Tribological Investigation and the Effect of Karanja Biodiesel on Engine Wear in Compression Ignition Engine

Ajay V. Kolhe, R. E. Shelke, S. S. Khandare

Abstract—Various biomass based resources, which can be used as an extender, or a complete substitute of diesel fuel may have very significant role in the development of agriculture, industrial and transport sectors in the energy crisis. Use of Karanja oil methyl ester biodiesel in a CI DI engine was found highly compatible with engine performance along with lower exhaust emission as compared to diesel fuel but with slightly higher NOx emission and low wear characteristics. The combustion related properties of vegetable oils are somewhat similar to diesel oil. Neat vegetable oils or their blends with diesel, however, pose various long-term problems in compression ignition engines. These undesirable features of vegetable oils are because of their inherent properties like high viscosity, low volatility, and polyunsaturated character. Pongamia methyl ester (PME) was prepared by transesterification process using methanol for long term engine operations. The physical and combustion-related properties of the fuels thus developed were found to be closer to that of the diesel. A neat biodiesel (PME) was selected as a fuel for the tribological study of biofuels.

Two similar new engines were completely disassembled and subjected to dimensioning of various vital moving parts and then subjected to long-term endurance tests on neat biodiesel and diesel respectively. After completion of the test, both the engines were again disassembled for physical inspection and wear measurement of various vital parts. The lubricating oil samples drawn from both engines were subjected to atomic absorption spectroscopy (AAS) for measurement of various wear metal traces present. The additional lubricating property of biodiesel fuel due to higher viscosity as compared to diesel fuel resulted in lower wear of moving parts and thus improved the engine durability with a bio-diesel fuel. Results reported from AAS tests confirmed substantially lower wear and thus improved life for biodiesel operated engines.

Keywords—Transesterification, PME, wear of engine parts, Metal traces and AAS.

I. Introduction

THE world's economy depends upon the burning of fossil fuels equivalent of some 180 million barrels of oil each day. The need to exploit bio-origin-based alternative fuels to quench the world's energy thirst has long been realized. By now, it has been conclusively realized that internal combustion engines form an indispensable part of modern life style. They play a vital role in transportation and modern mechanized agricultural sector. Ever since the advent of the IC engines, vegetable oils have been tried as an alternative to the diesel fuel. The inventor of the diesel engine, Rudolf Diesel, used peanut oil as a diesel fuel for demonstration at the 1900 world exhibition in Paris. The same petroleum-based fuel used in Diesel's days is still the fuel of choice in modern motorized society. It is only in recent years that systematic efforts have been made to utilize vegetable oils as fuels in engines. But, in the Indian context, only non-edible vegetable oils can be seriously considered as a fuel for CI engines as the edible oils are in great demand and are far too expensive at present. Moreover, there is a vast forest resource from which oil can be derived and formulated to give combustion-related properties close to that of diesel oil. The biodiesel has emerged as alternative for diesel fuel [1], [3]-[5], due to renewable nature, better ignition quality, comparable energy content, higher density, better safety due to higher flash point [2], [6]-[9]. It is sulphur free, non aromatics, non toxic, and oxygenated. Therefore, the process of utilizing Biodiesel in the IC engines for transport as well as other applications, is gaining momentum. The international energy agency has recognized biodiesel as an alternative fuel for the transportation sector. Karanja plant can be grown in the wasteland and does not require too much care. It can be cultivated in all available wasteland to meet the total fuel requirement in future [10]-[12]. The process of transesterification yields vegetable oil esters. Vegetable oil esters have better fuel properties compared to neat vegetable oils. Their viscosity reduces, volatility increases, and they lose their polyunsaturated character after transesterification. The stoichiometry of the overall transesterification reaction requires 1 mole of triglyceride for 3 moles of glycerol. Transesterification process breaks the triglycerides present in vegetable oils into two components, fatty acid esters, and glycerol. Glycerin is a valuable by-product, which is used in pharmaceuticals, cosmetics, toothpaste, and many other commercial products. Biodiesel is often blended with petroleum diesel to offset its high production cost. Pure 100 percent ''neat'' methyl esters of rapeseed, soybean, sunflower, tallow, Jatropha, pongamia and other fats and oils can be used as diesel fuel with little or no modifications of the engine. Biodiesel from Karanj oil shows no corrosion on piston metal and piston liner whereas biodiesel from *Jatropha curcas* has slight corrosive effect on piston liner. In the present investigation, biodiesel was prepared from Karanj oil and its properties were analyzed to ascertain its suitability as biodiesel. Stanislav Pehan have

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performed test on a fully equipped engine test bed, on a fuel injection test bed and on a discharge coefficient testing device. The tested fuel was neat biodiesel produced from rapeseed. Attention was focused on the biodiesel influence on the pump plunger surface roughness, on the carbon deposits in the combustion chamber, on the injector and in the injector nozzle hole. The pump plunger surface was analyzed by experimentally determined roughness parameters and by a microscope. The carbon deposits at fuel injector and in the combustion chamber were examined using endoscopic inspection. The deposits in the injector nozzle were investigated indirectly by measuring the nozzle discharge coefficient. Numerical simulation has been performed in order to estimate the influence of the discharge coefficient variation on the computed injection characteristics. The obtained results indicate that biodiesel usage may even improve the pump plunger lubrication conditions [13]-[15]. Jianbo Hu studied unrefined biodiesels containing small quantities of monoglycerides, di glycerides, and triglycerides, and refined biodiesels not containing these glycerides were added to diesel fuel and the resulting lubricity was measured using the High Frequency Reciprocating Rig (HFRR) method. The unrefined biodiesels showed higher lubricity properties than refined biodiesels. The chemical factors influencing the lubricity properties of biodiesels were investigated. Methyl esters and monoglycerides are the main compositions that determine the lubricity of biodiesels that meet international standards [16].

II. Experimental Set Up

For the present work, pongamia oil methyl ester was prepared using methanol in the presence of potassium hydroxide as catalyst, and then separating by-product glycerol formed in the esterification reaction. The use of pongamia oil methyl ester in compression ignition engines was found to develop a very compatible engine fuel system with low emission characteristics. The physical and combustion related properties of the fuels thus developed by the Process of esterification were determined in the laboratory and most of them were found very close to that of diesel oil. The constant speed experimental test unit, manufactured by Kirloskar oil engine Ltd., India, is a compact, portable captive 4.41 kWh gen-set run by diesel fuel. It is widely used in the country mostly for agricultural purposes and in many small and medium scale commercial purposes. This is a single-cylinder four-stroke air-cooled system that develops 4.41 kW power output in pure diesel mode. It has a provision of loading electrically, and is flexibly coupled with a single-phase alternator. Detailed specifications of the engines used in present investigations are given in Table I. The engine can be started by hand cranking. The test engine is directly coupled to a 220 volts AC generator of sufficient capacity to absorb the maximum power produced by the engine.

III. Engine Tests

After developing the appropriate fuel, it was tested on the engine through a series of engine tests. In the long-term endurance test, the effect due to the use of biodiesel on various parts of the engine and diesel fuel was studied. For this purpose, two similar new engines were subjected to similar loading cycles and operating conditions. The assessment of wear of various parts of pure biodiesel and diesel-fueled engines was done after dismantling the various parts of the engine and lubricant analysis by using atomic absorption spectroscopy. The various tests on the two-engine systems are conducted as per the procedure specified in IS10000, 1980.

TABLE I
Technical Specifications of the Test Engine

Manufacturer	Kirloskar oil engine Model Single cylinder C.I.Engine
I.S.Rating(1500rpm)	4.41kw (6 bhp)
Bore	87.5mm
Stroke	110 mm
Displacement	662 cm3
Nozzle pressure	210 bar
Compression ratio	17.5:1

Fig. 1 Loading panel and experimental set up

IV. Preliminary Runs

The purpose of preliminary run for both the engines is that they should be made trouble free, by operating both the engines for their running-in period. Under the preliminary run, constant speed engines are subjected to a preliminary run of

49 hours at the rated speed under the operating temperature specified by the manufacturer, in nonstop cycles of seven hours each, conforming to the following cycle pattern. During the preliminary run, attention was paid to engine vibration and quietness. Oil pressure was checked time to time.

V. Long-Term Endurance Test

The lubricating oil from the oil sump was drained off and the engines were refilled with SAE 30 grade of fresh lubricating oil as specified by the manufacturer and the engines were then ready for long-term endurance test. Then both the engines were run for 10 cycles each of 16 hours continuous running at rated speed. The first engine was using 100 percent biodiesel, and the second engine was using neat diesel oil as fuel. The engines were then topped up with engine oil, if required and the quantity consumed recorded. The lubricating oil samples were collected from the engines after every 32 hours for conducting various Tribological studies.

VI. Engine Wear

Wear debris originate from various sliding and rotating component in engine and washed away by lubricants and finally get accumulated in the oil sump. The metallic wear debris, which originates from different parts, may have different composition depending on the origin. Hence metal analysis of lubricating oil gives a fair idea of wear of vital components of the engine. Various metals such as Iran (Fe), Copper (Cu), Chromium (Cr), Aluminum (Al), and Lead (Pb) were analyzed.

VII. Atomic Absorption Spectroscopy

Atomic absorption spectroscopy was used for quantitative and qualitative analysis of wear debris of lubricating oils. The data was correlated with the extent of wear, the performance characteristics of either lubricating oils or diagnosis of failure of moving components. Atomic absorption spectroscopy works on the principle of absorption interaction, where atoms in the vapor-state absorb radiation at a certain wavelength that are well defined and show the characteristics of a particular atomic element. In this process, the source of radiation projects a beam of a specific wavelength through a pure flame on to a sensor and the amount of radiation arriving at the photo sensor is recorded. The fluid sample is introduced into the flame and vaporized. The amount of radiation arriving at the photo sensor is reduced in proportion to the quantity of the specific element present in the sample.

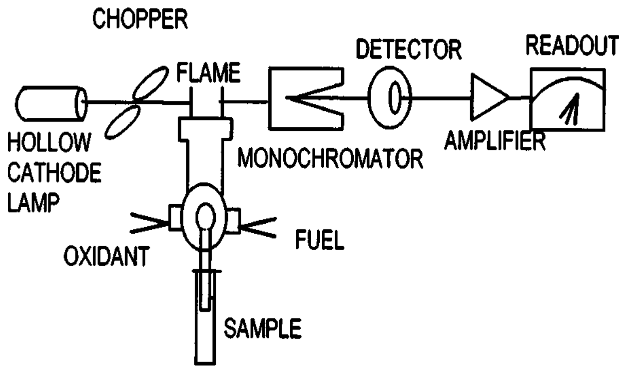

Fig. 2 Schematic diagram of Atomic Absorption Spectroscopy

VIII. Elemental Analysis of Lubricating Oil by Atomic Absorption Spectroscopy

The test of AAS was done to evaluate the concentration of various metals present in the lubricating oil samples from POME fueled and diesel-fueled CI engines. This gave a fair idea about the wear of different parts, material compatibility of the new fuel with the existing engines. In the present study, since many sliding components were involved, it was anticipated that the wear debris originating from different metallic parts appeared in the lubricating oil. Hence, various elements such as Fe, Cu, Zn, Cr, Cd, Ni, Co, and Pb were analyzed by AAS.

IX. Graphical Representation for Lube Oil Concentration

A. Iron

The iron in wear debris could be because of wear of the cylinder liner, piston, rings, valves, valve guides, gears, shafts, bearing, rust, and crankshaft. The results on concentration of iron as a function of oil usage are shown in graphs. It is clearly seen that for both the systems, iron increased at a higher rate during the endurance test. The most important observation was that lubricants from POME fueled system indicated a lower increase in iron content and hence lesser wear, which is because of improved lubricating efficiency of biodiesel fuel.

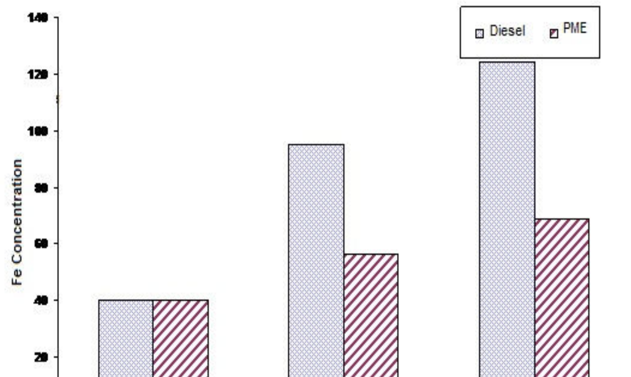

Fig. 3 (a) Iron concentration as function of lube oil usage

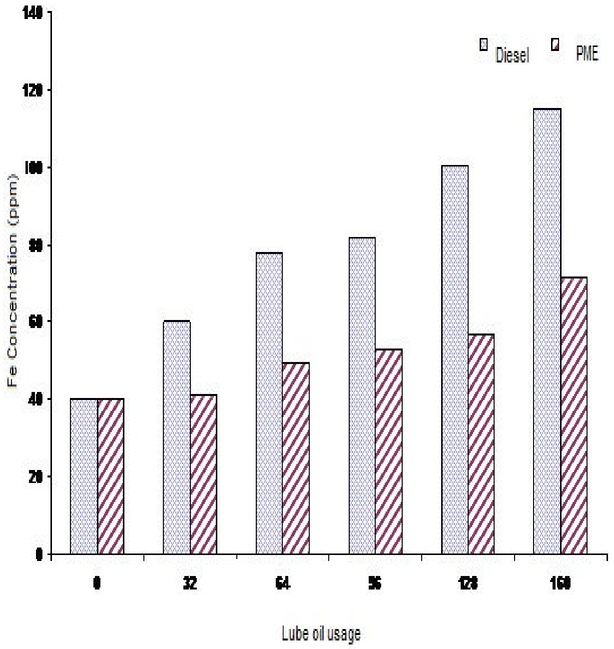

Fig. 3 (b) Iron concentration as function of lube oil usage

B. Copper

The copper in wear debris comes from wear of bearings, and bushings. The results on concentration of copper as a function of oil usage are shown in graphs.. It is evident that for both the systems in pre test, copper increases at a constant rate. An important observation is that lubricant from POME fueled system indicates percent lower copper content till first 64 hours and thereafter higher wear rate.

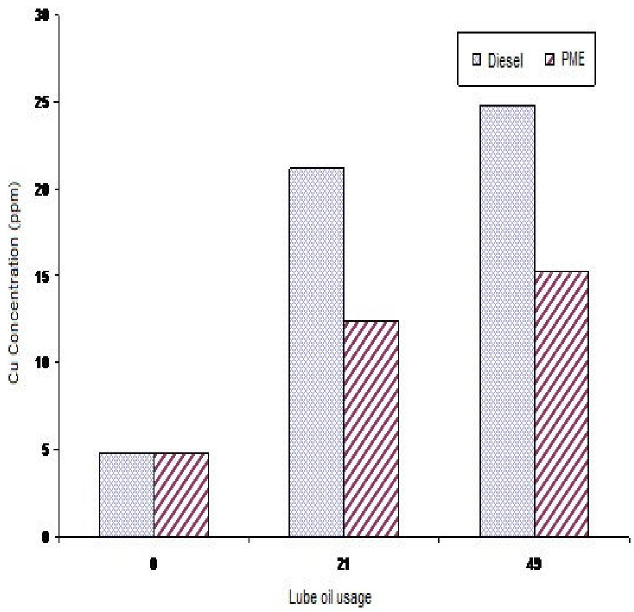

Fig. 4 (a) Cu Concentration as a function of lube oil usage

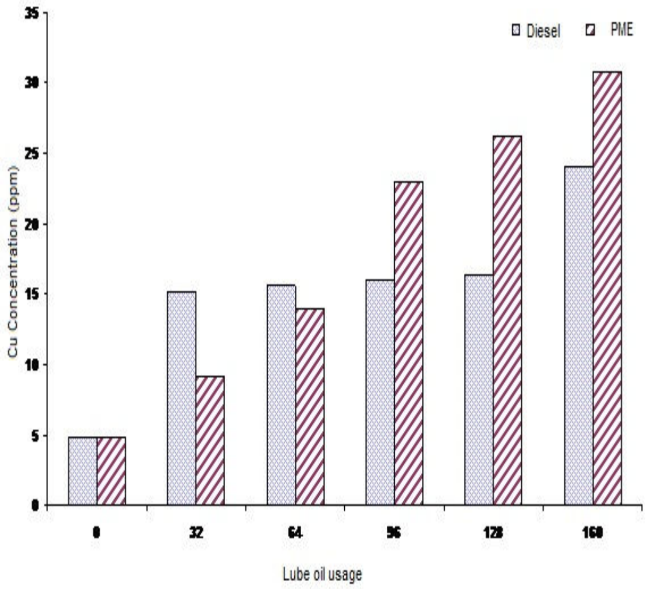

Fig. 4 (b) Cu Concentration as a function of lube oil usage

C. Zinc

The zinc in wear debris could be because of wear of bearings, brass components, neoprene seals, etc. The results on concentration of zinc as a function of oil usage are shown in graphs. The main zinc source in the engine is ZDDP, an additive in lubricating oil. An important observation is that lubricant from POME fueled system indicated lower zinc content increases, hence lower wear of zinc containing components and lower lubricating oil consumption.

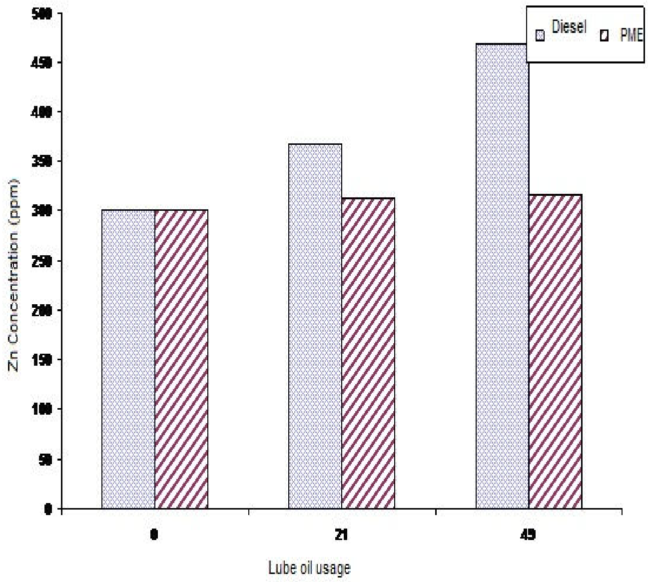

Fig. 5 (a) Zinc concentration as a function of lube oil usage

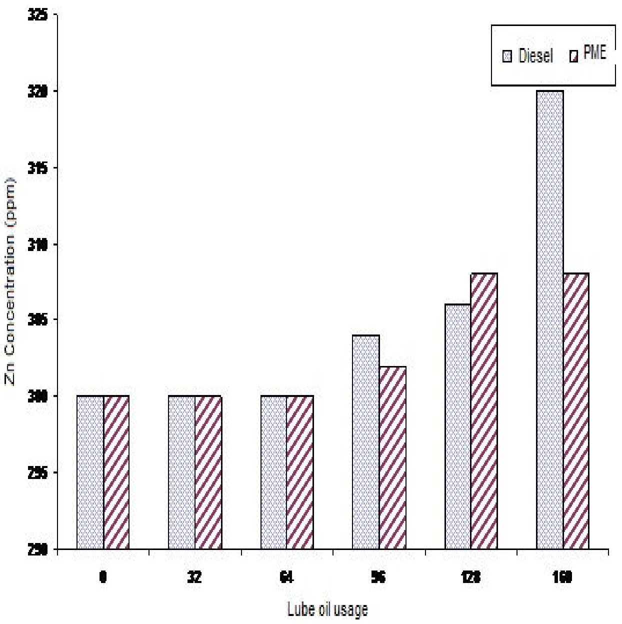

Fig. 5 (b) Zinc concentration as a function of lube oil usage

D. Lead

The lead in wear debris could be because of wear of bearings, paints, and grease addition. The concentration of lead as a function of oil usage is shown in graphs. For both the systems, lead increased at a steady rate. Lubricant from the POME fueled system indicated approximately a 50 percent lower increase in lead during pre test. During main test there steady increase in wear All these observations suggested better additional lubricity properties of biodiesel fuel apart from fuel value, confirming the results of physical wear measurements.

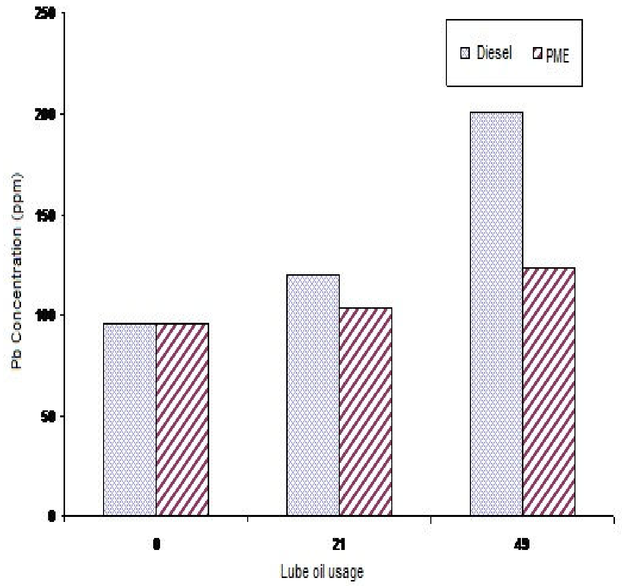

Fig. 6 (a) Lead concentration as a function of lube oil usage

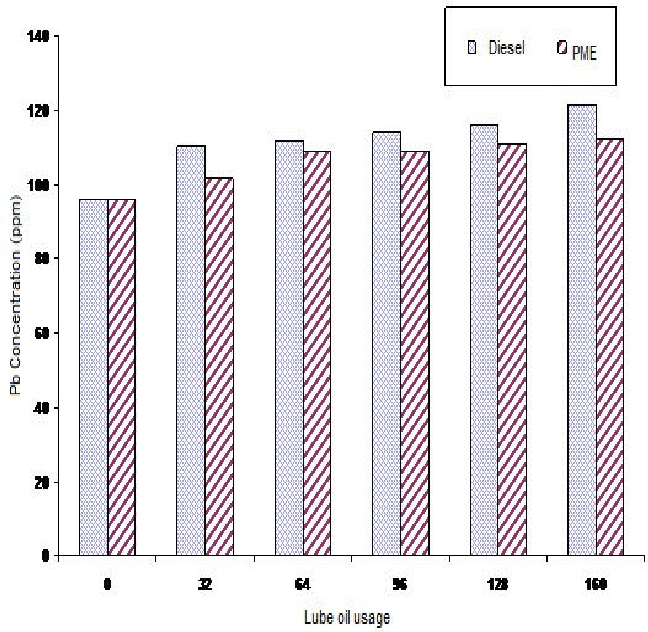

Fig. 6 (b) Lead concentration as a function of lube oil usage

X. Discussions

The wear of various vital parts reduced up to 30 percent because of additional lubricity properties of biodiesel. These results of wear measurements by physical methods were also confirmed by atomic absorption spectroscopy. Oil analysis studies proved to be a powerful tool to estimate not only the condition of the engines, but of other moving parts as well. Moreover, these tests provided valuable and relevant information on the effect of fuel chemistry on the lubricating oil system. Ash content, which mainly represents wear debris, was found to be lesser in the case of a 100 percent biodiesel-fueled system. Atomic absorption spectroscopy studies on lub oils indicated that biodiesel fuel led to lesser wear of engine moving parts in terms of lesser amount of metallic debris ~such as Fe, Cu, Zn, Mg, Cr, Pb, and Co present in lube oil samples. Each element, which is present in oil in the form of wear debris, originated from a different moving part. Such an analysis strongly demonstrated that not only the performance characteristics but also wear characteristics of moving parts are better for a 100 percent biodiesel-fueled engine system.

It has been observed that the wear debris of metals such as Fe, Cu, Cr, Al, Ni and Pb (Figs. 3 to 6) decrease up to 30% with pure Karanja oil biodiesel. One of the possible reasons for lower concentration may be the improved lubricating efficiency due to improved combustion and lower soot formation with biodiesel fuel. Each element, which is present in oil in the form of wear debris, originated from a different moving part.

XI. Analysis of Various Physical Properties of Lubricating Oil

Viscosity of oil is measure of its resistance to flow and is usually measured in terms of Saybolt Universal Seconds, for a given quantity of the oil to flow through a capillary tube under specified conditions. Viscosity is usually measured at two temperatures -18^{0}C and 99^{0}C. Viscosity is expressed in centistokes, centipoise and Redwood seconds. The variation in viscosity of the lubricating oil after endurance test can be seen in above graphs. During pre test as well the main test the viscosity is reduced considerably. This indicates the crankcase dilution. The viscosity variation is more in POME fueled engine.

XII. Conclusions

Based on the studies presented, it is concluded that the fuels of bio-origin are superior in wear performance to conventional fuels, environment-friendly, biodegradable, and do not add to global warming problems. Biodiesel can be readily adopted as a substitute fuel to the existing diesel engines, which are widely used in the rural agricultural sector of the country. It has been observed that the wear debris of metals such as Fe, Cu, Cr, Al, Ni and Pb decrease up to 30% with pure Karanja oil biodiesel. A diesel engine can perform satisfactorily on biodiesel fuel without any engine hardware modifications. Esterification has been found to be an effective technique to prevent all long-term usage problems associated with utilization of vegetable oils such as fuel filter plugging, injector coking, formation of carbon deposits in the combustion chamber, ring sticking, and contamination of lubricating oils.

References

[1] Agarwal A.K., Bijwe and Das,"Wear assessment in a biodiesel fueled compression ignition engine", ASME,Vol.125, Jully 2003.
[2] Agarwal A.K., Bijwe and Das, "Effect of biodiesel utilization of wear of vital parts in compression ignition engine", ASME, Vol.125, April 2003.
[3] Agrawal Deepak, Sinha S., Agrawal A., "Experimental investigation of control of NO_x emissions in Biodiesel-fueled Compression ignition engine.", 6 December 2005, Renewable Energy.
[4] Labeckas G., Slavinskas S.., "The effect of rapeseed oil methyl ester on a direct injection diesel engine performance and exhaust emissions"., Energy Conversion and Management 11(2005),1-14.
[5] D. Karonis, G. Anastopoulos, E. Lois, S. Stournas, F. Zannikos and A. Serdari, "Assessment of the Lubricity Greek Road Diesel and the Effect of the Addition of Specific Types of Biodiesel", SAE paper No.1999-01-1471.
[6] G.Anastopoulos, E.Lois, S.Stournas, F.Zannikos and A. Serdari; "Assessment of The Lubricity of Reek Road Diesel and the Effect Of The Addition of Specific Types of Biodiesel".SAE, 1999-01-1471
[7] Harold K. Speidal and Irshad Ahmed,"Biodegradability characteristics of current and newly developed alternate fuels." SAE,1999-01-3518.
[8] L.Schumacher, S.C.Borgelt,Hires,Wetherell and Nevils," 100000 Mile of Fueling 5.9L Cummins Engines With 100%Biodiesel."SAE.962233.
[9] S.K. Karmee, A. Chadha, "Preparation of biodiesel from crude oil of Pongamia Pinnata", Bioresource Technology 96(2005), 1425-1429.
[10] K. Anand, R.P.Sharma, P.S.Mehta, "Experimental investigations on combustion, performance and emission characteristics of neat karanji biodiesel and its methanol blend in a diesel engine" , Biomass and bioenergy 35 (2011) 533-541.
[11] P.V.Rao, "Experimental investigations on the influence of properties of Jatropha biodiesel on performance, combustion and emission characteristics of a DI-CI engine" , World academy of science, engineering and technology 75 (2011) 855-867.
[12] A.S. Ramadhas, C. Muraleedharan., "Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil"., RenewableEnergy30(2005),1789-1800.
[13] Mustafa C., Eradil A., Arcaklioglu E., "Performance and Exhaust emissions of a Biodiesel engine", Applied Energy 83(2006), 594-605.
[14] Anand Kumar Pandey and M R Nandgaonkar, "Experimental Investigation of the Effect of Esterified Karanja Oil Biodiesel on Performance, Emission and Engine Wear of a Military 160hp Turbocharged CIDI Engine" Proceedings of the World Congress on Engineering 2011 Vol III WCE 2011, July 6 - 8, 2011, London, U.K.
[15] Stanislav Pehan, Marta Svoljšak Jerman, "Biodiesel influence on tribology characteristics of a diesel engine", Elsevier, Fuel 88 (2009) pp 970–979.
[16] Jianbo Hu, Zexue Du, "Study on the lubrication properties of biodiesel as fuel lubricity enhancers" , Elsevier Fuel 84 (2005) pp 1601–1606.