PERFORMANCE EVALUATION AND TRIBOLOGICAL STUDIES ON A BIODIESEL- FUELLED COMPRESSION IGNITION ENGINE

by

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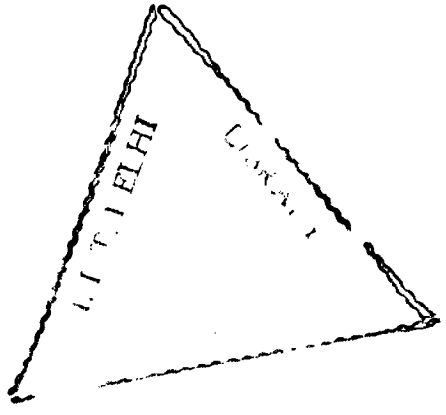

CERTIFICATE

1. I am satisfied that the thesis presented by Mr. Avinash Kumar Agarwal is worthy of consideration for the award of the degree of Doctor of Philosophy and is a record of the original bonafide research work carried out by him under my guidance and supervision and that the results contained in it have not been submitted in part or full to any other university or Institute for award of any degree/diploma.
2. I certified that he has pursued the prescribed course of research.

Dr L M Das

Supervisor of the Student

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The world at present is confronted with the twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground carbon-based resources. This has also resulted in serious modifications on the earth's surface layer due to dramatic increase in carbon dioxide levels from 280 ppm in pre-industrial era to 350 ppm today. Carbon dioxide is the main cause for global warming and still its levels are increasing as a function of fossil fuels being burnt.

Rapid escalation of fuel prices and depleting hydrocarbon resources of the world have forced us to look for alternative fuels, which can satisfy the ever-increasing demands of energy as well as protect the environment by repressing the levels of noxious pollutants. 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. There are more than 6.5 million diesel engines being used in the Indian agricultural sector for various activities. It is impossible to do away with these existing systems and hence alternative fuels must be expeditiously sought. The search for an alternative fuel, which promises a harmonious correlation with sustainable development, energy conservation, management, efficiency and environmental preservation, has become highly pronounced in the present context. As far as the application in rural agricultural sector of a developing country like India is concerned, such internal combustion engines should preferably utilize alternative fuels of bio-origin, which are locally available. The fuels of bio-origin in general, may be alcohol, vegetable oils, biomass, biogas, etc. which can be used by modifying their combustion properties. A lot of work has been done on alcohols (methanol and ethanol), biogas and producer gas. The present work is carried out using a typical vegetable oil by formulating its properties and bringing them closer to the conventional diesel. System design approach has taken care to see that these modified fuels can be utilized in existing diesel engines without any substantial hardware modifications. India is producing

around 6.7 million tonnes of non-edible oils such as, linseed, castor, karanji (*Pongamia glabra*), neem (*Azadirachta indica*), palash (*Butea monosperma*), kusum (*Schlelchera trijuga*). Some of these oils produced even now, are not being properly utilized, and it has been estimated that some other plant-based forest derived oils have a much higher production potential. 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 the country. Keeping this in view, several modes of fuel formulation such as blending, transesterification and emulsification were adopted in the present work to identify the most appropriate mechanism.

The combustion-related properties of vegetable oils are somewhat similar to diesel oil. Neat vegetable oils or their blends with diesel pose various long-term problems in compression ignition engines, e.g., poor atomization characteristics, ring-sticking, injector-coking, injector deposits, injector pump failure, and lube oil dilution by crank-case polymerization. Such problems are not usually experienced with short-term engine operations. Sometimes the engine fails catastrophically, if run on neat vegetable oils continuously for a longer period. The properties of vegetable oils, responsible for these problems are high viscosity, low volatility, and polyunsaturated character. Vegetable oils are renewable and after utilization as a fuel, emit carbon dioxide and water. The next generation crop for vegetable oil production can utilize carbon dioxide thus emitted to the atmosphere. Therefore vegetable oils, if produced sustainably, are non-polluting sources of fuel for engines. Biodiesel is such an alternative fuel derived from biological sources like vegetable oils. From amongst the large number of vegetable oils produced in the country, linseed oil was chosen for the present investigation because India has the largest acreage under linseed cultivation, and it is the fourth largest producer of linseed oil in the world. As far as the fuel formulation technique is concerned, transesterification was selected to prepare suitable fuels for long-term engine operation. The molecular structure of the fatty acid molecules present in the vegetable oil gets modified by way of transesterification. For the present work, linseed oil methyl ester was prepared using methanol in the presence of potassium hydroxide as

catalyst, and then separating glycerol formed in the esterification reaction. Use of linseed oil methyl ester (LOME) 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 closer to that of diesel oil. Tests were conducted for determination of properties like density, viscosity, flash point, aniline point /cetane number, calorific value, etc. Some specific tests like infrared spectroscopy, carbon, hydrogen, nitrogen, oxygen analysis, and nuclear magnetic resonance spectroscopy were carried on biodiesel and linseed oil in order to study the effect of transesterification at molecular level. Transesterification brings about modification in the molecular structure of linoleic acid present in the linseed oil, thus converting it into biodiesel for utilization in diesel engine.

Two single-cylinder, water-cooled, four-stroke, portable compression ignition engine gensets with a rated capacity of 4 kW at 1500 rpm were selected for the experimental investigations. A dual fuel test rig was developed and the engines were suitably instrumented to measure power output, fuel flow rate, air flow rate, exhaust heat losses, smoke opacity, cooling losses, oxides of nitrogen, and combustion parameters. An oscilloscope was used to monitor combustion characteristics of the fuels by analysing pressure-crank angle (P-θ) diagrams during several stages of engine operation.

After characterization of these significant parameters for biodiesel as well as diesel oil, engine tests were conducted according to Indian Standard Code IS: 10000 for comparison of two new identical engines running under similar operating conditions and loading cycles but fuelled by different fuels. First of all, the engines were subjected to preliminary run (seven cycles of seven hours each) according to loading cycle prescribed by IS code in order to eliminate the initial run-in problems. Then the generators of both the engines were calibrated. Performance and emission tests were conducted on engines using blends of various concentrations of biodiesel and diesel oil to determine the optimum blend concentration. Baseline data was generated using diesel as a reference fuel. Optimum blend was selected on the basis of thermal efficiency and exhaust emission parameters. After the tests, a blend of

20% was selected as optimum biodiesel blend. Initially, the engines were disassembled for physical inspection and dimensioning of vital parts of both the engines. The two engines were reassembled and 12-hour rating tests were conducted on both the engines in order to prepare them for long-term endurance test. Fuel consumption tests were also conducted for verifying the fuel consumption pattern of both the engines.

The engines were finally subjected to long-term endurance tests (32 cycles of 16 hours each) prescribed by IS codes on the optimum biodiesel blend and diesel oil. Lubricating oil samples were drawn from both the engines after an interval of 128 hours. After completion of these tests, both the engines were again disassembled for physical inspection and dimension measurements of various vital parts. Thus the wear was calculated with reference to the initial values recorded before the test. The physical wear of various vital parts was found to be up to 30% lower in case of biodiesel-fuelled engine. Injector coking and carbon deposits on piston, ring sticking were also substantially lower in case of biodiesel-fuelled engine. The pressure-crank angle diagrams during engine operation were taken, which clearly showed that there were no undesirable combustion features with biodiesel operation.

Various tribological studies on lubricating (lube) oil samples were conducted in order to correlate the comparative performance of the two fuels. Density of oils from both the systems showed increasing trend but biodiesel-fuelled system showed a slower rate of increase in density indicating lesser wear debris and lower degradation of the lubricating oil. Viscosity of the lubricating oils at 40°C and 100°C from both the systems showed a decreasing trend but biodiesel-fuelled system oil showed a slower decrease indicating lesser deterioration and lower fuel dilution. Flash point of the oil samples also decreased with usage but lube oils from biodiesel-fuelled system showed slower reduction in flash point, indicating lower fuel dilution. Moisture content of the lube oils increased with usage but lube oil from a biodiesel-operated system showed slower rise in moisture content indicating better sealing properties of biodiesel. Pentane and benzene insolubles also showed an increasing trend for both the lube oil systems, but the lube oils from biodiesel-operated system showed a slower rise indicating lower

amount of wear debris and lower polymerization of the lube oil. Infrared spectroscopy for the lube oil samples from both the systems indicated slightly higher oxidation of lube oils base stock for biodiesel-operated system. Thin layer chromatography results using palladium chloride and rhodamine B as revealing agents indicated that the depletion of zinc-di-alkyl-di-thio-phosphate additive was lower in case of biodiesel-operated system indicating its higher residual useful life. Ferrography results showed that the size and amount of wear debris were lower in case of biodiesel-operated system indicating better lubricity properties and material compatibility with the system. Atomic absorption spectroscopy was done on all lube oil samples for analyzing the elemental composition of the wear debris. This confirmed the earlier results of physical measurements of wear of various parts, and ferrography, which revealed that the wear of various moving parts was lower by 30% in case of biodiesel-operated system. Few tests on sealed pan differential scanning calorimetry were conducted for analyzing the oxidation stability of the lubricating oil samples. It was found that the oxidation stability of the lube oil samples was lower in case of biodiesel-operated system. Since the data from the present investigation was indicator of trend only and was inadequate to confirm the oxidation stability of oil decisively, hence an in-depth study may reveal more information.

This series of engine data analysis and tribological investigations provided adequate relevant information that the biodiesel can be used as an alternative, environment-friendly fuel in the existing engine sets without substantial hardware modifications. The work carried here established the feasibility of biodiesel-fuelled CI engine utility system for agricultural and field applications. The work suggested the practical curative steps to ensure utilization of vegetable oils in small horsepower compression ignition engines. Last but not the least, the present work experimentally demonstrates that a biodiesel-fuelled compression ignition engine, apart from its implementation potential can contribute significantly to the twin problem of diesel oil scarcity and environmental pollution.

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