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Performance Evaluation of a Biodiesel (Rice Bran Oil Methyl Ester) Fuelled Transport Diesel Engine

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ABSTRACT

This experimental study was undertaken to investigate the use of vegetable oil derivatives to substitute mineral diesel fuel. Straight vegetable oils pose some problems like injector coking, carbon deposits etc., when used as a fuel in an engine. These problems are due to high viscosity, low volatility and polyunsaturated character of vegetable oils. Transesterified vegetable oil derivative called "biodiesel" appear to be most convenient way of utilizing vegetable oil as a substitute fuel in diesel engines. In present investigation, rice bran oil (non-edible) was transesterified to methyl ester and reaction conditions for transeterifcation process for rice bran oil were optimized. Various properties like viscosity, density, flash point of the biodiesel thus prepared are comparable to diesel and found to be in acceptable range as per ASTM norms (ASTM D6751). Experimental investigations were carried out on a four stroke, four cylinders, transportation DI diesel engine. Various blends of biodiesel (rice bran methyl ester) and diesel ranging from 5% to 50% ester in the blend were used for performance and emission test in the transport diesel engine and the results are compared with the baseline data obtained using mineral diesel. Detailed engine tests show that biodiesel can be used as partial substitute fuel in existing diesel engines without substantial hardware modification and it significantly lower the emissions of harmful species from diesel engines without jeopardizing the engine performance.

INTRODUCTION

The Diesel fuels have an important role in the industrial economy of any country. Compared to the rest of the world, India's demand for diesel fuels is roughly six times that of gasoline fuels and it stands at one third of total petroleum product consumption in the country. India lacks fossil energy resources and imports almost half to total petroleum requirements. In 2000-01 consumption of petroleum product was approximately 110 million tons, with approximately 9% growth rate. This unsteady and unreliable external energy supply has been a burden to the national economy.

Increased environmental concerns, tougher vehicle emission norms, increasing prices and uncertainties concerning petroleum availability necessitate the search for a viable alternative fuel, which is more environment friendly. Vegetable oils have comparable energy density and cetane number as that of mineral diesel. The idea of using vegetable oils as fuel for diesel engine is not new. When Rudolf diesel first invented the diesel engine, he demonstrated it at the 1900 world exhibition in Paris, employing peanut oil and said "The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become in course of time as important as petroleum and the coal tar products of the present time" [1]. However, several properties of oils, such as high viscosity, high molecular weight, and low volatility etc. cause poor fuel atomization leading to incomplete combustion resulting in problems like severe engine deposits, injector coking and piston ring sticking [2, 3]. Due to these adverse effects on engines, straight vegetable oils are not suitable for use in engines. Several experimental researches have shown that fuel properties of vegetable oils can be improved by transesterifcation process.

$$\begin{array}{llll}
\overset{\displaystyle O}{\overset{\|}{CH_2\text{-}O\text{-}C\text{-}R^1}} & & CH_2\text{-}OH & \\
\mid \quad\ \overset{\displaystyle O}{\overset{\|}{}} & & \mid & \\
CH\text{-}O\text{-}C\text{-}R^2 & +\ 3\ R^4OH \leftrightarrow & CH\text{-}OH + R^4O\overset{O}{\overset{\|}{C}}R^1 + R^4O\overset{O}{\overset{\|}{C}}R^2 & \\
\mid \quad\ \overset{\displaystyle O}{\overset{\|}{}} & & \mid & \\
CH_2\text{-}O\text{-}C\text{-}R^3 & & CH_2OH \quad + \quad R^4O\overset{O}{\overset{\|}{C}}R^3 & \\
\text{Triglyceride} & \text{Alcohol} & \text{Glycerol} \qquad \text{Esters} &
\end{array}$$

Figure 1: Transesterification Reaction

Transesterifcation is a chemical process in which triglycerides in vegetable oils are converted to mono alkyl esters of the same fatty acid, which are called biodiesel, using primary alcohols in presence of a catalyst. In a stoichiometric reaction, three moles of alcohol are required for transesterification of one mole of triglycerides but it is a reversible reaction hence excess alcohol is required to shift the equilibrium to product side. Conversion rate for base catalyzed transesterification is higher than acid catalyzed transesterification [4, 5, 6]. Transesterification reaction is shown in figure 1. Biodiesel is biodegradable, non-toxic, essentially sulphur free, renewable and can be produced from agriculture and plant resources available locally. Carbon cycle time for fixation of CO_2 from biodiesel is quite small compared to mineral diesel. It means that biodiesel usage reduces greenhouse gas emissions compared to mineral diesel [7, 8]. Depending upon climate and soil conditions, several nations are looking into different vegetable oils as substitute for diesel fuels, e.g. Soya bean oil in the United States, rapeseed and sunflower oils in Europe and other oils like peanut, saffola, palm in different countries. Many researchers have found that diesel engines can run with biodiesel successfully and the performance of the engine is comparable to mineral diesel. Some researchers reported improved performance particularly thermal efficiency for biodiesel fuelled engines, [9-14]. With the use of biodiesel as a fuel in the engine there is considerable reduction in the harmful emissions like CO, HC and smoke, but NO_x emissions increase, [8-14]. Antolin et al found Emissions with sunflower oil biodiesel were similar or less than diesel as fuel, [15]. Raheman *et. al* executed performance and emission tests on single cylinder stationary engines and found that CO, Smoke, HC and NO_x decreased with the karanja oil methyl ester, [16]. Similar results were reported by Kalligerous *et. al* for sunflower oil methyl ester and olive oil methyl ester [17]. Kalam *et. al* used palm oil methyl ester with additive and found that with increasing the concentration of biodiesel in the blend, power as well as CO, HC and NO_x emissions decreased [18]. Most of the western countries have used soybean, sunflower, saffola oil for production of biodiesel and investigations on the engines. These oils are edible in nature. India is a net-importer of edible vegetable oils hence biofuel research in the country cannot be based on edible vegetable oils. In India variety of non-edible oils like linseed, mahua, karanji, rice bran, Jatropha are available in abundance, which can be utilized for production of biodiesel and utilization in diesel engines.

The present experimental research is carried out to optimize the transesterification parameters for rice bran oil and to investigate the effect of transesterified rice bran oil (as an alternative fuel) on the performance and emissions of medium duty direct injection transportation diesel engine.

FUEL PREPARATION & CHARACTERIZATION

Rice bran oil was transesterified using methanol in presence of NaOH catalyst. Process parameters e.g. temperature, catalyst amount, molar ratio of alcohol to oil, and reaction time were optimized and it is found that 9:1 molar ratio of alcohol to oil, 55°C temperature, 0.75 % (w/w) catalyst and one hour reaction time is optimum for transesterification of rice bran oil. For transesterifcation in laboratory, rice bran oil was heated in a round bottom flask. NaOH was dissolved in methanol in a separate vessel and was poured in to round bottom flask, while stirring the mixture continuously. The mixture was stirred while being maintained at 55°C for approximately one hour. The reaction products were kept in a separating funnel for about 24 hours. The products formed during transesterification were rice bran oil methyl ester and glycerol. The glycerol forms lower layer during gravity separation. The lower layer of glycerol was separated. The ester was washed with (10% v/v) warm water (70°C) and kept for about 24 hour for removal of catalyst by settling of catalyst dissolved water.

The ester (biodiesel) was blended with mineral diesel in various concentrations ranging from 5% to 50%. These biodiesel blends were used as a fuel in the CI engine for conducting various experiments. The blends were referred as Bxx where xx refers the percentage of ester in that blend. Characterization of biodiesel blends and mineral diesel were done in laboratory as per the relevant ASTM norms. Some fuel properties are shown in the table 1. Specific gravity of fuels and blends was measured using precision hydrometer. Kinematic viscosity was measured (ASTM D 445) using kinematic viscometer (Setavis make). The calorific value and flash point (ASTM D93) were measured using Bomb calorimeter and Pensky Marten's closed cup tester respectively.

Table 1: Fuel Properties

Fuel Sample	Specific Gravity @ 30°C	Viscosity (cSt) @ 40°C	Calorific Value (MJ/kg)	Flash point (°C)
B 00	0.839	3.18	44.8	48
B 05	0.841	3.24	44.7	-
B 10	0.843	3.31	44.5	-
B 20	0.847	3.48	44.1	-
B 30	0.851	3.62	43.8	-
B 50	0.858	4.16	43.1	-
B 100	0.877	5.30	42.2	265

ENGINE EXPERIMENTS

A transportation DI diesel engine (Make: Mahindra & Mahindra Ltd, India, model: MDI 3000) was used for conducting engine tests. The specifications of the engine are given in table 2.

The engine was coupled with Eddy current dynamometer (Make: Schenck Avery). Data for engine speed (rpm), torque (N-m), inlet and outlet cooling water temperatures; exhaust gas temperature etc was collected. Engine speed and load were controlled by varying excitation current to the eddy current dynamometer.

Table 2: Specifications of the Engine

Manufacturer	Mahindra & Mahindra Ltd, India
Model	MDI 3000
Type of Engine	Four stroke, Naturally Aspirated, Water Cooled
Number of Cylinders	Four Cylinders
Bore/ Stroke	88.9 mm/ 101.6 mm
Displacement Volume	2520 cc
Compression Ratio	18 :1
Rated Power	40.4 kW at 3000 rpm
Max. Torque	152 N-m at 1500 rpm

Exhaust gas emissions were measured using raw exhaust gas analyzer (Make: Horiba, Japan; Model: EXSA-1500). It measures CO and CO_2 by NDIR, Total hydrocarbons (THC) by heated flame ionization detector (hot FID) and NO_x by Chemiluminescence. The equipment was installed with heated sample gas piping maintained at 191°C to prevent condensation of moisture. Exhaust gas opacity was measured using exhaust gas smoke meter (Make: AVL, Austria; Model: 437). The schematic layout of the experimental setup is shown in figure 2.

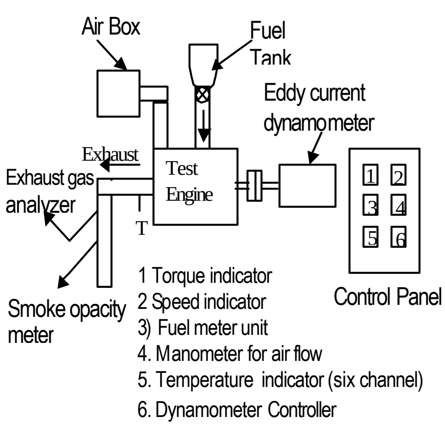

Figure 2: Schematic Diagram of the Experimental Setup

Engine tests were conducted according to Indian Standard Codes [19-21]. According to this, engine performance parameters such as power output, efficiency, torque, emissions, smoke opacity etc. were measured for each fuel blend. The engine was initially operated at full throttle at 1350 rpm and data collection for all engine performance and emission parameters was done. The engine performance was then observed at different engine speeds of 1500, 1800, 2100, 2400 and 2700 rpm at full throttle. Before observing the data sufficient time was allowed for the engine to be stabilized. The engine tests were conducted in triplicate and average data is reported in this paper.

RESULTS AND DISCUSSION

A series of exhaustive engine tests were carried out using mineral diesel and different biodiesel blends ranging (B05 to B50). The engine performance and emissions data obtained for biodiesel blends were compared with the baseline data for mineral diesel.

Characteristic curves for brake power, torque, brake specific fuel consumption (bsfc), thermal efficiency, brake specific energy consumption (bsec) and exhaust gas temperature were drawn for different biodiesel blends and mineral diesel. These characteristic curves are shown in figures 3-13. Figure 3 shows the torque generated by the engine for different fuels.

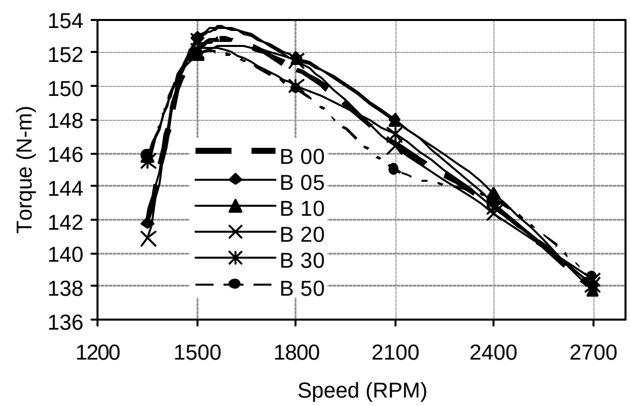

Figure 3: Engine Torque for Different Blends

Torque characteristics of the engine did not change significantly with change in fuel and all the fuel blends give maximum torque at 1500 rpm. Torque was either equal or slightly higher for the lower blends (B05, B10, and B20) and decreased slightly for higher blends. At higher speed torque was almost same for each fuel.
Figure 4 shows the variation of brake power for different fuel blends.

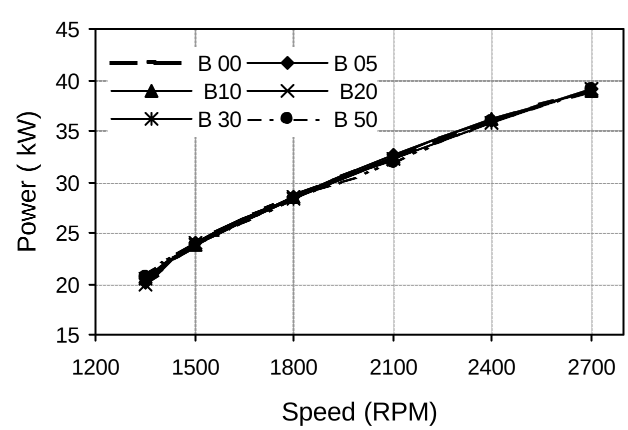

Figure 4: Brake Power Output for Different Blends

Characteristic of brake power curve did not changed with fuel and engine power increased with engine speed. The results showed no noticeable differences in the power output for different biodiesel blends and mineral diesel and no power loss was observed upto 50% biodiesel blend.

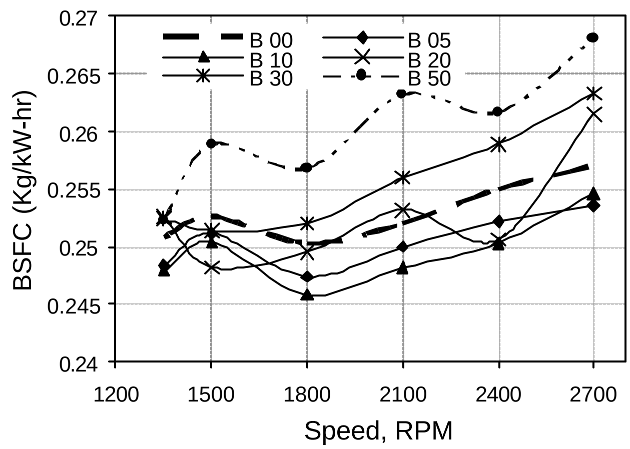

Figure 5: Brake Specific Fuel Consumption for Different Blends

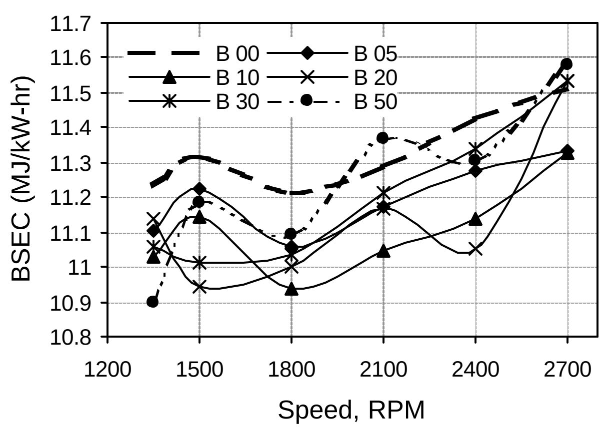

Figure 6: Brake Specific Energy Consumption for Different Blends

Figures 5 and 6 show the brake specific fuel consumption (bsfc) and brake specific energy consumption (bsec) for different fuel blends. These figures reflect that bsfc is lower for B05, B10 and B20 compared to mineral diesel, the bsfc increased with further increase in biodiesel in the blends. However brake specific fuel consumption is not a much rationale parameter for comparing the fuels having different calorific value. Therefore engine characteristic curves for brake specific energy consumption are also drawn. Figure 6 reveals that bsec for all biodiesel blends is lower than mineral diesel. Biodiesel blends of 10% and 20% (B10 and B20) shows minimum bsec for all loads, proving that these blends are more efficient. The characteristic curves for thermal efficiency of the engine for different fuels are shown in figure 7.

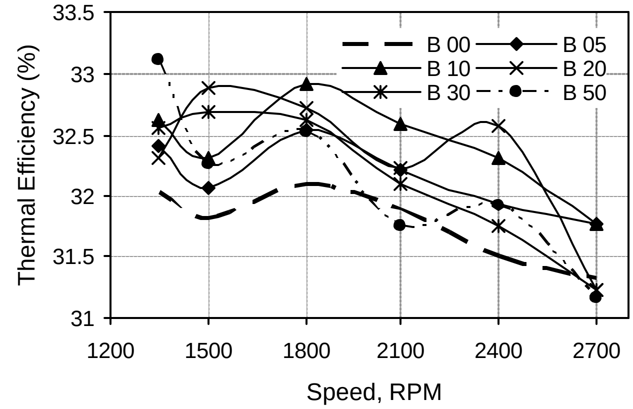

Figure 7: Thermal Efficiency for Different Blends

Thermal efficiency for all biodiesel blends is higher than mineral diesel at all speeds under full load. The biodiesel blends of 10% and 20% shared maximum improvement in thermal efficiency. The air fuel ratios for the engine at different speeds for different blends are shown in figure 8.

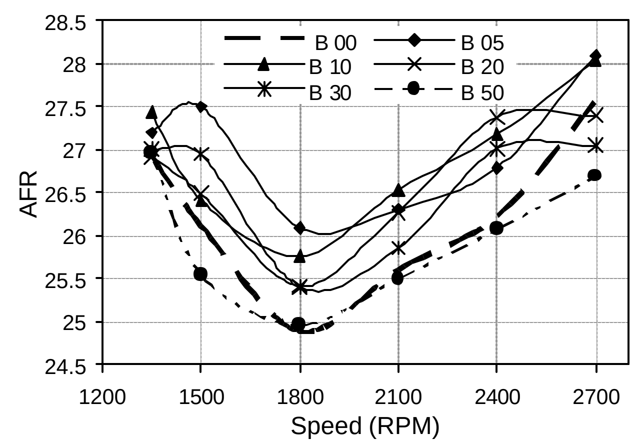

Figure 8: Air Fuel Ratio for Different Blends

Air fuel ratio for each blend has shown similar trends. It first decreases with increase in speed, goes to minimum at about 1800 rpm, and then again increases. Air fuel ratio for biodiesel blends is generally higher compared to diesel. This result is in agreement with the result of bsfc shown in figure 5. The exhaust gas temperatures for different fuels are shown in figure 9. The exhaust gas temperatures for all blends and diesel were in a narrow band. Exhaust gas temperatures were generally lower for biodiesel blends and this difference increased at higher engine speeds

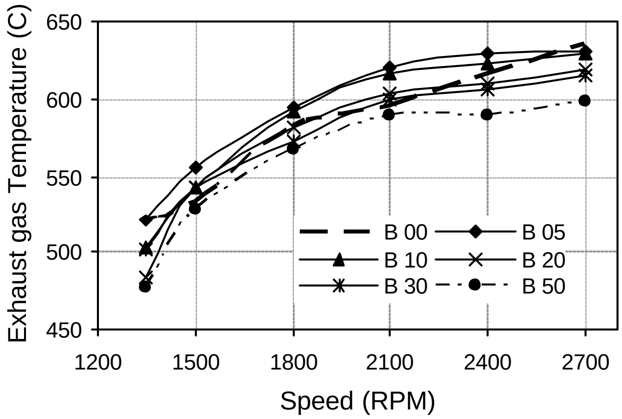

Figure 9: Exhaust Gas Temperatures for Different Blends

The HC, CO and NO_x emissions from the engine for different fuels are shown in figure 10–12. Exhaust gas emission analyzer measures the emissions in ppm which are converted to mass specific emissions [21]. The HC emissions were more than mineral diesel for lower biodiesel blends (B05, B10, and B20), with a maximum for B10. On increasing the concentration of the blend further, HC emissions come down in the range of mineral diesel. HC emissions are found to be higher at low speed and decreases with increase in speed.

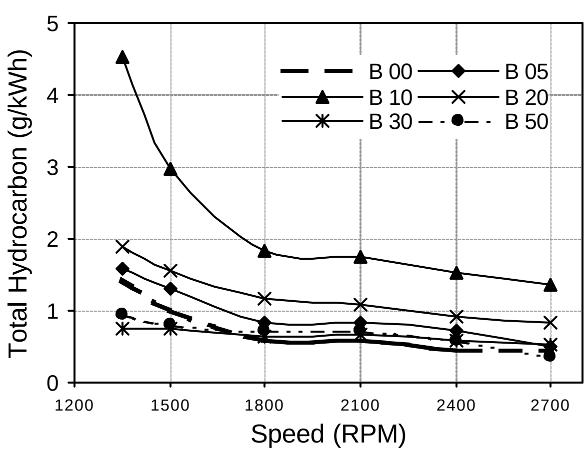

Figure 10: Hydrocarbon Emissions for Different Blends

CO emissions for all the biodiesel blends were generally lower than mineral diesel and they decrease with increase in biodiesel blend concentration. The oxygen atom present in biodiesel molecule possibly plays an important role in reducing CO emissions.

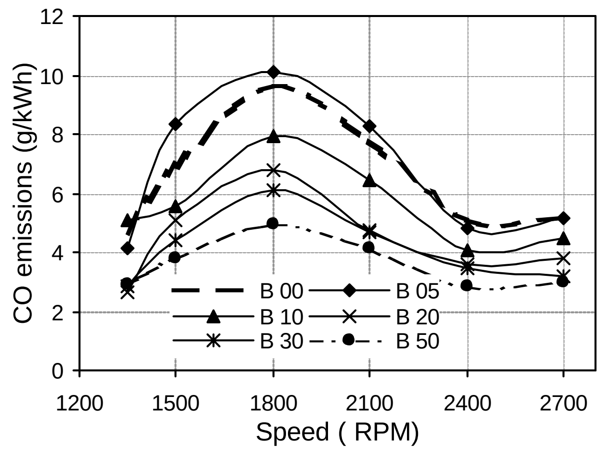

Figure 11: CO Emissions for Different Blends

Higher NO_x emissions were observed for all biodiesel blends compared to mineral diesel as shown in figure 12. Smoke opacity for exhaust from different fuels is shown in figure 13.

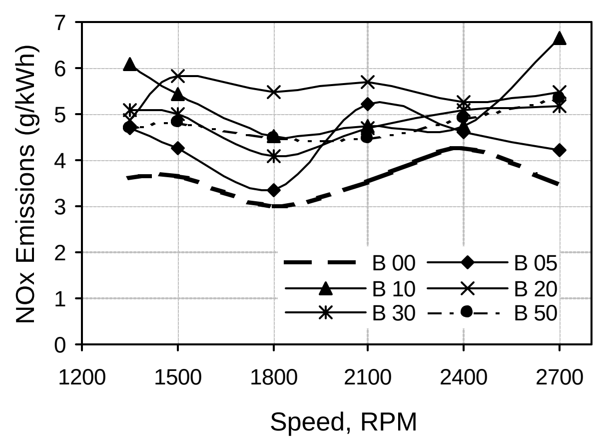

Figure 12: NO_x Emissions for Different Blends

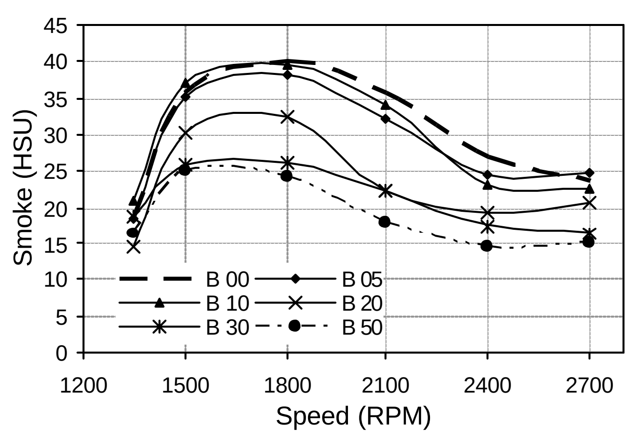

Figure 13: Smoke Opacity for Different Blends

The figure show that the smoke opacity values for all biodiesel blends are lower than mineral diesel and smoke opacity decreases with increase in biodiesel blend concentrations. This result suggests lower particulate emissions from biodiesel fuelled engine.

CONCLUSION

Here Biodiesel is a strong candidate as an alternative fuel for diesel engines, particularly for developing countries in the era of soaring petroleum prices.

In the present investigations, transesterified reaction conditions are optimized for rice bran oil. The optimum conditions are (9:1 methanol to oil molar ratio, 55°C temperature, base catalyst 0.75% (w/w), and 1 hour reaction time. Rice bran methyl ester has a viscosity of 5.3 cSt at 40°C and specific gravity of 0.877, which is significantly lower than rice bran oil (44 cSt at 40°C and 0.928). Several blends of biodiesel and mineral diesel were prepared ranging from 5% to 50% and the performance and emissions of these blends on a transportation engine were compared with mineral diesel.

Power developed and torque characteristics of the engine remained almost similar for all blends and diesel for all speeds at full throttle conditions. Lower concentrations of biodiesel showed improved bsec performance. All blends of biodiesel also exhibited superior thermal efficiency with an overall improvement of 1.5% to 3%. Exhaust gas temperatures for biodiesel blends are also comparable to diesel. Biodiesel blends showed higher HC and NO_x emissions, lower CO emission and smoke opacity.

Overall, biodiesel showed improved engine performance with lower emissions and this has potential to meet significant future emission norms with appropriate exhaust post-treatment technology to offset disadvantage of higher HC and NO_x emissions, without any change in engine hardware.

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REFERENCES

1. Krawczyk, T., Biodiesel – Alternative fuel makes inroads but hurdle remains, INFORM 7, 1996, pp 801-815.
2. Peterson, C.L., Wagner, G.L. & Auld, D.L., “Vegetable oil substitution for diesel fuel”, Transaction of ASAE, 26, 1983, pp 322-327.
3. Muniyappa, P.R., Brammer, S.C., Noureddini, H., Improved conversion of plant oils and animal fats into biodiesel and co-product, Bioresource Technology 56, 1996, pp19-24.
4. Freedman, B., Pryde, E.H., Mounts, T.L., Variables affecting the yields of fatty esters from transesterified vegetable oils, JAOCS 61, 1984, pp 1638-1643.
5. Ma, F., Hanna, M.A., Biodiesel production: a review, Bioresource Technology 70, 1999, pp1-15.
6. Canakci, M., Van Gerpen, G., Biodiesel production via acid catalysis, Trans ASAE 42, 1999, pp 1203-1210.
7. Ali, Y., Hanna, M.A., Alternative diesel fuels from vegetable oils, Bioresource Technology, 50, 1994, pp153-165.
8. Dorado, M.P., Ballesteros, E., Arnal, J.M., Gomez, J., Lopez. F.J., Exhaust emissions from a diesel engine fueled with transesterified waste olive oil, Fuel, 82, 2003, pp 1311-1315.
9. Agarwal, A.K., Vegetable oil versus diesel fuel: development and use of biodiesel in a compression ignition engine, TIDE 8(3), September 1998, pp 191-204.
10. Agarwal, A.K., Das, L.M., Biodiesel development and characterization for use as a fuel in compression ignition engine, Transaction of the ASME, Journal of engineering for gas turbines and power, vol 123, April 2001, pp440-447.
11. Altin, R., Cetinkaya, S., Yucesu, H.S., The potential of using vegetable oil fuels as fuel for diesel engine, Energy conversion & management 42, 2001, pp 529-538.
12. Scholl, K.W., Sorenson, S.C., Combustion of soybean oil methyl ester in a direct injection diesel engine, SAE 930934.
13. Neto da silva, F., Prata, A.S., Teixeira, J.R., Technical feasibility assessment of oleic sunflower methyl ester utilization in diesel bus engine, Energy conversion & management 44, 2003, pp 2857-2878.
14. Al-Widyan, M., Tashtoush, G., Abu-qudais, M., Utilization of ethyl ester of waste vegetable oils as fuel in diesel engines, Fuel Processing Technology, 76, 2002, pp 91-103.
15. Antolin, G., Tinaut, F.V., Briceno, Y., Castano, C., Perez, C., Ramirez, A.I., Optimisation of Biodiesel production by Sunflower oil transesterification, Bioresource Technology 83, 2002, pp111-114.
16. Raheman, H., Phadatare, A.G., Diesel engine emissions and performance from blends of karanja methyl ester and diesel, Biomass & bioenergy 27 2004, pp 393-397.
17. Kalligeros, S., zannikos, F., stournas, S., Lois, E., Anastopoulos, G., Teas, ch., sakellaropoulos, F., An investigation of using biodiesel/ marine diesel blends on the performance of a stationary diesel engine, Biomass & bioenergy 24, 2003, pp 141-149.
18. Kalam, M.A., Masjuki, H.H., Biodiesel from palm oil-an analysis of its properties and potential, Biomass & bioenergy 2, 2002, pp 471-479.

19. Indian standard code IS:10000, 1980, Method of tests for internal combustion engines.
20. Indian standard code IS: 10003, 1981 Specification for performance requirements for compression ignition (diesel) engines for automotive purposes.
21. Indian standard code IS: 14273, 1999, Automotive vehicles- Exhaust emissions- gaseous pollutants from vehicles fitted with compression ignition engines- method of measurements.