuels such as ethanol, butanol and methanol, neat vegetable oils and biodiesel fuels. From the review, it is observed that the emissions pollutants (HC, CO, NOx and PM) are typically the same or lower with regards to ethanol fuels than conventional diesel fuel. Methanol contains oxygen in its chemical structure; hence less air is required for complete combustion. This is the reason for reduced CO_2 emissions from motor vehicles using methanol/diesel blends. However, this could also increase NO x. The previous studies revealed the beneficial effects of using various blends of n-butanol with diesel fuel on smoke and CO emissions at various loads, however at the expense of higher NOx and HC emissions. Again, it is the high oxygen content of n-butanol that leads to enhanced in-cylinder soot oxidation, which is responsible for the decrease in smoke emissions. The combustion of straight vegetable oil (SVO) in internal combustion engines has shown conflicting results in emissions. Vegetable oils with high percentages of fully saturated fatty acids have the potential to produce lower NOx emissions. The reported value of oxides of nitrogen emission from biodiesels were higher as compare to diesel, whereas the carbon monoxide, hydrocarbon, and smoke emission of biodiesel fuels are lower than diesel. From the review, it is observed that the combustion characteristics of biodiesel are almost similar to that of diesel and slightly inferior performance as compared to diesel.

Keywords: *Biodiesel, Vegetable Oil, Alcohol Fuel, Carbon Monoxide, Nitrogen Oxide, Hydrocarbon, Smoke*

1. Introduction

Many countries are evaluating a variety of alternative fuels foe use in motor vehicles in an attempt to reduce greenhouse gas emissions and to improve the energy security of the country. Due to the better fuel economy diesel engines have been widely used in automotive area but the limited reserve of fossil fuel and deteriorating environment have made scientists seek to alternative fuels for diesel while keeping the high efficiency of diesel engine. Since last decades researchers around the world have been trying to find new alternative fuels that are available, technically feasible, economically viable and environmentally acceptable (A. Agarwal, et al., 2009). As a dominant role in diesel substitutes, biodiesel produced from animal fats, algae or non-food crop plants will evidently lower oil import for the domestic energy market (R. Burrett, et al.,2007) The previous studies (T. Fang, et al., 2009) shown that biodiesel produces less CO, CO_2, soot and unburned hydrocarbon, albeit a slight increase in NOx. This is particularly important with the increasing emission restrictions. Meanwhile, alcohol is also a popular replacement to fossil fuels due to a variety of locally available feedstock. The blending of 10% ethanol in gasoline without significant modification to engine has shown encouraging results (H.S. Yücesu, et al., 2006). In addition, numerous articles present that blending ethanol with diesel fuel will reduce CO, NOx and soot simultaneously (X. Li, et al., 2005) However, from previous studies, n-butanol is a better alternative over ethanol because of issues with higher lubricity, solubility, heating value and longer ignition delay in diesel engines (A. Chotwichien, et al., 2009) Vegetable oils are ‘‘greener’’ for the environment, as they seldom contain sulphur elements and aromatic compounds. Lastly, they do not contribute to a net rise in the level of CO_2 in the atmosphere, and consequently exert less influence on the greenhouse effect (Alcantara et al., 2000), (Demirbas¸ et al., 2000), and (Zanzi et al., 2002).

2. Alcohol Fuel Combustion, Performance, and Emission

Throughout history, alcohol has been used as a fuel. The first four aliphatic alcohols (methanol, ethanol, propanol, and butanol) are of interest as fuels because they can be synthesized chemically or biologically, and they have characteristics which allow them to be used in internal combustion engines. The general chemical formula for alcohol fuel is $C_nH_{2n+1}OH$. The only oxygenated hydrocarbons that are viable as alternative fuels are methanol (CH3OH), and ethanol (C2H5OH). Methanol is

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the more versatile of the two alcohols because of its huge potential resource base (it can be manufactured from any organic material).

Methanol is a simple compound. It does not contain sulphur or complex organic compounds. The use of pure methanol requires substantial modifications to the engine. Methanol blends are used in engines with either no or only minor modification. These fuels usually contain 5-15% by volume of methanol and hence they are designated methanol blends such as M5, M15, and etcetera. High methanol fuel blends are also possible but require a new engine design. These blends are termed M85, M90, and etcetera. Note that a similar system is used for ethanol, for example, E5, E15, etcetera. One of the major benefits of using methanol is the improvement in fuel consumption. (Verde's, et al., 1982) investigations have claimed such an improvement due to the addition of methanol to gasoline whereas others have claimed a deterioration in fuel consumption when the methanol blends were compared with gasoline (petrol) alone. However, based on limited observations with prototype engines for methanol vehicles, the US.EPA (1989) projected that the potential efficiency gain is 30% compared to that of conventional gasoline (petrol) engines. This is due to the higher octane number values which permit higher engine compression ratios and the wider 14 flammability limits which allow leaner combustion; thus resulting in an increase in engine efficiency. Methanol contains oxygen in its chemical structure; hence less air is required for complete combustion. This is the reason for reduced CO2 emissions from motor vehicles using methanol/gasoline blends. However, this could also increase NOX. The fire hazard is greater with methanol than gasoline, because the saturated vapour which forms over liquid methanol stored in a tank is within the flammable range and it can burn invisibly (M. Dougall, 1991). Gasoline vapour under similar conditions is too rich to ignite. Methanol engines experience cold-start problems because of the fuel's low vapour pressure and the high latent heat of vaporization. The biggest challenge with the use of methanol is that it is more corrosive than gasoline (Kowalewicz, 1993). In addition, a methanol operated vehicle needs a fuel tank twice as large as a gasoline tank due to its low heating value (Ingamells, et al., 1980). Another challenge in using methanol is that it is a highly toxic alcohol. Ethanol is a grain alcohol, which is produced mainly from sugar cane. Every time the price of sugar rises, it tends to create a fuel shortage because the producers move their production in the direction of sugar instead of fuel. However, (Kowalewicz, et al., 1993) indicates that the ethanol-gasoline dual fuel engine operation in Brazil has been technically successful, but worldwide, it is likely that it will remain an additive for gasoline and diesel unless the economics of its production change rapidly. Ethanol possesses a high anti-knock quality due to its high octane number and high latent heat of evaporation. As a result, torque and thermal efficiency increase when compared to that of gasoline. Emissions pollutants (HC, CO, NOx and PM) are typically the same or lower with regards to ethanol fuels than conventional gasoline. Unfortunately, ethanol does not possess suitable ignition properties under typical diesel conditions; this is due to the temperatures and pressure that are characteristic of the diesel engines and cause a longer ignition delay when using ethanol. Therefore, in order to make use of ethanol in a diesel engine, either a system to improve the ignition quality of ethanol or a system of some aids to ignition is necessary. Amongst the disadvantages, ethanol has a lower heat value of slightly less than 70% of the heat value of diesel or petrol. Although this does not have an effect in terms of thermal efficiency, which is actually higher for alcohol engines, it affects the range of the vehicle per unit volumetric capacity of the fuel tank. About 1.7 litres of ethanol would produce the same energy efficiency as a litre of diesel fuel. Ethanol is more corrosive than diesel or petrol and hence the fuel system must be made of more ethanol compatible materials. It has poor lubricity and suitable lubricants may be a necessary addition to the fuel pumps. Ethanol is more expensive to produce. Higher energy input is required in ethanol production compared to other energy crops and this leads to environmental problems such as soil degradation. Ethanol blends well with gasoline. A major drawback in ethanol-diesel fuel blends is that ethanol is immiscible in diesel over a wide range of temperatures because of their difference in chemical structures and characteristics. These can result in fuel instability due to phase separation. This may cause a problem for a vehicle's fuel system and the performance of the engine. The literature concerning the use of butanol/diesel fuel blends in diesel engines and its effects on their performance and exhaust emissions is very limited. (Miers et al.2008), reported on a drive cycle analysis of *n*-butanol/diesel blends in a light-duty, turbo-diesel vehicle. (Yoshimoto et al. 2002) dealt with the performance and exhaust emission characteristics of diesel engine fueled with vegetable oils blended with oxygenated organic compounds, including ethanol and *n*-butanol. Armas et al. have reported results of smoke opacity during various individual transients using either vegetable oil methyl esters (Armas O et al, 2006) (including starting tests) or bio-ethanol/diesel fuel blends (Armas O et al, 2007). Some studies indicate that E10 blends generally cause higher emissions of nitrogen oxides compare to neat petrol (CARB 1998; Koshland et al. 1998; NRC 1999; Reuter et al. 1992; Hsieh et al. 2002), some studies indicate mixed results (He et al. 2003b; Knapp et al. 1998) and some show no change or marginally lower emissions (Egeback et al. 2005; Reading et al. 2002). The average increase of NOx emissions is in the order of 1%, with a range from -10% to 7%, as shown from various experiments conducted on passenger cars (Karlsson 2006; Reading et al. 2002; TNO 2004). Another recent report released through the GAVE project (DeServes 2005) compared emissions of four different ethanol blends (E5, E10, E70, E85) from three Euro 4 flexifuel passenger cars. The tests were performed on a range of different driving cycles, including NEDC and Artemis urban, road and motorway cycles. No consistent change was found in NOx emissions from E5 and E10 blends. According to the same project, NEDC tests conducted at -7ºC did not show higher emissions compared to those at 22ºC, indicating that the temperature has no impact on NOx emissions. (Canakci et al.) experimentally investigated the combustion and exhaust emissions of a single cylinder diesel engine at three (25, 20 original injection timing and 15^{o} CA BTDC) different injection timings when methanol/diesel fuel blends were used from 0 to 15%, with an increment of 5%. The results indicated that the P_{max} decreased and the ID increased with the increase of methanol mass fraction at all injection timings. The increment in the ID caused to the deteriorating combustion thereby reduced the P_{max}. Also advanced injection timing boosted the P_{max} and the rate of heat release because of the increase in ID.(Huang et al. used the diesel/methanol blend and combustion characteristics and heat release analysis in a CI engine. According to the experimental results, the increase in methanol mass fraction in the diesel/methanol blends resulted in an increase in the heat release rate at the premixed burning phase and shortened the combustion duration of the diffusive burning phase. The ID increased with increasing of the methanol mass fraction. This trend was more obvious at low engine load and high engine speed. TCD and P_{max} increased by advancing fuel delivery timing. The P_{max}, the $(dP/d\theta)_{max}$ and the $(dQ/d\theta)_{max}$ of the diesel/methanol blends obtained a higher value than that of diesel fuel. (Yao et al. 2008) researched the effect of diesel/methanol compound combustion (DMCC) fuel injection method on combustion characteristics. In this fuel injection method, the methanol was injected into the air intake of each cylinder. The diesel fuel was injected into the cylinder to ignite a methanol/air mixture. This system was tested on naturally aspired diesel engine. The test results showed that the ID increased and the cylinder gas temperature reduced with the DMCC fuel injection method due to the high latent heat of methanol. (Xing-cai et al. 2004) conducted research on the heat release and emissions of a high speed diesel engine fuelled with ethanol/diesel blend. They found that the ID increased and TCD shortened for ethanol/diesel fuels when compared to diesel fuel. It was observed that the maximum heat release rate of ethanol/diesel blends were lower than that of diesel fuel. In the other studies, (C. Rakopoulos. et al. 2007) investigated the effect of ethanol/diesel blends with 5%, 10% and 15% (by vol.) ethanol on the combustion and emissions characteristics of a high speed direct injection diesel engine. According to the experimental results, the ID for the E15 blend was higher than pure diesel fuel; also there was no significant difference among the P_{max} for each load conditions. The combustion characteristics of IDI diesel engines are different from the DI diesel engines, because of greater heat-transfer losses in the swirl chamber. This handicap causes the brake-specific fuel consumption (bsfc) of the IDI engine to increase and the total engine efficiency to decrease compared to that of a DI diesel engine. Because of these disadvantages of the IDI diesel engines, most engine research has focused on the DI diesel engines. However, IDI diesel engines have a simple fuel injection system and lower injection pressure level because of higher air velocity and rapidly occurring air-fuel mixture formation in both combustion chambers of the IDI diesel engines. In addition, they do not depend upon the fuel quality and produce lower exhaust emissions than DI diesel engines.(A.A. Abdel-Rahman, 1998)(D.C. Rakopoulos et al. 2010**)** investigated that to evaluate the effects of using blends of n-butanol (normal butanol) with conventional diesel fuel, with 8% and 16% (by vol.) n-butanol, on the performance and exhaust emissions of a fully instrumented, six-cylinder, water-cooled, turbocharged and after-cooled, heavy duty, direct injection (DI), Mercedes-Benz engine, installed at the authors' laboratory, which is used to power the mini-bus diesel engines of the Athens Urban Transport Organization sub-fleet. The tests are conducted using each of the above fuel blends, with the engine working at two speeds and three loads. Fuel consumption, exhaust smokiness and exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide and total unburned hydrocarbons are measured. The differences in the measured performance and exhaust emissions of the two butanol/diesel fuel blends from the baseline operation of the engine, i.e. when working with neat diesel fuel, are determined and compared. It is revealed that this fuel, which can be produced from biomass (bio-butanol), is a very promising bio-fuel for diesel engines. The differing physical and chemical properties of n-butanol against those for the diesel fuel, aided by sample cylinder pressure and heat release rate diagrams, are used to interpret the observed engine behaviour.

3. Vegetable Oil Combustion, Performance, and Emission

The use of pure vegetable oils in diesel engines is nearly as old as the diesel engine itself. The inventor of the diesel engine, Rudolf Diesel, reportedly used groundnut (peanut) oil as a fuel for demonstration purposes in 1900 (Auld, Bettis and Peterson,1982). Experiments have been conducted with a number of vegetable oil like rapeseed oil, sunflower oil, soybean oil, rice bran oil, neem oil, palm oil, rubber seed oil, Jatropha oil, karanja oil, coconut oil, etc as fuel in diesel engines an acceptable performance over a short period of time in unmodified diesel engine has been reported. However, studies also indicate that long-term use of vegetable oils results in problems like heavy smoke emissions and carbon deposition in various parts of the engine due to high viscosity and carbon residue. Use of 100% vegetable oils in diesel engine results in almost same engine power with slightly lower thermal efficiency in comparison to diesel engine. (Bacon, et al., 1981) have evaluated the use of several vegetable oils as potential fuel for diesel engine. It has been stated that the vegetable oils developed acceptable power, but these oils caused high carbon build up in the combustion chamber. It has been concluded that the continuous running of an engine with vegetable oil at part-load and at mid-speed caused rapid carbon deposit on the injector tips. It has been further concluded that long-term engine testing has to be carried out to determine the overall effects of using vegetable oils in a diesel engine. (Yarbrough, et al., 1981) have studied the performance of a diesel engine with six variants of sunflower oil as fuel. It has been reported that the refined sunflower oil gave satisfactory results. It has been further reported that degumming and dewaxing the vegetable oil prevented engine failure. It has been concluded that raw sunflower oil could not be a fuel but modified sunflower oil could be used as a better fuel. (Pyror, et al., 1983) have also conducted short and long term engine performance tests using 100% soy bean oil in a small diesel engine. It has been reported that the short-term test with soy bean oil indicated performance similar to that of diesel fuel and long-term engine testing could not be carried out due to power loss and carbon build up on the injectors. It has been concluded that the soy bean oil could be considered for short term operation. (Seppo, et al., 1997) have tested a turbo charged four cylinder direct injection diesel engine using mustard oil. It has been reported that the engine developed power equal to that of diesel. It has been further stated that the smoke and NOx emissions were lower than diesel. It has been concluded that long term tests be carried out. (Yu, et al., 2002) have tested the use of waste cooking oil as alternative fuel for diesel engine. It has been further reported that the combustion characteristics were similar to that of diesel fuel. It has also been reported that the peak pressure was little higher and it occurred earlier by 1.1º-3.8 º CA than diesel. It has also been stated that the engine performance deteriorates for long term use, because, heavy carbon deposition on the piston crown is higher than diesel. It has been concluded that the waste cooking oil developed similar engine performance but deteriorated after long use. (Pugazvadivu and Jayachandran, 2003) have tested a single cylinder direct injection diesel engine with waste frying oil as fuel. It has been stated that the specific fuel consumption and smoke emission was marginally higher than diesel, but NOx emissions were lower than diesel which were due to low solubility of waste frying oil. (Laxminarayana Rao, et al., 2004) have investigated the use of unrefined rice bran oil, coconut oil and neem oil on a direct injection diesel engine. It has been reported that the brake thermal efficiency was lower for vegetable oil than diesel, due to lower calorific value. It has also been reported that the carbon dioxide and hydrocarbon emissions were slightly higher than diesel, but NOx emissions were lower than diesel. It has been conducted that the sluggish combustion and increased fuel consumption are due to lower caloric value and atomization. (Nazar, et al., 2004) have studied the use of coconut oil as an alternative fuel in direct injection diesel engine. It has been reported that the peak thermal efficiency for coconut oil was 28.67% and for diesel, it was 32.51%. It has also been concluded that the smoke, CO, HC and NOx emissions were lower than diesel emissions while the exhaust gas temperature was higher than diesel. (Wang et al., 2006) have studied the use of vegetable oil on a direct injection diesel engine. It has been reported that the CO and HC emissions were lower at full load and it was higher at lower loads. It has also been reported that the NOx emissions were lower at all blends. (Narayana Reddy and Ramesh, 2006) have tested a diesel engine with neat Jatropha oil with various parameters like injection timing injector opening pressure, injection rate and swirl level. It has been reported that the marginal improvement in brake thermal efficiency and reduction in HC and smoke emissions while advancing the injection timing by 3ºCA. It has also been reported that by increasing the injector opening pressure, the marginal improvement in brake thermal efficiency and all emissions are reduced, due to better spray atomization. (Deshmukh and Bhuyar, 2009**)** have tested a single cylinder direct injection diesel engine with the use of Hingan oil as fuel. It has been reported that slight power loss and higher specific fuel consumption occur with Hingan oil. This may be due to lower heating value of the Vegetable oil. It has also been reported that the CO and HC emissions were reduced and the NOx emissions are same for Vegetable oil compared to diesel fuel. (Rakopoulos et al., 2009) have investigated the use of Vegetable oil like, Cotton seed, Soybean oil, Sunflower oil, Rapeseed oil, Palm oil, Corn oil and Olive oil on a diesel engine. It has been reported that the smoke, CO emissions are increased with increase in vegetable oil blends. It has also been reported that the brake thermal efficiencies were nearly same and the brake specific fuel consumptions are higher due to lower calorific value of the vegetable oil. (Nazar et al., 2004) have studied the effect of preheated Karanja oil at 165ºC in a 3.67kW direct injection diesel engine. It has been reported that the brake thermal efficiency increased as the fuel temperature increased. It has been reported that CO and HC emissions were decreased for preheated karanja oil. It has been further reported that the smoke level was 3 BSU, while it was 4 BSU for karanja oil without preheating. It has been concluded that there was an improvement in performance, reduction in emissions and also that long term effect has to be tested. (Pugazhvadivu and Jayachandran, 2005) have tested the use of waste frying oil preheated to 70-135oC in a direct injection diesel engine. It has been reported that the preheated oil improved the performance of the engine. It has also been reported that the CO and smoke emissions were reduced considerably. It has also been further reported that the NOx emissions were increased with increased fuel inlet temperature. It has also been concluded that the preheated oil at 135oC could be used as diesel fuel for short term engine operation. (Ramadhas et al., 2005) have investigated the suitability of rubber seed oil as an alternative for the diesel fuel in compression ignition engine. It has been reported that the brake thermal efficiency were higher and the specific fuel consumptions were also higher in rubber seed oil blends. It has also been reported that the smoke emissions were lower for rubber seed oil blends and it was higher for raw oil. It has been concluded that 20-40 % blends yielded the engine performance closely to diesel fuel and carbon deposits in the combustion chamber of engine was higher in the case of rubber seed oil blends due to incomplete combustion of the fuel. At the Southwest Research Institute, (Reid *et al*. 1982) evaluated the chemical and physical properties of 14 vegetable oils. These studies pointed out that the vegetable oils behave very differently to the petroleum-based fuels. Engine tests showed that carbon deposits in the engine were reduced if the oil was heated prior to combustion. It was also noted that carbon deposit levels differed for oils with similar viscosities, indicating that the composition of an oil was also an important factor. (Bruwer *et al*., 1980) studied the use of sunflower seed oil as a renewable energy source. When operating tractors with 100% sunflower oil instead of diesel fuel, an 8% power loss occurred after 1000 hours of operation. The power loss

was corrected by replacing the fuel injectors and injector pump. After 1300 hours of operation, the carbon deposits in the engine were reported to be equivalent to an engine fuelled with 100% diesel except for the injector tips, which exhibited excessive carbon build-up. (Tahir *et al*., 1982) tested sunflower oil as a replacement for diesel fuel in agricultural tractors. The sunflower oil's viscosity was 14% higher than that of diesel fuel at a temperature of 37ºC. Engine performance using the sunflower oil was similar to that of diesel fuel, but with a slight decrease in fuel economy. Oxidation of the sunflower 37 oil left heavy gum and wax deposits on the test equipment, which could lead to engine failure. (Bacon *et al*. 1981) evaluated the use of several vegetable oils as potential fuel sources. Initial engine performance tests using vegetable oils were found to be acceptable, while nothing indicated that the use of these oils caused carbon build up in the combustion chamber. Continuous running of a diesel engine at part-load and mid-speeds was found to cause rapid carbon deposition rates on the injector tips. Short 2-hour tests were used to visually compare the effects of the use of different vegetable oils as a replacement for diesel fuel. Although short-term engine test results were promising, (Bacon *et al.1981)* recommended long-term engine testing to determine the overall effects of the use of vegetable oils as a fuel in diesel engines. (Schoedder, 1981) used rapeseed oils as a diesel fuel replacement in Germany with mixed results. Short-term engine tests indicated that rapeseed oil recorded similar energy outputs when compared to diesel fuel. Initial long-term engine tests demonstrated that difficulties arose in engine operation after 100 hours due to deposits on piston rings, valves, and injectors. He indicated that further long-term testing was needed to determine whether these difficulties could be averted. (Auld *et al*., 1982) made use of rapeseed oil to study the effects of using an alternative fuel in diesel engines. An analysis of the oil revealed a relationship between viscosity and fatty acid chain length. Engine power and torque results using this oil were similar to those of diesel fuel. Results of the short-term tests indicated that further 38 long-term testing was needed to evaluate engine durability when rapeseed oil was
Used. (Engelman *et al*.,1978) presented data for 10 to 50% soybean oil fuel blends used in diesel engines. The initial results were encouraging. They reported that at the conclusion of a 50-hour test the carbon build-up in the combustion chamber was minimal. For the fuel blends studied, it was generally observed that vegetable oils could be used as a fuel source in low concentrations. The BSFC and power measurements for the fuel blends only differed slightly from 100% diesel fuel. Fuel blends containing 60% or higher concentrations of vegetable oil caused the engine to sputter. Engine sputtering was attributed to fuel filter plugging. They concluded that a soybean oil fuel blend could be used as a diesel fuel extender with no engine modifications.

4. Biodiesel Combustion, Performance, and Emission

The main drawbacks of vegetable oil are the high viscosity and low volatility, which causes poor combustion in diesel engine. The transesterification is the process of removing the glycosides and combining oil esters of vegetable oil with alcohol. Due to this process the viscosity of the ester is equal to that of diesel and improves the combustion. (Gomez *et al*. 2000) investigated the exhaust emission and performance characteristics of a Toyota van powered by an IDI, naturally aspirated diesel engine operating on vegetable based waste cooking oil methyl ester. The waste vegetable oil methyl ester developed a significantly lower smoke opacity level and reduced CO, CO2 and SO2 values, whereas the O2, NO2 and NO levels were higher when compared to those of the No. 2 diesel fuel. The power values were comparable for the two fuels. (Al-Widyan *et al*. 2002) investigated the performance of an ethyl ester of waste vegetable oil in a diesel engine. The fuels tested consisted of different ester/diesel blends, including a 100% ester and No. 2 diesel fuel. The results demonstrated that the blends burned more efficiently with less specific fuel consumption and therefore, resulted in a higher engine thermal efficiency. The blends produced less CO and unburned HC than diesel fuel. The exhaust emissions of a diesel DI Perkins engine fuelled with waste olive oil methyl ester and No. 2 diesel fuel were studied by (Dorado *et al*. 2006) at several steady state operating conditions. The use of biodiesel resulted in lower emissions of CO, CO2, NO and SO2 with an increase in the emissions of NO2. Biodiesel fuel also presented a slight increase in brake specific fuel consumption. (Leung, 2001) has studied the properties and performance of biodiesel produced from used waste cooking oil and animal fats from restaurants as feedstock. Tests of the blend with three different proportions: 0%, 10% and 15%, of diesel have been conducted on various diesel engines. A 7% reduction in smoke opacity at a blending ratio of 15% was observed. A reduction of air pollutants from 1.5% to 44% was observed for most of the pollutants other than NO, which had a slight reduction at the idle condition but increased by about 16% at 2500 rpm. Another test was conducted on a diesel generator (Robin GS 3300RD) that consisted of a generator and a four stroke single cylinder diesel engine with a rated power of 3.4 kW. CO levels decreased with increasing biodiesel percentages for both idle and loaded conditions. The NOx level indicated a decreasing trend for the idling case, whereas at loaded conditions, the level fluctuated within a narrow range. The fuel consumption showed a slight increase with an increasing biodiesel percentage for idle and loaded conditions. (Reed *et al*. 1992) have tested biodiesel produced from waste vegetable oil in a Denver public bus. The results demonstrated that the engine output power using biodiesel was comparable to that of diesel. The smoke opacity was reduced when using biodiesel fuel. (Najafi *et al*., 2007) conducted a comprehensive combustion analysis to evaluate the performance of a commercial DI , water cooled two cylinders, in-line, naturally aspirated, RD270 Ruggeri diesel engine using biodiesel from waste cooking oil as an alternative fuel. The maximum power and torque produced using diesel fuel were 18.2 kW and 64.2 Nm at 2400 rpm respectively. By adding 20% of waste cooking oil methyl ester, it was noticed that the maximum power and torque increased by

2.7 and 2.9% respectively. In addition, the concentrations of the CO and HC emissions were significantly decreased when biodiesel was used. (M.G. Bannikov, 2011) has used Mustard methyl esters (further biodiesel) and regular diesel fuel in direct injection diesel engine. Analysis of experimental data was supported by an analysis of fuel injection and combustion characteristics. Analysis of combustion characteristics revealed earlier start of injection and shorter ignition delay period of biodiesel. Resulting decrease in maximum rate of heat release and cylinder pressure was the most probable reason for reduced emission of nitrogen oxides. Analysis of combustion characteristics also showed that cetane index is not a proper measure of ignition quality of biodiesel. Also, increased consumption of biodiesel led to longer injection duration. Advanced biodiesel injection would result in longer ignition delay period since biodiesel was injected in the lower pressure and temperature environment. Nevertheless, ignition delay period of biodiesel was shorter than that of diesel fuel at all loads which is the evidence of the better ignition quality of biodiesel. (P.K. Sahoo et al.,2009) have investigated the use of Non-edible filtered Jatropha (Jatropha curcas), Karanja (Pongamia pinnata) and Polanga (Calophyllum inophyllum) oil based mono esters (biodiesel) and blended with diesel in a single cylinder diesel engine used in generating sets and the agricultural applications in India. Diesel; neat biodiesel from Jatropha, Karanja and Polanga; and their blends (20 and 50 by v%) were used for conducting combustion tests at varying loads (0, 50 and 100%). The engine combustion parameters such as peak pressure, time of occurrence of peak pressure, heat release rate and ignition delay were computed. Combustion analysis revealed that neat Polanga biodiesel that results in maximum peak cylinder pressure was the optimum fuel blend as far as the peak cylinder pressure was concerned. The delays are consistently shorter for JB100, varying between 5.9º and 4.2 º CA lower than diesel with the difference increasing the load. Similarly, delays are shorter for KB100 (varying between 6.3 º and 4.5 º CA) and PB100 (varying between 5.7 º and 4.2 º CA) lower than diesel.(M. Boyd et al., 2008) have used four South Australian produced biodiesel fuels and a petroleum diesel fuel in a high speed, direct injection engine. They have found that biodiesel fuels produced longer measured ignition delays than petroleum diesel, when the reverse was expected. This result highlights the uncertainty surrounding the ignition process of biodiesel. All biodiesel fuels produced derived cetane numbers of over 61, with petroleum diesel measured at 49.8. Hence it was expected that biodiesel would show the shorter ignition delay, however with the exception of the two highest load petroleum diesel cases, biodiesel produced longer ignition delays. There are several possible explanations for the unusual ignition delay results; for example the fuel spray may have impinged on the combustion chamber wall during the higher load petroleum diesel cases and in all biodiesel cases (due to the biodiesel fuel's high viscosity). Alternatively, the high viscosity of the biodiesel fuels could have interfered with the fuel/air mixing process, extending ignition delay and increasing premixed combustion. (Utlua *et al.* 2008) evaluated the usage of methyl ester obtained from waste cooking oil in a turbocharged, four cylinder DI diesel engine. The results gathered were compared with those of No. 2 diesel fuel. The engine test results obtained with the aim of comparing the measurements of torque, power; specific fuel consumptions were similar. In addition, the amounts of emissions such as CO, CO2, NOx, and smoke opacity of biodiesel are less than that of the No. 2 diesel fuel. (Schumacher et al., 1996) have investigated the use of soybean methyl ester in a heavy duty diesel engine. It has been reported that the biodiesel blends reduced the particulate matter, total hydrocarbon emissions and increased the NOx emissions. It has been concluded that 3o retarding the injection timing reduced the NOx emissions while maintaining the other emissions. (Recep Altin et al., 2001) have studied the performance and emissions of diesel engine with various vegetable oils and its methyl esters as fuel. It has been reported that the power developed by methyl esters of all vegetable oils was lower by 7% to 10% less than diesel. It has also been reported that the particulate emissions were higher and NOx emissions were lower for vegetable oil methyl esters compared to diesel. It has been further reported that the CO emissions were higher for raw vegetable oil compared to diesel. It has been concluded that the raw vegetable oil could be used as alternative fuel with little modifications in engine. (Dorado et al., 2003) have tested the direct injection diesel engine with the use of olive oil methyl ester. It has been reported that the CO, CO2 and NOx emissions were significantly reduced compared to diesel fuel. It has also been reported that the SO2 emissions were less because biodiesel contains less sulphur content. (Nazar et al., 2004) have tested the use of karanja oil as an alternative fuel in direct injection diesel engine. It has been reported that the thermal efficiency for karanja oil ester was 29.6% compared to 31.5% for diesel. It has been reported that the HC and CO emissions for ester were lower than diesel at all loads. It has been further reported that the smoke level was 3.0 BSU for karanja oil methyl ester. It has been concluded that the peak pressure and maximum rate of pressure rise for karanja oil methyl ester were very similar to that of diesel. (Usta et al., 2005) have tested the use of tobacco seed oil methyl ester as fuel in a turbo charged indirect diesel engine. It has been reported that the performance of the engine running with biodiesel of tobacco seed oil was lower than that of diesel. It has been further reported that the CO emission was lower and NOx emission was higher than diesel. It has also been reported that the exhaust emissions had some traces of SO2 emission. It has been concluded that the tobacco seed oil methyl ester could be partially substituted for diesel fuel as blend without any modification. (A. Balasubramanian**,** 2012) investigated the performance and emission characteristics of various dual biodiesel blends (mixture of Jatropha biodiesel and neem biodiesel) with diesel on a stationary single cylinder, four stroke direct injection compression ignition engine**.** The blends of BB 10 (combination of Diesel 90% by volume, Jatropha biodiesel 5% by volume and Neem biodiesel 5% by volume) and BB 20 (combination of Diesel 80% by volume, Jatropha biodiesel 10% by volume and Neem biodiesel 10% by volume) gave better brake thermal efficiency and lower brake specific fuel consumption than other dual biodiesel blends (BB 40, BB 80 and BB 100). The blends of BB 10 and BB 20 have superior emission characteristics than other blends and closer to diesel values. (K.Tapan et al., 2011) have analyzed the performance and combustion characteristics of 10%, 20%, 30% and 40% blending of Koroch Seed Oil Methyl Ester (KSOME) and Jatropha Methyl Ester (JME) with diesel as fuels in a diesel engine. They reported that the ignition delay was less and the combustion duration was more for the JME blends as compared to the KSOME blends. They have found that the ignition delay period for the KSOME and JME blends was less. Further, the delay period was found to be less for the JME blends compared to the KSOME blends and the prediction made in pressure CA and heat release analyses was found to be correct. Cetane index of the KSOME and JME blends were higher and therefore the ignition delays were less for the biodiesel blends. Cetane index of the JME blends were comparatively higher and hence delay periods were lower for the JME blends compared to KSOME blends. They have found that, the combustion durations of KB30 and NRL diesel were the same (47° CA duration) and it was slightly less for the other KSOME blends. Even though the amount of injected fuel was more for the KSOME blends but slightly lesser combustion duration may be due to fact that biodiesel is oxygenated in nature which helps in early completion of combustion of the blends as it was the case for KB10. But with the increase in the amount of biodiesel in the blend, combustion duration increased for KB20 and KB30 which may be due to increase in the amount of fuel injected. But again the combustion duration decreased in case of KB40, which may be due to higher viscosity of this particular blend. However for the JME blends, the combustion durations were slightly more compared to the KSOME blends and these were 46, 47, 50 and 50° CA for JB10, JB20, JB30 and JB40 respectively. Slightly higher duration of combustion particularly with respect to JB30 and JB40 could be due to earlier start of combustion and relatively longer diffusion combustion for these blends. (Yusuf Ali et al., 1995) have studied the use of soy methyl ester/diesel blend in two different turbo charged, 6 cylinder diesel engines. It has been stated that the engine performance did not differ for a blend of 70/30 diesel/soy ester but there was increase in power output for 80/20 blend. It has been reported that the lower HC emissions, increase in NOx emissions were found with increase in soy ester concentration. It has been reported that the CO emissions are same as diesel for all blends but the smoke emissions were lower than that of diesel. It has been concluded that the blends of ester gave better performance and reduction in emissions.

Conclusions

From the present review, it is observed that the blend of alcohol fuel with diesel fuel up to 20% can be used in diesel engine without any modification. There are no significant differences in the power produced or in the thermal efficiency of the diesel engine with alcohol fuels. Generally alcohol fuels have a longer ignition delay and shorter combustion duration and slightly more brake specific fuel consumption. Soot, CO_2 and SO_2 emissions are less for the alcohol-diesel blended fuels, but UHC and NO_x emissions are more when compare to that of pure diesel fuel.

From the present review, it is observed that the long-term use of vegetable oils results in problems like heavy smoke emissions and carbon deposition in various parts of the engine due to high viscosity and carbon residue. Use of 100% vegetable oils in diesel engine results in almost same engine power with slightly lower thermal efficiency in comparison to diesel engine. Studies showed that the 20% mix of vegetable oil fuel blends would provide better results. Also carbon deposit in the engine are reduced if the oil was heated prior to combustion. Similar performance and higher emissions with vegetable oils as compare to diesel fuel are reported. Carbon monoxide and hydro carbon emissions are higher than diesel fuel. These higher emissions are due to high fuel viscosity and fuel spray characteristics of vegetable oil. NO_x emission is lower for vegetable oil because of high percentages of fully saturated fatty acids.

From the present review, it is observed that the injection and ignition process can be altered significantly by biodiesels and their blends. Generally Biodiesel has a lower ignition delay. Studies showed that the 20% of biodiesel blends can be substituted for diesel fuel in CI engine. Value of oxides of nitrogen emission from biodiesels were higher as compare to diesel, whereas the carbon monoxide, hydrocarbon, and smoke emission of biodiesel fuels are lower than diesel. From the review, it is observed that the combustion characteristics of biodiesel are almost similar to that of diesel and slightly inferior performance as compared to diesel.

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