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A Review on Performance and Emission Studies of CI Engine Fuelled With Vegetable Oil and Bio-Diesel

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***Abstract*— Vegetable oils and their derivatives (especially methyl esters), commonly referred to as "biodiesel," are prominent candidates as alternative diesel fuels. They have advanced from being purely experimental fuels to initial stages of commercialization. They are technically competitive with or offer technical advantages compared to conventional diesel fuel. Straight vegetable oil (SVO), an alternative fuel of petroleum diesel, is mainly used to reduce the environmental impact of emission without modifying engines. It was found that the performances mainly torque and brake power of both SVO and biodiesel reduces with increasing blend ratio which can be attributed to lower energy content of SVO. Specific fuel consumption increases for both SVO and bio-diesel compared with diesel fuel.**

The methyl asters of vegetable oils, known as biodiesel are becoming increasingly popular because of their low environmental impact and potential as a green alternative fuel for diesel engine and they would not require significant modification of existing engine hardware. Besides being a renewable and domestic resource, biodiesel reduces most emissions while engine performance and fuel economy are nearly identical compared to conventional fuels. SVO of rice bran oil (RBO), jatropha, karanja etc. are derived through oil extraction process from respective plant seeds. Experimental investigations have been carried out to examine properties, performance and emission of different blends of SVO (RBO and jetropha) and biodiesel (karanja) in comparison to diesel. Results indicate that blends of 25% RBO show results closure to diesel, Thermal efficiency was lower for unheated Jatropha oil compared to heated Jatropha oil and diesel. CO_2, CO and HC were higher for Jatropha oil compared to that of diesel. These emissions were found to be close to diesel for preheated Jatropha oil. The engine performance and emissions with biodiesel of Karanja and its blends were comparable to the performance with diesel fuel. The BTE was about 3 - 5% lower with Karanja biodiesel and its blends with respect to diesel. The oxides of nitrogen from Karanja biodiesel and its blends were higher than diesel fuel at all loads and emissions such as CO, smoke density and HC were reduced as compared to diesel.

***Keywords*- Biodiesel, diesel engine performance, emissions, Trans-esterification, Vegetable oil.**

I. INTRODUCTION

The invention of internal combustion engine and subsequent developments in engine technology led to wide spread exploitation of the petroleum reserves, which are being depleted at a rapid rate. Moreover, the combustion of these fuels has polluted the environment. Renewable fuels, such as vegetable oils and alcohols, are an alternative. Various problems are associated with vegetable oils being used as fuel in diesel engines. This problem is due to high viscosity, density, iodine value and poor non-volatility of the vegetable oil, which lead to problems in pumping, atomization and poor combustion inside the combustion chamber of a diesel engine. In the case of long-term operation of vegetable oils problems such as gumming, injector fouling, piston and ring sticking and contamination of lubricating oils are bound to occur. All these problems are due to the high viscosity of vegetable oils. Hence, it is necessary to reduce the viscosity of vegetable oil more approximate to that of diesel. The solution to the problems has been approached in several ways, such as preheating the oils, blending them with diesel, thermal cracking and transesterification. Tranesterification, or alcoholysis, is the reaction of a fat or oil with an alcohol to form esters and glycerol.

The literature clearly shows that transesterification is the best way to use vegetable oil as fuel existing diesel engine.

A. *Methods of improving the performance of straight vegetable oils*

- Preheating the vegetable oil
- Addition with another light vegetable oil for example orange peel oil
- Blending with fossil fuels like diesel
- Trans-esterification

Blending with fossil fuels: In this method the vegetable oil is blended with fossil fuels (diesel is commonly used).As a result of this blending the reduction in viscosity is accompanied by decrease in its density, its volatility is also improved .Thus desirable fuel characteristics are obtained.

Trans-esterification: In this method the vegetable oil is converted into what is better known as biodiesel. This process is used to convert the vegetable oil into a product which is nothing but a methyl ester or ethyl ester of the vegetable oil.

Trans-esterification also called alcoholysis is the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis. This process has been widely used to reduce the viscosity of triglycerides. The trans-esterification reaction is represented by the general equation.

RCOOR' + R"OH = RCOOR" + R'OH

If methanol is used in the above reaction, it is termed methanolysis. The reaction of triglyceride with methanol is represented by the general equation. Triglycerides are readily trans-esterified in the presence of alkaline catalyst at atmospheric pressure and at a temperature of approximately 60 to 70°C with an excess of methanol. The mixture at the end of reaction is allowed to settle. The lower glycerol layer is drawn off while the upper methyl ester layer is washed to remove entrained glycerol and is then processed further. The excess methanol is recovered by distillation and sent to a rectifying column for purification and recycled. The trans-esterification works well when the starting oil is of high quality. However, quite often low quality oils are used as raw materials for biodiesel preparation. In cases where the free fatty acid content of the oil is above 1%, difficulties arise due to the formation of soaps which promote emulsification during the water washing stage and at an FFA content above 2% the process becomes unworkable.

TABLE I

Engine type	Four-stroke, stationary, water cooled diesel engine
Injection type	Direct injection
Loading type	Eddy current dynamometer

TABLE II

Property	**Diesel**	**RBO**	**Jatropha**	**karanja**
Density, kg/l	0.8	0.935	0.918	0.938
Calorific value, kJ/kg	43356	38952	37500	41660
Viscosity centis-okes (cSt)	3.39	28.7	37	35.98
Flash point, ºC	70	200	238	237
Cetane number	40 - 60	30	43	38

II. EFFECT ON ENGINE PERFORMANCE

S. Saravanan, G. Nagarajan, G. L. N. Rao and S. Sampath conduct experiment using crude rice bran oil (RBO) without modification and various blends used as a fuel in diesel engine and Testing is carried out at various loads starting from no load condition to 100 % of the rated load condition. The engine is loaded by means of an eddy current dynamometer.

Studies conducted indicated that 25 % RBO shows better results than other blends and RBO in performance, emission and combustion. The results of this blend are similar to those of diesel and superior to those of pure RBO. Figure 1 shows the variation of specific energy consumption (SEC) with load for diesel, RBO and the blends of RBO. SEC is the amount of heat energy consumed by the engine to generate 1 kWh of energy. It is a function of efficiency of energy conversion and calorific value. The SEC of RBO is higher than that of all the other fuels at all loads. It was also observed that diesel has the lowest SEC. However, the SEC of 25 % RBO is very close to that of diesel. At higher loads its value is slightly higher than that of diesel.

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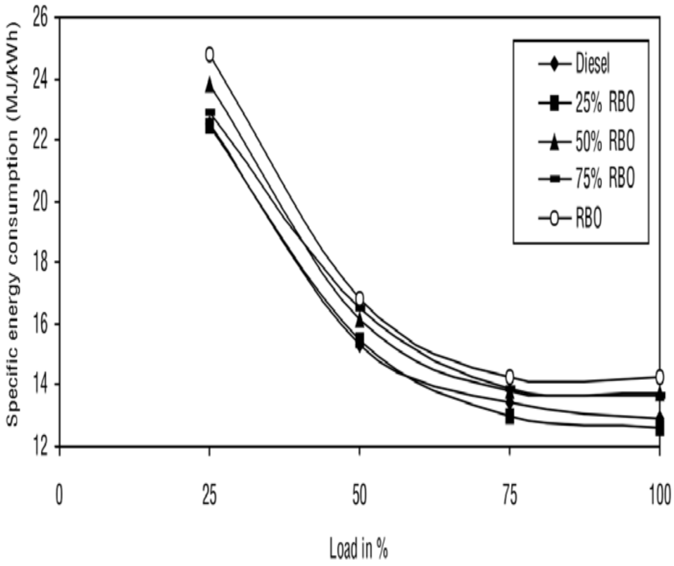

Fig.1. Specific energy consumption as a function of load

B.S. Chauhan et al. in 2012 study the performance and emission characteristic of diesel engine fuelled with karanja biodiesel and its blends. It was observed that BTE of mineral diesel is higher than any of the biodiesel based fuel and its blends which is shown in fig. 2.

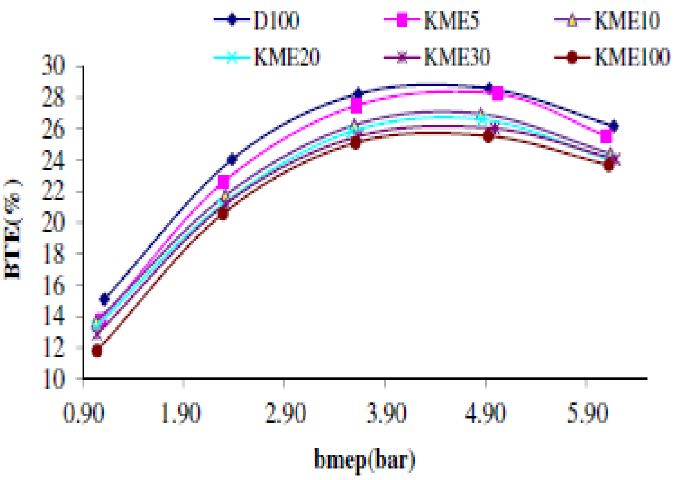

Fig.2. Variation of brake thermal efficiency with brake means effective pressure.

The BTE of biodiesel based fuel samples were found to be decreasing with increasing biodiesel content in the biodiesel/diesel blends. It was also observed that the power produced with biodiesel based fuels is lower than mineral diesel. This may be due to the lower calorific value of biodiesel and its higher density. The lower BTE obtained for B100 fuels could be due to the reduction in calorific value and increase in fuel consumption as compared to diesel fuel [4]. This indicates that the thermal efficiency is a more representative reflection of the fuel economy by using the diesel equivalent energy consumption rate when operated on oxygenated fuels like biodiesel.

Fig. 3 shows the variation of exhaust temperature of diesel fuel and Karanja biodiesel and its blends. It is clear that the exhaust gas temperature increases with increase in brake power for all the test fuels. The maximum exhaust temperature of all the biodiesel fuels is lower than diesel.

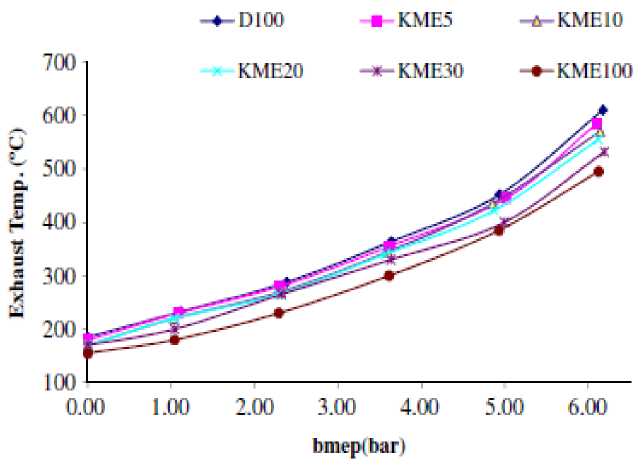

Fig.3. Variation of exhaust temperature with brake means effective pressure.

It was also observed that the exhaust gas temperature of all the biodiesel based fuels were lower than the petroleum diesel. It is also seen that as the biodiesel substitution in diesel is increased, the exhaust gas temperature reduces. This may be due to the reason that the exhaust gas temperature is affected by the change in ignition delay. Longer ignition delay results in a delayed combustion and higher exhaust gas temperature.

D. Agarwal, A.K. Agarwal in 2007 conduct experiment on jatropha oil and its blend with diesel and they found that BSFC as shown in fig 4 was found to increase with higher proportion of Jatropha oil in the blend compared to diesel in the entire load range. Calorific value of Jatropha oil is lower compared to that of diesel, therefore increasing proportion of Jatropha oil in blend decreases the calorific value of the blend which results in increased BSFC. Thermal efficiency as shown in fig. 5 of Jatropha blends was lower than that with diesel. Thermal efficiency was lower for unheated Jatropha oil compared to heated Jatropha oil and diesel. However, thermal efficiency of blends up to J20 was very close to diesel. Oxygen present in the fuel molecules improves the combustion characteristics but higher viscosity and poor volatility of vegetable oils lead to their poor atomization and combustion characteristics.

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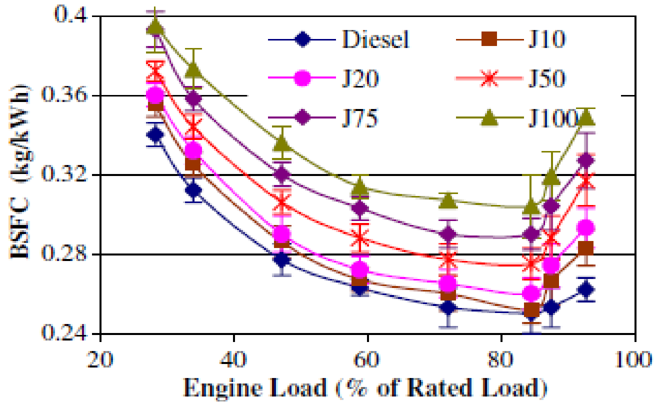

Fig.4. BSFC vs. Engine load

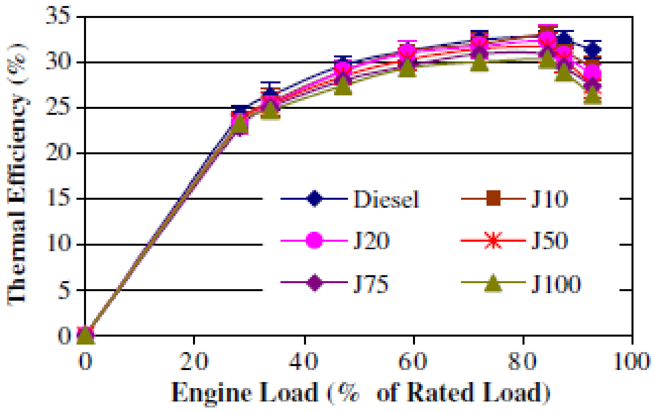

Fig.5. Thermal Efficiency vs. Engine load

Therefore, thermal efficiency was found to be lower for higher blend concentrations compared to that of mineral diesel.

III. EFFECTS ON ENGINE EMISSIONS:

RBO: Emissions of unburnt hydrocarbons (UBHCs) occur due to incomplete combustion of fuel molecules. This is an effect of wall quenching. The study of UBHC emissions is important as they contribute to photochemical smog.

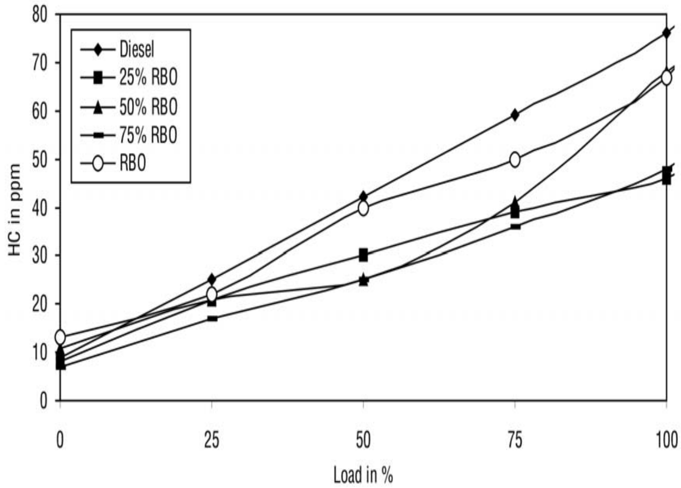

Fig. 6 Hydrocarbon emission as a function of load

The variations of UBHC emissions for RBO and its blend with load are shown in Figure 6. The UBHC emissions of all the fuels are lower at partial load, but tend to increase with load due to fuel-rich mixture at higher loads. As the air-fuel (A/F) ratio is high, the UBHC emissions of RBO and its blends are considerably lower than that of diesel fuel. The oxygen content in the RBO may improve the combustion process but its higher viscosity results in improper atomization. Hence the blends of RBO result in a lower UBHC emission than the pure form.

CO emissions are a result of the lack of oxygen and low combustion temperature, resulting in incomplete oxidation of CO to CO2. Haemoglobin present in the blood has a greater affinity for CO than for O2 and thus inhaling CO leads to a lack of oxygen in the blood, resulting in headaches, unconsciousness, coma or even death, depending upon the duration and concentration of CO. Hence study of CO emissions is very important. Figure 12 compares the CO emissions of the fuels under investigation. CO emissions from diesel engines are usually low since they operate on lean mixtures. In Figure 7 it can be observed that the CO emissions increase with loads for all fuel blends. Moreover, CO emissions appear to be lower for some blends compared to diesel or pure RBO. It is not clear, however, why the 50 % blend emits more CO than either the 25 % or the 75 % blend. The factors that are likely to influence CO formation are viscosity, atomization of the fuel, and oxygen content of the fuel.

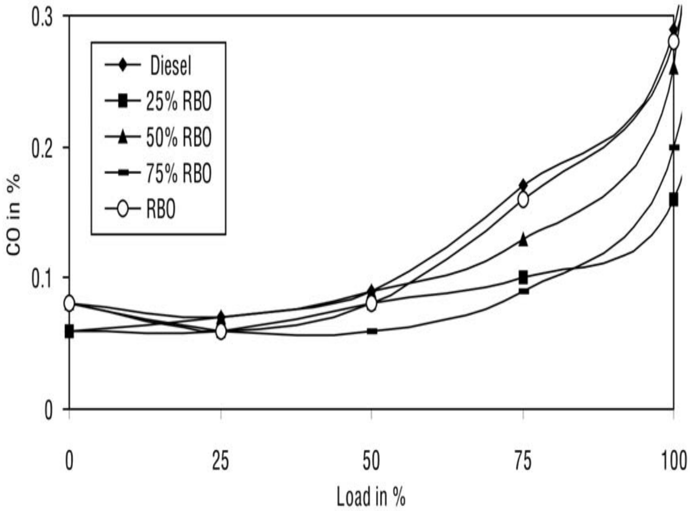

Fig.7. CO emission as a function of load

The higher viscosity of RBO affects the atomization process, resulting in localized rich mixtures of the blend. This should result in higher CO formation. But the oxygen content in the fuel in addition to the air supplied during induction helps to reduce CO formation by combining with CO to form CO2. The two effects counteract each other with the result that CO emissions are substantially reduced at high loads with the 25 % RBO blend.

Carbon dioxide is an inevitable product of combustion of hydrocarbons. CO2 emitted from combustion of fossil fuels contributes to the greenhouse effect, resulting in global warming. However, the CO2 emissions of bio fuels do not contribute to the greenhouse effect as they maintain the CO2 balance in the atmosphere (CO2 produced by combustion is absorbed by the plants from which the bio fuel is produced).

Figure 8 compares the CO2 emissions of diesel with RBO and various blends of RBO. CO2 emissions were virtually identical for all fuel blends for most of the loads.

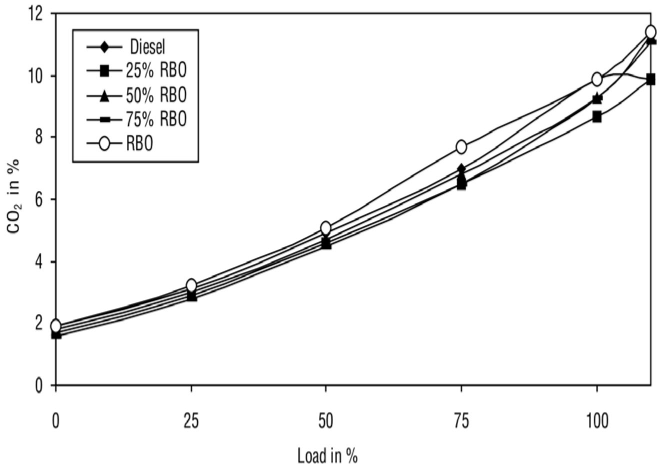

Fig.8 Carbon dioxide emission as a function of load

Oxides of nitrogen (NOx) are a major air pollutant and also contribute to acid rain. NOx are formed by the combination of nitrogen and oxygen in air at high temperatures. Higher combustion temperatures in CI engines result in higher NOx emissions. Figure 9 shows the comparison of NOx emissions of diesel with RBO and various blends of RBO. It is evident that there is considerable reduction in NOx at all loads for RBO when compared with diesel and blends of RBO. 25 % RBO produces slightly higher NOx than diesel fuel. Due to the shorter ignition delay the combustion temperature of RBO is lower than that of diesel, which reduces the NOX emission. The heat release during the late combustion phase for 25 % RBO is marginally higher than that for diesel. The constituents of RBO with higher boiling points continue to burn in the late combustion phase. This results in a higher combustion temperature for 25 % RBO when compared to diesel. Due to the higher viscosity of RBO its combustion temperature is lower than those of diesel and 25 % RBO.

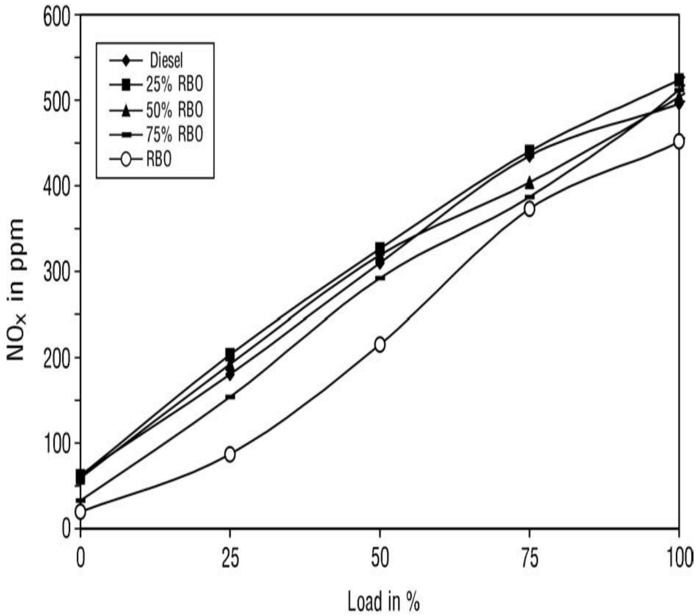

Fig.9 NOx emission as a function of load

Karanja Biodiesel: The values of unburned hydrocarbon (UBHC) emission from the diesel engine in case of Karanja methyl ester and its blends is less than diesel fuel as evident from the Fig. 10. The UBHC emissions are found lower at partial load conditions and increases at higher engine load [4].

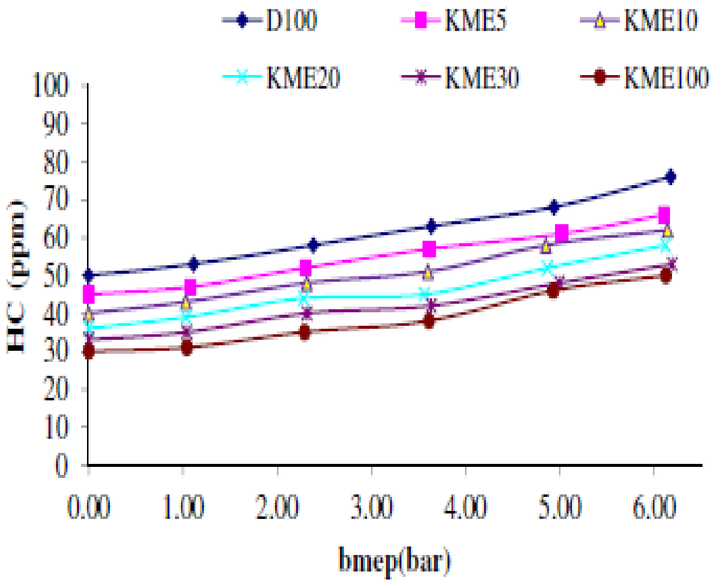

Fig.10 Variation of hydrocarbon with brake mean effective pressure

This is due to relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at higher engine load. The value of UBHC emission from no load to full load is higher in case of diesel compared to biodiesel based fuels.

Hydrocarbons emissions are mainly caused due to the incomplete combustion of hydrocarbon fuel. The maximum reduction in UBHC was achieved for neat biodiesel fuels. For the blended biodiesel fuel, the reduction in UBHC was lower than neat diesel.

Within the whole experimental range, the CO emission from the Karanja methyl ester and its blends is lower than neat diesel fuel as shown in the Fig. 11. For all the biodiesel fuels and their blends, CO emissions were found to be lower. As the load is increased on the engine, there is an increase in CO emission for all the test fuels. The increase in CO emission levels at higher load is due to rich mixture at higher load condition than at lower load which results in incomplete combustion of fuel. Within the experimental range, the lower CO emissions have been observed with blended biodiesel fuel and least in B100 samples [5, 6]. This is possible because of complete combustion of biodiesel based fuels since biodiesel contains more oxygen than diesel and as such carbon monoxide is converted in to carbon dioxide.

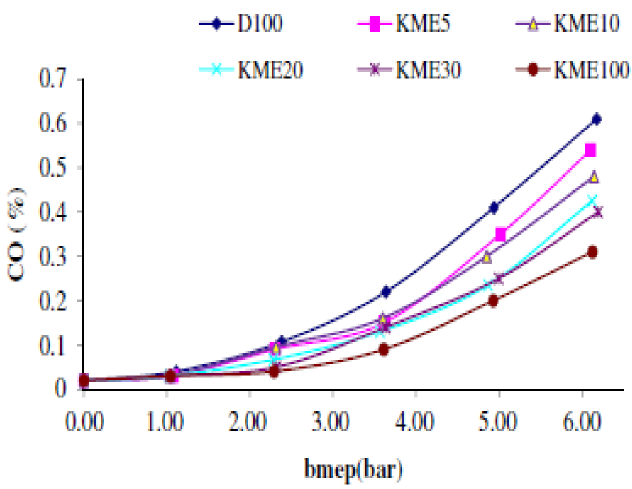

Fig.11. Variation of carbon mono oxide with brake means effective pressure.

The variation in CO2emissions is shown in the Fig. 12. In the range of whole engine load, the CO2 emissions of diesel fuel are lower than that of Karanja biodiesel and its blended fuels. The highest CO2 emissions have been observed in case of neat biodiesel fuel. This is because biodiesel and its blends contain more oxygen element, which results in better combustion. The carbon content is relatively lower in the same volume of fuel consumed at the same engine load, because of more oxygen content in B100 and their blends; there was a considerable increase in CO2 emissions with all the biodiesel fuels and their blends. CO2 emission was found to increase as the proportion of biodiesel increases in mineral diesel.

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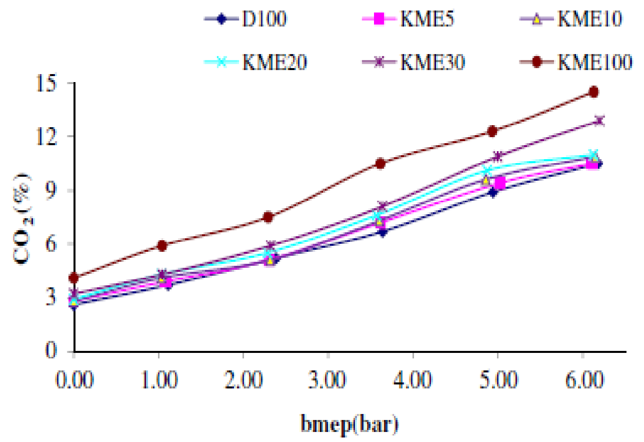

Fig.12. Variation of carbon dioxide with brake means effective pressure.

The variation of NOx emissions from Karanja methyl ester and its blends with respect to diesel fuel are shown in Fig. 13.The NOx emissions increased with the increasing engine load, due to a higher combustion temperature. The NOx emissions are determined by equivalence ratio, oxygen concentration, combustion temperature and time. NOx are formed in cylinder areas where high temperature peaks appear mainly during the uncontrolled combustion.

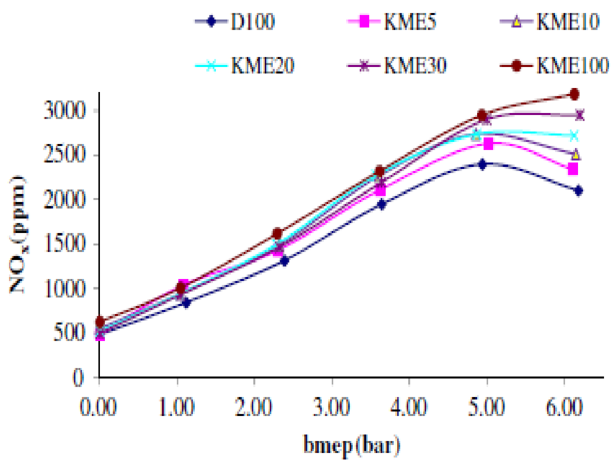

Fig.13. Variation of oxides of nitrogen with brake means effective pressure.

The NOx emissions of biodiesel based fuels have been found higher than diesel on all load conditions. It is quite obvious, that with biodiesel addition in diesel, more amount of oxygen is present in combustion chamber, leading to formation of higher NOx in biodiesel fuelled engines. For blended biodiesel fuels, NOx emissions were higher than neat diesel. This is the most important emission characteristic of biodiesel as the NOx emission is the most harmful gaseous emissions from engines and this emission can be reduced by several methods.

Jatropha Oil: The exhaust gas temperature with blends having higher percentage of Jatropha oil was higher compared to that of diesel at higher loads (Fig. 14). The smoke opacity increases with increase in Jatropha oil concentration in blends particularly at higher loads (Fig. 15). Higher smoke opacity may be due to poor atomization of the Jatropha oil. Bulky fuel molecules and higher viscosity of Jatropha oil result in poor atomization of fuel blends. Lowest CO2 emissions were observed for diesel. CO2 emissions for lower blend concentrations were close to diesel. But for higher blend concentrations, CO2 emissions increased significantly(Fig. 16). The emissions of CO increase with increasing load (Fig. 17). Higher the load, richer fuel–air mixture is burned, and thus more CO is produced due to lack of oxygen. At lower loads, CO emissions for Jatropha oil are close to mineral diesel. Jatropha oil blends exhibit higher HC emissions compared to diesel (Fig. 18). It can be observed that HC emissions increase with increasing proportion of Jatropha oil in the blends. These emissions were found to be close to diesel for preheated Jatropha oil.

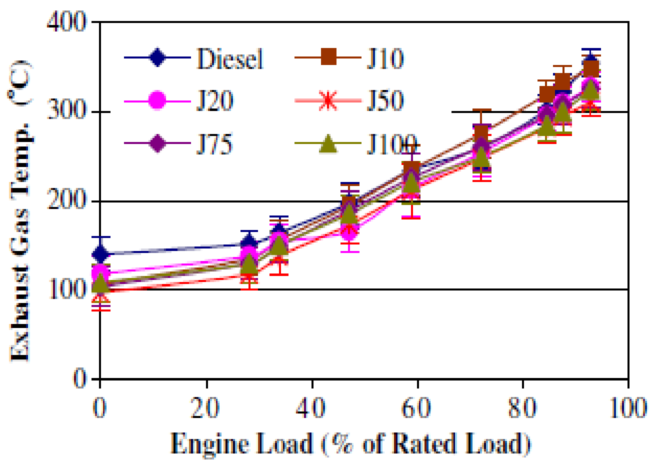

Fig.14. Exhaust gas temperature vs. Engine load

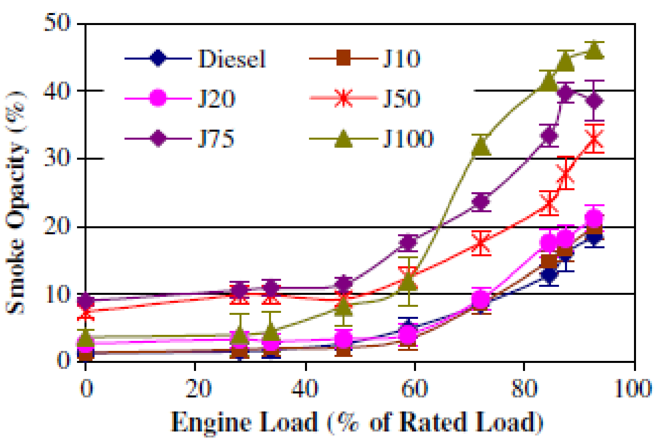

Fig.15. Smoke opacity vs. Engine load

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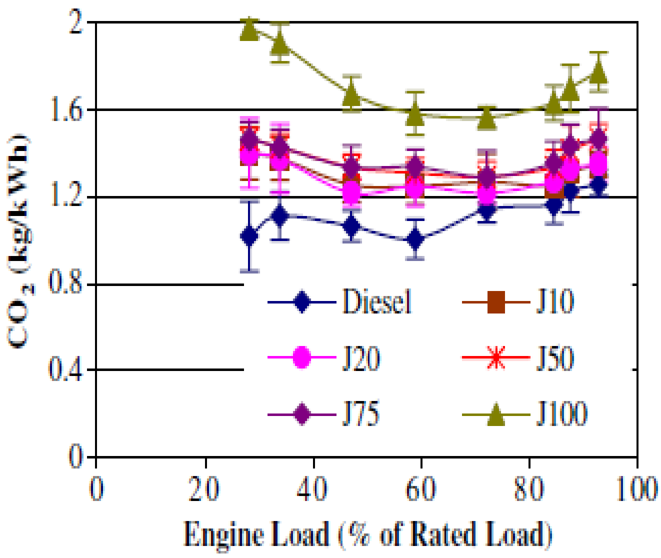

Fig.16 CO2 vs. Engine load

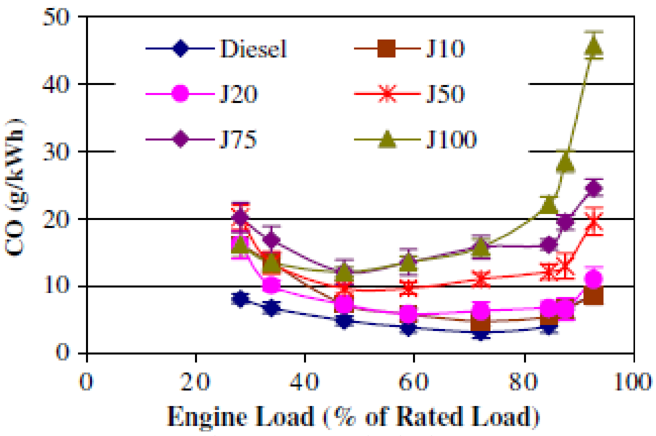

Fig.17. CO vs. Engine load

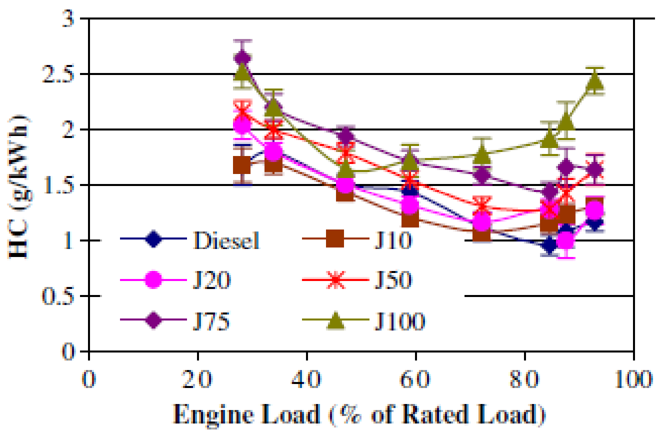

Fig.18. HC vs. Engine load

CONCLUSION

From the above-summarized studies it can be concluded that the usage of pure vegetable oil, straight or in a blend with fossil diesel, in a compression ignition engine cannot be underrated. Certainly in tropical developing countries like India the use of pure vegetable oil, straight or as a blend, is believed to have great potential. The diesel engines in these countries are easier to adapt to the characteristics of these fuels as the tropical temperatures lower the viscosity of the oil. Stationary diesel engines running at low speed, such as irrigation pumps and electricity generators, are believed to be suitable to pure vegetable oil and their blends without a too high environmental burden. Straight vegetable oils have the potential to reduce NOx emissions which is one of the major concerns of the world today. The review conclusively establishes that straight vegetables and their blends still hold a lot of promise as regards to their usage in compression ignition engines. Further research can be taken up in this field.

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