

Characterization and Lubricity Testing (SRV Wear Tester) of Diesel and Diesel Biodiesel (LOME) Blends

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ABSTRACT

The main aim of this work is to optimize the transesterification process for production of Biodiesel from linseed oil, which has better properties of Viscosity, Flash point, and Calorific value. Efforts have been made to optimize transesterification process for Biodiesel production by considering methanol quantity, potassium hydroxide quantity, reaction time, reaction temperature and stirrer speed. Different analytical methods such as TLC, NIR Spectroscopy, and ¹H NMR Method are used to analyze transesterification reaction. In addition to this, various Physio-Thermal properties and lubricity of Biodiesel (Linseed Oil Methyl Ester-LOME) and Diesel - Biodiesel blends were studied using SRV Wear tester machine and these are compared with that of petrodiesel.

KEY WORDS: Biodiesel, Methanol, fuel, SRV Wear Tester, Lubricity, Transesterification.

INTRODUCTION

The world is confronted with the twin crises, of fossil fuel depletion and environmental degradation. The increasing import bill has necessitated the search for liquid fuels as an alternative to diesel, which is being used in large quantities in transport, agriculture, industrial, and domestic sectors. Development of the compression ignition (C.I) engine, since its invention, has been parallel with diesel fuel development. Utilizing vegetable oil as a fuel may require property changes in the oil or perhaps, some engine modifications or operating changes. The major difficulties in using the crude vegetable oils in diesel engines are because of their high viscosity, low volatility and poor cold flow conditions [1].

Vegetable oil when used as a fuel cause nozzle choking and coking, gumming, deposition on the piston top, sticking of piston rings and contamination of the lubricating oil. Injection problem and poor atomization

due to its high viscosity is a major problem. Apart from these, starting the engine may become difficult especially in cold weather. Because of poor atomization and low volatility of fuel, smoke and particulate emissions are relatively more; to overcome the above difficulties vegetable oil derived fuel called "Biodiesel" has been used. Biodiesel is the name of a clean burning alternative fuel, produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil and, renewable resources [2].

Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a Biodiesel blend. It can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics. The process used to produce Biodiesel is called transesterification. The largest possible source of suitable oil comes from both edible and non-edible vegetable oils such as rapeseed, palm or soybean, Mahua, Pongamia, Karanja, Jatropha and Neem oil [3],[4].

EXPERIMENTAL SETUP

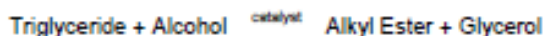
A round bottom flask was used as laboratory scale reactor with a reflux condenser and it consists of motorized stirrer, straight coil electric heater, and stainless steel containers for the experimental purposes. The mixture was stirred at constant speed for all test runs and the temperature range of 60 degree C - 85 degree C was maintained during this experiment. Three trial runs were carried out for each combination of reactants and process conditions and average results are explained graphically in the Figures.1-2.

The SRV wear tester is used for studying wear between rubbing surfaces subjected to reciprocating motion. The machine used in this work allows a small section of a piston ring to be moved relative to the small piece of a cylinder liner. The device is such that the stroke of the piston ring piece and frequency can be varied to control

the speed at which piston ring piece moves. The force that can be applied pushes down on the fixture holding the piston ring piece. Temperature can also be controlled by heating the liner disc. The test specimen discs were prepared from the engine cylinder liner (high phosphorus cast iron) and then machined in the form of a circular disc of diameter 24 mm and thickness of 9.8 mm (outer most) and 7.8 mm inner most.

ESTERIFICATION PROCESS

Transesterification is the chemical reaction between triglycerides and alcohol in the presence of catalyst to produce monoesters. The long and branched chain triglyceride molecules are transformed to monoesters and glycerin. Transesterification process consists of a sequence of three consecutive reversible reactions. That is, conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides. The Glycosides are converted into glycerol and yielding one ester molecule in each step. The properties of these esters are comparable to that of diesel. The overall transesterification reaction can be represented by the following reaction scheme [4].



Stoichiometrically, three moles of alcohol are required for each mole of triglyceride, but in practice, a higher molar ratio is employed in order to displace the equilibrium for getting greater ester production. Though esters are the desired products of the transesterification reactions, glycerin recovery also is important due to its numerous applications in different industrial processes. Commonly used short chain alcohols are methanol, ethanol, propanol and butanol. The yield of esterification is independent of the type of alcohol used. Therefore, the eventual selection of one of these four alcohols will be based on cost and performance considerations [5].

The methanol is used commercially because of its low price, its physical and chemical advantages (polar and shortest chain alcohol) and KOH is easily dissolved in it. Alkaline hydroxides are the most effective transesterification catalysts as compared to acid catalysts. Potassium hydroxide and sodium hydroxide are the commonly used alkaline catalysts. Alkaline catalyzed transesterification of vegetable oils is possible only if the acid value of oil is less than four [6].

STAGES OF BIODIESEL PRODUCTION PROCESS

In the transesterification process, alcohol reacts with oil to release three "ester chains" from the glycerin backbone of each triglyceride. Production of Biodiesel by transesterification process will consist of the following stages [8].

- Removal of moisture from the oil.
- Heating the oil to a required temperature.

- Mixing of alcohol and catalyst in a required proportion.
- Reaction of the alkoxide and vegetable oil in the reactor.
- Separation of the glycerol.
- Washing of the methyl ester.
- Removal of the Moisture from the Biodiesel

Factors effecting Biodiesel production

Optimization of transesterification process for Biodiesel production depends upon various parameters such as

- Ratio of alcohol to oil.
- Reaction temperature.
- Duration of the reaction
- Catalyst type and concentration.
- Mixing intensity.
- Purity of reactants.

OPTIMIZATION OF TRANSESTERIFICATION PROCESS

Efforts have been made to optimize transesterification process by considering some of the above parameters. The following sections give the details of the effects of the above parameters in producing Biodiesel [7] [8]. The conclusion arrived from the effect of different variables was that the sample which consists of 200ml of vegetable oil, 96ml of methanol, 2g of potassium hydroxide and a reaction time of 180minutes, had properties fairly close to diesel fuel. It was necessary to see the effect of reaction time on the transesterification process on the optimized sample as mentioned above. Below Fig. 1 and 2 shows the plot of percentage yield of Biodiesel and viscosity versus reaction time for the optimized sample.

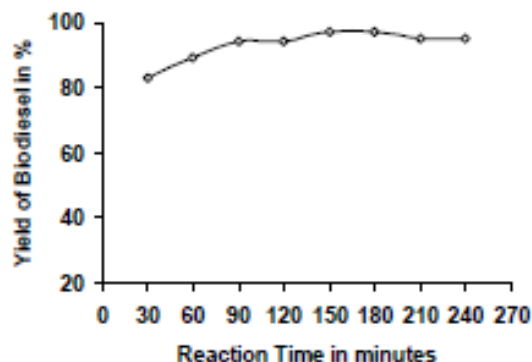


Figure1. Effect of reaction Time on Yield of Biodiesel produced from optimized parameters

It is observed from Fig.1 that the maximum Biodiesel yield was obtained for the sample whose reaction time was 150 minutes and lowest yield for a reaction time of 30 minutes; another peak occurs at a reaction time of

about 120 minutes, third peak occurs at a reaction time of 180 minutes. For other reaction times, the yield of Biodiesel was more or less the same. Based on the above graph one can conclude that 180 minutes of reaction time was sufficient to produce Biodiesel. As shown in Fig.2 that the lowest viscosity was observed for the sample whose reaction time was 180 minutes and highest viscosity was observed for the sample whose reaction time was 30 minutes. Samples whose reaction time was 150, 180, 210 and 240 minutes had nearly the same viscosity.

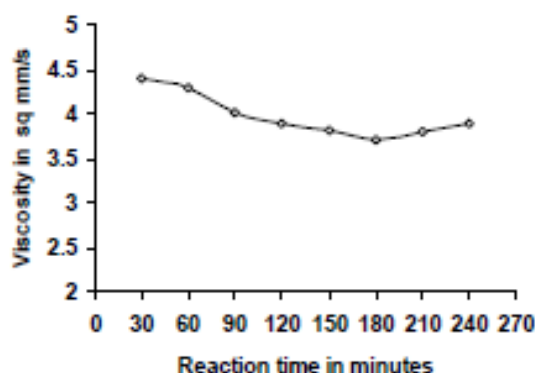


Figure 2 Effect of reaction Time on viscosity of Biodiesel produced from optimized parameters

Therefore, one could select the sample whose reaction time was 180 minutes as a standard sample for Biodiesel production in the laboratory and optimal values are given in Table 1.

Table 1 Optimized quantities for Biodiesel Production

Oil (ml)	Methanol (ml)	KOH (g)	Temp ($^{\circ}$ C)	Time (min)	Yield (%)	μ (mm^2/s)
200	96	2	65	180	97	3.70

ANALYTICAL METHODS USED TO MONITOR TRANSESTERIFICATION REACTION

Following different analytical methods are used to analyze Transesterification reaction. These methods will give the detail information about the quantity of glycerol, mono-, di-, and tri glycerides present in vegetable oil methyl esters [8] [9].

1. Gas chromatographic method
2. High performance liquid chromatography method
3. Gel permeation chromatography method
4. Near Infrared Spectroscopy (NIR Spectroscopy)
5. Proton nuclear magnetic resonance spectroscopy (^1H NMR Method)

But in the present experimental analysis the following three methods have been used and these are explained below.

1. Thin layer chromatography
2. Near Infrared Spectroscopy (NIR Spectroscopy)
3. Proton nuclear magnetic resonance spectroscopy (^1H NMR Method)

THIN LAYER CHROMATOGRAPHY

Below Fig.3.gives the details of the thin layer chromatography test i.e. this test will give an idea for polarity of a liquid fuel, generally liquids which are less non-polar they will not rise in the solution of hexane, ethyl acetate and acetic acid.

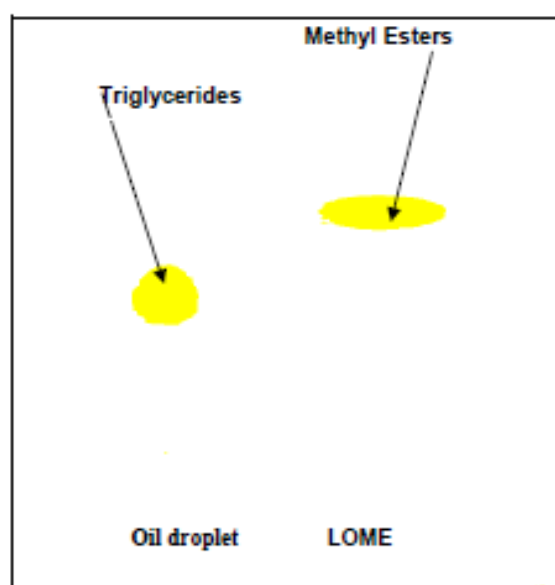


Figure 3. Thin Layer Chromatography

That is triglycerides are less non-polarity as compared to esters hence they will raise at a lower length in the column.

NEAR INFRARED SPECTROSCOPY (NIR SPECTROSCOPY)

Recently, NIR spectroscopy has been used to monitor the Transesterification reaction. The basis for quantization of the turn over from triglyceride feedstock to methyl ester product is differences in the NIR spectra of these classes of compounds. NIR spectra were obtained with the aid of a fiber optic probe coupled to the spectrometer, which render their acquisition particularly easy and time-efficient. Fig.4. shows the infrared (IR) spectra, which is almost common for all petroleum products and esterified oils. The IR spectra of neat esterified oil shows the pronounced functional groups, which indicates the presence of alkanes and lesser

extent of aromatics and poly aromatics groups with a clear absence of phosphorus and sulfur [8] [8].

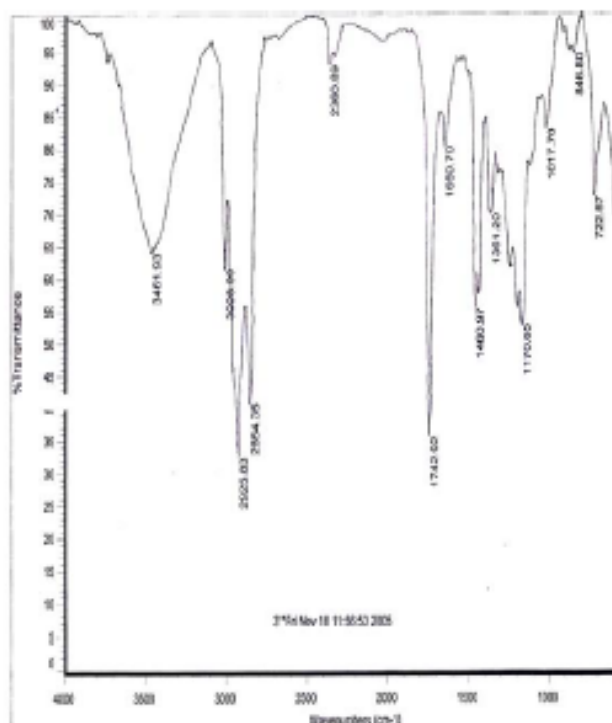


Figure 4 IR Spectroscopy of Linseed oil Methyl ester

The IR spectrum of esterified linseed oil shows that they contain significant amount of esters. The esterified linseed oil contains the little amount of water and this water is removed by heating the ester before using in the engine. The higher percentage of esters, alkanes and absence of phosphorus and sulfur make this esterified linseed oil as a future candidate for alternative, environmentally friendly diesel fuel. The comparative frequency ranges of IR spectra; their corresponding functional groups and indicated compounds are presented in the Table 2.

Table 2 Functional groups and indicated compounds of Linseed oil methyl ester

Frequency range (cm ⁻¹)	Linseed oil Methyl Ester	
	Functional groups	Class of compound
3461.93	O-H stretching	Alcohol (strong) Due to CH ₃ OH base
3008.09	C-H stretching	Alkanes, alkenes
2925.83	C-H stretching of CH ₃ and CH ₂	Acid oxygenated compound, aldehydes and ketones.
1742.92	-C=O Stretching	Ester Link
1170.85	-C-O- Stretching of Ester	Ester and Other aromatic compounds

1361.2,	-C-H- Deformation	
1460.97	-C-H-Asymmetric Stretching	
1017.84	Bending frequencies	
8,722.5		

PROTON NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY (¹H NMR METHOD)

Figure 5 shows the ¹H NMR spectrum of the sample. The spectrum exhibits a very simple and neat spectrum indicating the presence of very discrete molecular species.

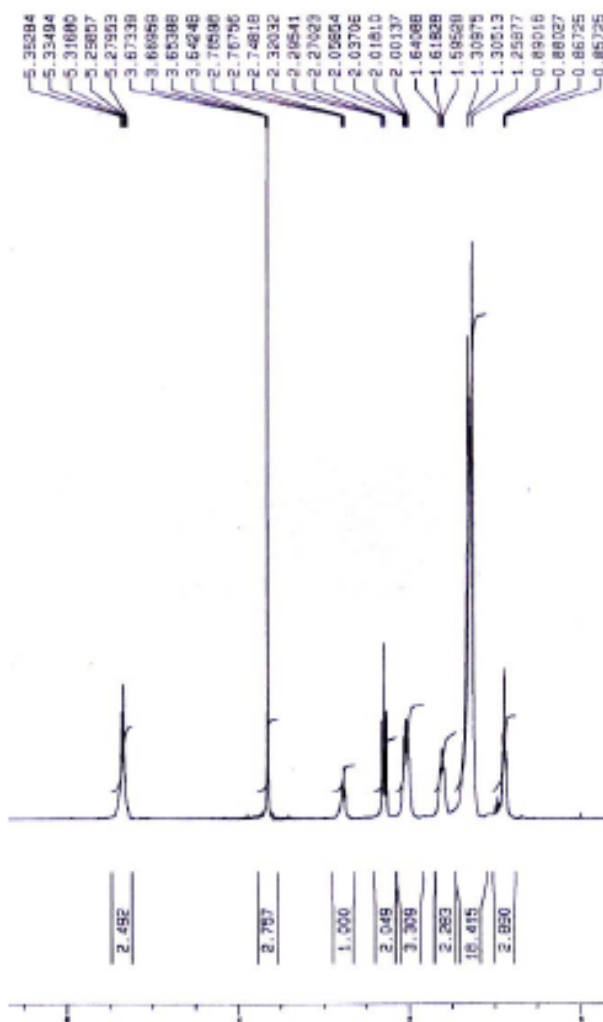
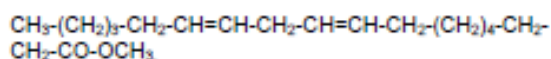


Figure 5 ¹H NMR Linseed oil Methyl ester

Nuclear magnetic resonance was carried out using proton and carbon 13 techniques. Absorption resonance frequencies were recorded using CDCl₃ as a solvent.

The difference in the δ values specifies the particular number of protons in the form of peak splitting. The following observations as shown in below Table 3 is made from the proton NMR spectroscopy of Linseed oil methyl ester. Therefore confirming to the result obtained from IR analysis and ^1H NMR spectroscopy interpretations, the following structure was confirmed for the Biodiesel [9].



The following formula was used to calculate the percentage conversion of triglyceride to corresponding methyl ester [7] [9].

$$C = 100 \times (2A_{\text{ME}}/3A_{\text{CH}_2})$$

Where C, percentage conversion of triglycerides to corresponding methyl ester; A_{ME} , integration value of the protons of the methyl esters; and A_{CH_2} , integration value of the methylene protons. The factors 2 and 3 derived from the fact that the methylene carbon possesses two protons and the alcohol (methanol derived) carbon has three attached protons. From the Fig.5 $A_{\text{ME}} = 2.757$ and $A_{\text{CH}_2} = 2.017$.

Hence, $C = 100 \times (2 \times 2.757 / 3 \times 2.017) = 91.1125$

Table 3 Details of Proton Nuclear Magnetic Resonance Spectroscopy

Proton	δ Values	Interpretation
(3H) Triplet	0.85-1.00	Due to Methylene group CH_3
(14H) Triplet	1.59-1.64	Due to seven equivalent Methylene groups
(4H) Quintet	2.001-2.058	Due to two equivalent Methylene groups adjacent to $-\text{CH}=\text{CH}-$ linkage
(2H) Triplet	2.27-2.32	Due to methylene group adjacent to carbonyl group
(2H) Triplet	2.74-2.78	Due to Methylene group flanked by 2, $-\text{CH}=\text{CH}-$ groups
(3H) Quintet	3.642-3.673	Due to $-\text{O}-\text{CH}_3$ group
4H	5.27-5.35	Due to the four equivalent protons of 2, $-\text{CH}=\text{CH}-$ groups

COMPARISON OF PROPERTIES OF BIODIESEL WITH RESPECT TO DIESEL FUEL

It is necessary to install a standardization of fuel quality to guarantee engine performance, so as to evaluate various physical, chemical, and thermal properties, because that Biodiesel is produced in quite differently scaled plants from vegetable oils of varying origin and quality. Several tests were conducted to characterize Biodiesel in relation to diesel oil. The properties of linseed oil Biodiesel, as given in Table 4, shows many similarities with diesel fuel, and therefore, Biodiesel is rated as a strong candidate as an alternative to diesel[2].

Table 4 Various Properties of different fuels

Property	ASTM TEST	Diesel	LOME	Linseed Oil
Viscosity at 40 °C (mm ² /s)	D445	2.246	3.70	22.1
Viscosity at 100 °C (mm ² /s)	D445	1.10	1.98	9.80
Viscosity index	D445	359.3	256.37	185.71
Calorific value (MJ/Kg)	D240	43.68	40.13	39.20
Specific gravity	D1298	0.856	0.889	0.903
API gravity (°C)	D4052	34.97	30.97	25.19
Flash point (°C)	D93	66	163	238
Cloud point (°C)	D2500	-6	-3.5	2
Pour point (°C)	D97	-16	-14	-4
Aniline point (°C)	----	72	30 - 100	----
Copper strip corrosion	D130	---	1a	---
Raid vapor pressure (kPa)	D323	---	13.79	---
Acid value (mg KOH/g)	D664	0.54	0.78	3.71
Carbon residue (wt %)	D524	0.015	0.032	0.28
Sulphur Content (ppm)	D5453	349	11	---
Distillation temperature (°C)	D1160	299	350	

Distillation Temperature of Diesel and Diesel Biodiesel blends

A property related to the flash point is the boiling point, which is the temperature at which a liquid transitions to a gas. For a pure substance the boiling point is a single temperature value. However, for a mixture of hydrocarbons as exists in the diesel fuel there is a range of boiling points for the different constituent chemical species. The standard procedure for measuring the boiling point range for a diesel fuel is the distillation test, which is ASTM D86.

As one would expect, the distillation characteristics, i.e. the boiling point range, have an important effect on the performance, storage and safety of the fuels [4] [8]. Table 5 shows the distillation temperatures of the diesel fuel and linseed oil methyl ester. Below Fig.6 shows the comparison of temperature development of the vapors produced during the ASTM D86 distillation test for linseed oil methyl ester and diesel fuel.

Table 5 Distillation temperatures for Diesel and Biodiesel

Percentage of fuel evaporated	Diesel	LOME
Initial Boiling Point	176	210
5%	196	261
10%	207	271
20%	213	273
30%	214	281
40%	217	291
50%	224	296
60%	234	310
70%	249	336
80%	281	342
90%	299	350
95%	304	356
End Point (98%)	306	358
Recovery (%)	98.73	97.6
Residue (%)	.73	1.3
Loss (%)	0.54	1.1

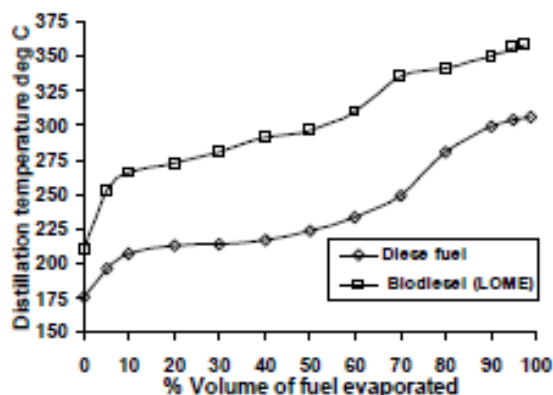


Figure 6 Comparison of Distillation temperatures for different fuel

It can be seen that vapor temperatures for the Biodiesel are higher than the diesel fuel for the majority of the test duration. Biodiesel fuel reached the temperature from 210 degree C to 358 degree C during the decomposition. Since the possibility exists for the decomposition of the methyl ester during the ignition delay period and the viscosity of the methyl ester is some what higher than that of typical diesel fuel, one might expect to observe some differences in the combustion behaviors of the methyl ester as compared to diesel fuel.

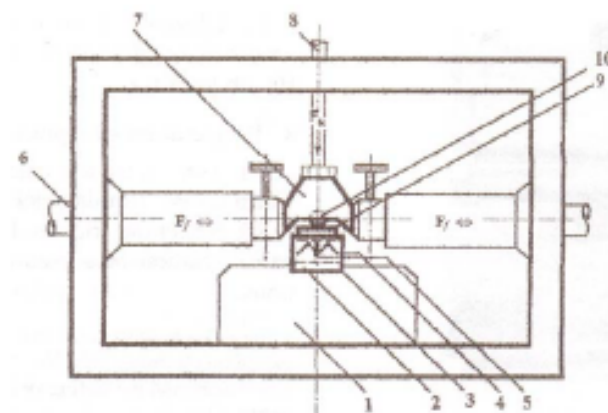
DETERMINATION OF COEFFICIENT OF FRICTION FOR DIESEL AND DIESEL BIODIESEL BLENDS BY USING SRV (ASTM-D6425-05) WEAR TESTER

Lubricity is a qualitative term describing the ability of the fluid to effect friction between, and wear to, surfaces in relative motion under load, like in fuel pumps, between piston ring and engine liner, and injectors. The fuel seems suspect, and presentation of machine failure due to heat generation, are the main purposes of lubricity and contamination testing of the oil [10].

Insufficient lubricity because of incorrect make up and lack of thermal and shear stability, and contamination due to particulate matter, water and inferior combustible liquids are the main problems of the diesel fuel. Lubricity of the fuel is measured by SRV testing, HFRR testing and SLBOCLE and contamination properties of the fuel are measured by Visual testing, Filtration, Boiling point curve determination and Crackle test [11].

EXPERIMENTAL SET UP AND INSTRUMENTATION

SRV Wear test method is used to determine EP lubricating oil's coefficient of friction and its ability to protect against wear at selected temperature and loads specified for use in applications, in which high speed vibrational or start stop motions are present for extended period of time under initial high Hertzian point contact pressure. The SRV test machine consists of oscillation drive, a test chamber as shown in below Fig.7 and a loading device with a servomotor and a load cell.



1. Receiving block.
2. Piezoelectric measuring device
3. Test disc holder.
4. Electrical resistance heater
5. Resistance Thermometer
6. oscillation drive rod
7. Holder for fixing the test specimen.
8. Load rod.
9. Test disc.
10. Test specimen

Figure 7 SRV Wear tester chamber

The machine is operated by a control device, a timer, a load control, a frequency control, a stroke control a data amplifier to determine the friction coefficient, and a switch and a controller for heating. Friction coefficients are recorded in relation to time by a chart recorder or by a data acquisition in a computer.

The machine used in this work allows a small section of a ring to be moved relative to the small piece of a liner. The device is such that the stroke of the ring piece and frequency can be varied to control the speed at which ring piece moves. The force that can be applied pushes down on the fixture holding the ring piece. The test specimen discs were prepared from the engine cylinder liner (high phosphorus cast iron) and then machined in the form of a circular disc of diameter 24 mm and thickness of 0.8 mm (outer most) and 7.8 mm inner most as shown in the below Fig.8.



Figure 8 Disc made from Engine Liner

The top surface of the disc is cylindrical since they are machined from the inner wall of the cylinder liner while bottom surface was machined flat. Sliding pins were fabricated from the top compression ring of the piston, which has chromium plating that makes it hard. Small segments of pin (piston ring) with a length of 10mm width 2.3mm and height 2.9 mm were cut from the piston ring. A special holder assembly as shown in below Fig.9 was also fabricated to hold the pin while reciprocating against the disc.



Figure 9 Holder with piston pin piece

The assembly (Holder with piston pin) was dipped in a fluid under boundary lubrication condition. A special cup as shown in below Fig.10 was also fabricated to hold the lubricated fluids for testing against the moving ring.

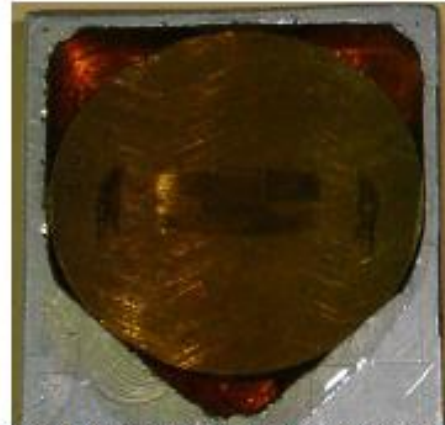


Figure 10 Cup and disc assembly with test fluid

Since the entire test is being conducted on a wear tester, it does not completely match the characteristics of the piston ring in an engine.

EXPERIMENTAL PROCEDURE

Due to the physical limitations the ability to change the stroke on the tester was limited. The maximum stroke length was 2mm and the frequency could be varied from 0-50 Hz. The loads could be varied from 0-500N. For the present investigations the following operating parameters are selected based on the engine parameters for the friction studies in the SRV wear tester. Stroke length = 1mm, Oscillation frequency = 50 Hz, Duration of each test = 1h, Total distance slid = 360m, Loads selected = 100N, 200N, 300N, 400N and 450N. All the conditions in the running engine could be simulated only partially because of the limitations of the SRV optimal wear tester e.g. engine used in the experiment has a stroke length of 95mm and frequency was 1500 rev/min i.e. reciprocating of 25Hz. The stroke length of the engine is substantially higher than in the wear tester. Hence we chose to operate the tester at a higher frequency (50Hz). However lower linear speeds in the wear tester result in a thinner oil film than in actual conditions inside the fired engine.

In the case of the engine in the fired conditions, the peak pressure in the combustion chamber reach up to the 10MPa. This pressure when applied to the ring piece used in these tests would be equivalent of a 415N Load. Hence we selected to conduct the test up to 450N. It should also be noticed that peak pressure in the four-stroke engine does not last over the entire cycle of the engine. The high pressures are only present for the part of a revolution of the engine. During the low-pressure portion of the cycle, only ring tension exerts the force on the liner. This is approximately equivalent to 14N load on the ring piece.

ANALYSIS OF THE RESULT

The SRV optimal tester had the necessary components to measure frictional force. The coefficient of friction was continuously monitored on the strip chart recorder. The wear tester data was analyzed for average coefficient of friction for various lubricating fluids and the result are shown in the following Table 6. Friction coefficient of the wearing pair is highly dependent on the lubricating fluid working as a boundary lubricant.

Table 6 coefficient of friction for different fuel

Coefficient of friction for Diesel and Diesel Biodiesel fuels						
Load (N)	Type of Fuel					
	B100	B80	B60	B40	B20	D100
100	0.058	0.078	0.082	0.085	0.09	0.1
200	0.06	0.083	0.095	0.1	0.102	0.112
300	0.075	0.091	0.098	0.101	0.106	0.125
400	0.08	0.1	0.103	0.107	0.108	0.14
450	0.07	0.09	0.1	0.103	0.11	0.142

These figures reflect that with increase in a LOME concentration friction coefficient of both pin and disc were decreased significantly. It can also be observed that with the increase in load friction coefficient was decreased almost in all the loads. This is because at higher loads boundary lubrication turns in to hydrodynamic lubrication [11] [12].

As seen from the below Fig. 11. A substantial decrease in coefficient of friction was observed in LOME blends. It was reduced from 0.1 to 0.09 due to addition of 20% LOME in a diesel at lowest load of 100N while at a highest load of 450N; it was reduced from 0.142 to 0.11. Friction coefficient shows different trends depending on the load and LOME content in the diesel.

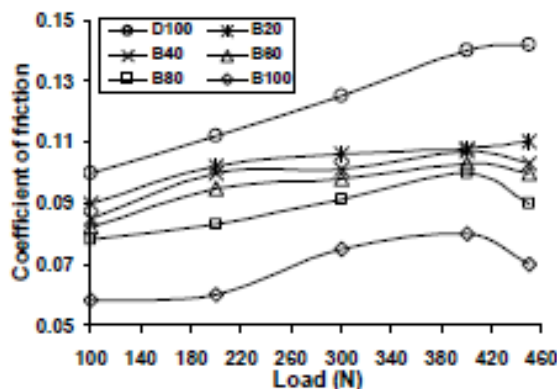


Figure 11 Coefficient of friction as a function of load for various test fuels

Friction coefficient increased linearly with increase in load in case of neat diesel, while in case of blends friction coefficient was maximum at 400N. Thus in case of neat diesel when load increases metal-metal asperity contact also increase substantially leading to the higher friction coefficient confirming the unsuitability of neat diesel as a boundary lubricant while in case of blends with increase in load, friction coefficient decreases showing lower metal to metal contact. This confirms that LOME has an inherent improved lubricity property [11].

CONCLUSION

Based on the above tests one can conclude that Transesterification is one of the best methods to improve the fuel properties of the triglycerides. Optimization of Transesterification process for Biodiesel production depends upon several parameters such as methanol quantity, potassium hydroxide quantity, reaction time, reaction temperature and stirrer speed. The results obtained from the present investigations shows that, the Transesterification process improved the fuel properties of the oil with respect to Specific gravity, Viscosity, Flash point and Acid value.

The higher percentage of esters, alkanes and absence of phosphorus (obtained from the analytical methods used to monitor esterification process) and sulfur make this esterified vegetable oil as a future candidate for alternative, environmentally friendly diesel fuel. Friction coefficient increased linearly with increase in load in case of neat diesel; while in case of blends friction coefficient was low but it follows the same trend as that of diesel fuel. Thus in case of neat diesel when load increases metal-metal asperity contact also increase substantially leading to the higher friction coefficient confirming the unsuitability of neat diesel as a boundary lubricant while in case of blends with increase in load, friction coefficient decreases showing lower metal to metal contact. This confirms that LOME has an inherent improved lubricity property

Dibenzothiophene, which is contained in nondesulfurized petrodiesel, does not enhance petrodiesel lubricity. Fatty compounds possess better lubricity than hydrocarbons, because of their polarity-imparting oxygen atoms. Neat free fatty acids, monoacylglycerols, and glycerol possess better lubricity than neat esters, because of their free OH groups. Lubricity improves somewhat with the chain length and the presence of double bonds. An order of oxygenated moieties enhancing lubricity ($\text{COOH} > \text{CHO} > \text{OH} > \text{COOCH}_3 > \text{C=O} > \text{C-O-C}$) was obtained from studying various oxygenated C_{10} compounds. SRV wear test shows that extra oxygen present in the ester fuel will enhance lubricity more than nitrogen and sulfur.

The comparison of these properties with diesel shows that methyl ester has a relatively closer fuel property values to that of diesel (than that of oil). Hence, no hardware modifications are required for handling this fuel (Biodiesel) in the existing engine. Biodiesel is proved to

be a potential candidate for partial substitution of mineral diesel oil.

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REFERENCES

1. Babu A K, Devardjane J. Vegetable Oils and their Derivatives as Fuels for C.I. Engines: An Overview. SAE 2003;0100767: 406-417.
2. Ramadhas AS, Jayaraj S, Murlidharan C. Characterization and effect of using Rubber Seed Oil as Fuel in Compression Ignition Engines. Renewable Energy 2005; 30:795-803.
3. Ramprasad, Anjana S. Triglycerides-based Diesel Fuels. Renewable and Sustainable Energy 2004; 4:111-133.
4. Bhusnoor SS, Gajendra Babu MK, Subrahmanyam JP. Optimization of Transesterification Process for Biodiesel Production from Linseed Oil. SAE 2006-28-0046.
5. Bhatt YC, Murthy NS, Datta RK. Use of Mahua Oil (*Madhuca Indica*) as a Diesel Fuel Extender. IE (I) Journal-AG 2004; 85:10-14.
6. Naik SN, VidyaSagar D, Mether LC. Technical aspects of Biodiesel Production by Transesterification-A review. Renewable and Sustainable Energy Reviews 2004; 29:1-21.
7. Raheman H, Ghadge VS. Biodiesel Production from Mahua (*Madhuca Indica*) oil having high Free Fatty Acids. Biomass and Bioenergy 2005; 28: 601-605.
8. Kapur GS, Sarpal AS, Sarita G, Mookken RT. A Protocol for Unambiguous identification of Components in Synthetic Ester based Lubricants using Modern NMR Experiments. SAE 2006; 28(0045): 1-6.
9. Rajiv KR, Brahma, Amjad A, Sudha T, Rao PVC. A Novel Method for the Estimation of Biodiesel Conversions and Finger Printing Analysis of Different Vegetable Oils using ^1H & ^{13}C NMR and Comparison with HPLC. SAE 20006; 28(0047) 27-34.
10. Gerhard K, Kevin RS. Lubricity of Components of Biodiesel and Petrodiesel, the Origin of Biodiesel Lubricity. Energy & Fuels 2005; 19, 1192-1200
11. Jianbo Hu, Zexue Du, Changxiu Li, Enze Min. Study on the lubrication properties of biodiesel as fuel lubricity enhancers. Fuel 2005; (84) 1601-1606.
12. Jayashree B, Atul S, Agarwal AK. Assessment of Lubricity of Biodiesel blends in Reciprocating wear mode. SAE 2004; 01-3068:2117-2124.