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A COMPARATIVE STUDY ON ENVIRONMENTAL EMISSIONS AND PERFORMANCE OF A STATIONARY TYPE DIESEL ENGINE FUELLED WITH BIODIESELS DERIVED FROM TWO DIFFERENT FEEDSTOCKS

The objective of the present study was to experimentally investigate environmental emissions and performance of a stationary type diesel engine fuelled with biodiesels derived from two different feedstocks; one is more unsaturated (rice bran biodiesel) and the other one is more saturated in nature (palm biodiesel) and compare with petrodiesel. Tests were conducted in a single cylinder, air cooled, direct injection diesel engine. From the experimental results, it was found that the nitrogen oxides emissions were higher with biodiesel fuels. The hydrocarbon and carbon monoxide emissions of palm biodiesel were lower than the other test fuels. The smoke emission of rice bran biodiesel was the lowest compared to the rest of the fuels. A considerable reduction in thermal efficiency was found with both the biodiesels when compared to diesel. From the present study, it is concluded that the biodiesels derived from palm and rice bran oils with their different fatty acid composition, show lower exhaust emissions and closer performance characteristics to diesel.

1. INTRODUCTION

Emissions from internal combustion engines are considered to contribute greatly to greenhouse gases [1]. Replacement of fossil fuels with renewable biofuels has been set as a target worldwide to reduce greenhouse effect and energy dependence as well as to improve agricultural economy. Biodiesels are renewable, biodegradable, and nontoxic fuels with the potential to reduce emissions of carbon dioxide (CO_2) [2]. In addition, biodiesel combustion results in a decrease in hydrocarbon (HC), carbon monoxide (CO), and particulate emissions compared to conventional petrodiesel. Whereas an increase in nitrogen oxides (NO_x) from biodiesel combustion compared to diesel has been reported in several papers [3–6]. The advantages of biodiesel as fuels

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are their minimal sulphur and aromatic content, higher flash point, better lubricity, and higher cetane number [7–10]. On the other hand, poor low temperature properties indicated by relatively high cloud points (*CP*) and pour points (*PP*) are higher for biodiesels which contain larger saturated fatty compounds compared to biodiesels with more unsaturated fatty acids [11, 12].

Numerous efforts have already been made to analyse the usage of biodiesel derived from jatropha, mahua, karanja, rubberseed, and rice bran oils in diesel engines [13–17]. In this context, biodiesel derived from rice bran and palm oils are considered as important diesel substitutes because of their high productivity and lower cost [1, 18]. When compared to other non-edible oils, not much work has been reported on biodiesel production from rice bran oil. It is not a common source of edible oil compared to other traditional cereal or seed sources such as corn, cotton, sunflower, or soybean [19]. Due to the presence of active lipase in the bran and lack of economical stabilization methods, most bran is used as livestock feed or boiler fuel and most rice bran oil produced is not of edible grade. Hence one of the best ways for the potential utilization of crude rice bran is the production of biodiesel [20]. Rice bran oil is an underutilized by-product of rice milling. As a residue from food production, it does not require land that might be used for food production, as is the case of ethanol production, or where biodiesel is produced from vegetable oils on land that could be used for food production [21]. The estimated potential yield of crude rice bran oil is about 8 million metric tons if all rice bran produced in the world were to be harnessed for oil extraction [18]. Similarly, South Eastern countries like Malaysia and Thailand have surplus palm crops [1]. The objective of the present study is to experimentally investigate the environmental emissions and performance of a stationary type diesel engine fuelled with biodiesels derived from two different feedstocks – one more unsaturated (rice bran biodiesel) and the other more saturated in nature (palm biodiesel) – and to compare them with petrodiesel.

2. EXPERIMENTAL

Preparation of biodiesel. The parent oils, i.e. rice bran oil and palm oil were procured from Annai Biocrops Pvt., Ltd., Chennai. The rice bran and palm biodiesels (methyl esters of rice bran and palm oils) were produced through transesterification, a process in which the reaction between triglyceride and alcohol occurs to produce alkyl ester and glycerol. Alkali (potassium hydroxide or sodium hydroxide) or acids (hydrochloric acid or sulphuric acid) are used to catalyze reaction [22–24]. Alkali catalyzed transesterification is faster than acid catalyzed transesterification and is most used commercially. The primary objective of the transesterification process is to reduce the viscosity of vegetable oil. The biodiesels were produced from 1000 g of vegetable oil, 200 g of methanol, and 5 g of sodium hydroxide (NaOH) as a catalyst (generally the alcohol and the catalyst quantities were 20% and 0.3–0.5% of the parent vegetable oil, respectively). The ester conversion ratio of rice bran and palm biodiesels are over 95%.

Fuel. The fuel properties were determined following the methods specified in ASTM standards as given in Table 1. The properties such as density, kinematic viscosity, cetane number, heating value, flash point, and pour point were measured at ITALAB Pvt. Ltd, Industrial Testing and Analytical Laboratories (an ISO 9001: 2000 certified organization), Chennai, India. The fatty acid profile analysis was done at the Tamil Nadu Oil Seeds Association, Chennai, India. The fatty acid compositions of biodiesel products were determined using a Gas Chromatography (Hewlett Packard Plus 6890 series).

Table 1

ASTM standards [25] for determination of properties of fuel

Parameter	ASTM Standard
Density, kg/m^3	D 1298
Kinematic viscosity, cSt	D 445
Net heating value, MJ/kg	D 240
Cetane number	D 613
Flash point, °C	D 93
Pour point, °C	D 97
Water content, vol. %	D 95

Experimental set-up and test procedure. A single cylinder air-cooled stationary DI diesel engine developing a power output of 4.4 kW at the rated speed of 1500 rpm was used for the experimental studies. The technical specifications of the engine are given in Table 2.

Table 2

Specification of the test engine

Parameter	Specification
Make	Kirloskar
Model	TAF-1
No. of cylinders	1
Type of cooling	air cooled
Bore × Stroke	87.5 × 110 mm
Compression ratio	17.5:1
Piston bowl	hemispherical
Rated power	4.4 kW at 1500 rpm
Injection opening pressure	200 bar
Fuel injection timing	23 °CA bTDC

The performance and emissions were studied at 25%, 50%, 75%, and 100% (full load) of the load corresponding to the load at the maximum power at the average speed of 1500 rpm. The fuel flow rate was measured on volume basis (time taken for 10 cc of fuel consumption was measured) using a burette and a stop watch. After the engine reached the stabilized working condition, the performance and emission parameters were measured. The exhaust gas temperature was measured using a K-type (Chrome-Alumel) thermocouple with a digital indicating unit. The emissions such as NO_x, HC, and CO were measured with DELTA 1600-L make MRU OPTRANS 1600 exhaust gas analyzer. The smoke density was measured by Bosch make TI diesel tune, 114-smoke density tester.

3. RESULTS AND DISCUSSION

The fatty acid profiles of rice bran and palm biodiesel are given in Table 3. Various fuel properties of diesel, rice bran biodiesel, and palm biodiesel as determined by the methods specified in ASTM standards are summarized in Table 4.

Table 3

Fatty acid composition of rice bran and palm biodiesels

Fatty acid chain	C:N	Type	Rice bran biodiesel	Palm biodiesel
Lauric	C12:0	saturated	0.1	0.2
Myristic	C14:0		0.3	2.7
Palmitic	C16:0		12.7	49.2
Stearic	C18:0		8.3	8.8
Oleic	C18:1	unsaturated	28.9	31.3
Linoleic	C18:2		36.6	7.5
Linolenic	C18:3		13.1	0.3

In C:N, C indicates the number of carbon atoms and N the number of double bonds of carbon atoms in the fatty acid chain.

The variation of brake specific fuel consumption (BSFC) with load for the test fuels is shown in Fig. 1. The BSFC decreases upon increasing load. At all loads, the BSFC was found to be lower for diesel compared to biodiesels. As the heating value of palm biodiesel is lower than that of diesel, more fuel quantity is required to produce the same power output. In addition, the BSFC is calculated on a mass basis. Therefore, for a given injection volume, more quantity of fuel is injected for a higher density fuel. Palm biodiesel has a higher density value than that of diesel. Similarly, the higher BSFC of rice bran biodiesel is due to the lower heating value and higher density compared to palm biodiesel. At full load, the BSFC of diesel, palm biodiesel, and rice bran biodiesel are 0.312, 0.351, and 0.418 kg/kWh respectively.

Table 4

Determined fuel properties of diesel, rice bran, and palm biodiesels

Parameter	Unit	Diesel	Rice bran biodiesel	Palm biodiesel
Density at 15°C	kg/m^3	830	886	879
Kinematic viscosity at 40 °C	cSt	2.62	4.7	4.1
Net heating value	MJ/kg	42	36.3	37.1
Cetane number		48	51	54
Flash point	°C	67	209	191
Pour point	°C	–19	2	14
Water content	vol. %	–	0.05	0.03

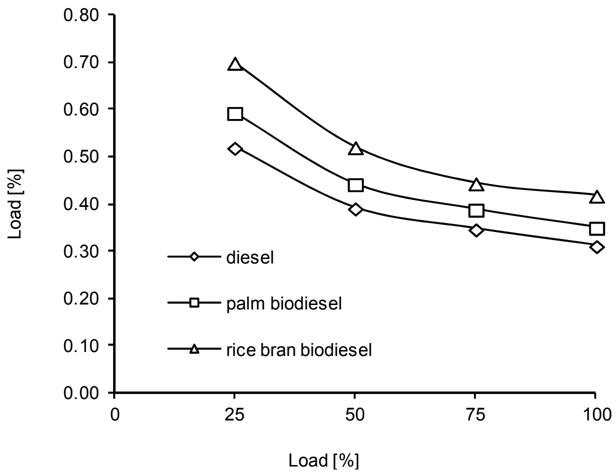

Fig. 1. Dependence of BSFC on load

Brake specific energy consumption (BSEC) is an ideal parameter, since it is independent of the fuel used. When comparing fuels of different densities and heating values, it is essential to discuss about BSEC, which can be obtained by multiplying the BSFC with heating value of the fuel. The dependence of BSEC on load is depicted in Fig. 2. The trend of BSEC was found to be similar to BSFC. At all loads like BSFC, diesel has lower BSEC and rice bran biodiesel has higher BSEC values. The BSEC of palm biodiesel lies in between diesel and rice bran biodiesel. Again this is due to the combined effect of increased density and lower heating value. At full load conditions, the BSEC for diesel, palm, and rice bran biodiesels are 13.09, 13.64, and 15.06 MJ/kWh respectively.

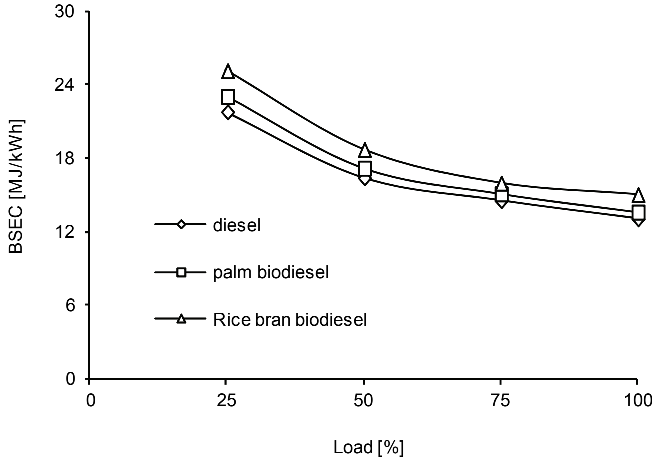

Fig. 2. Dependence of BSEC on load

Figure 3 shows the dependence of brake thermal efficiency on load. From the figure, it can be observed that the trend of brake thermal efficiency is exactly the reverse of BSEC at all loads for all the test fuels. This is because of the brake thermal effciency being the reciprocal of BSEC. At full load conditions, the brake thermal efficiencies for diesel, palm, and rice bran biodiesels are 27.5%, 26.4%, and 23.9% respectively.

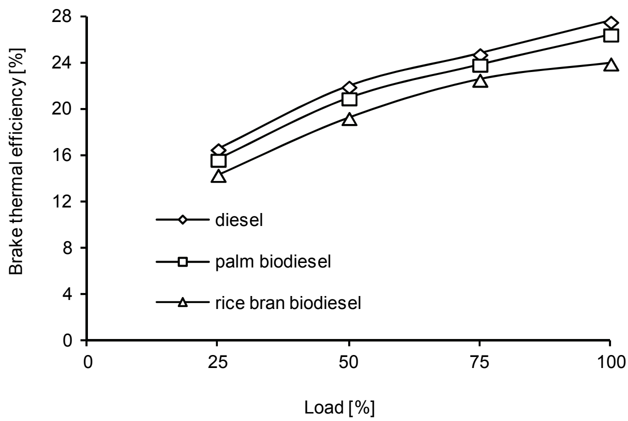

Fig. 3. Dependence of brake thermal efficiency on load

The dependence of exhaust gas temperature on load is shown in Fig. 4. Generally, this temperature increases upon increasing load. At all loads, the exhaust gas temperature was found to be lower for diesel and higher for rice bran biodiesel, while for palm biodiesel it lies between those for diesel and rice bran biodiesel. The idea of measuring and comparing exhaust gas temperature is to understand the effective utilization of heat energy by the engine. Higher exhaust temperature indicates poor energy utilization by the engine, which in turn represents lower brake thermal efficiency. Therefore, it is understood that the higher exhaust gas temperatures may be attributed to increased heat losses of palm and rice bran biodiesels compared to diesel. This can be perceived by the brake thermal efficiency of the respective fuels. At full load conditions, the exhaust gas temperature for diesel, palm, and rice bran biodiesels are 332 °C, 354 °C, and 395 °C, respectively.

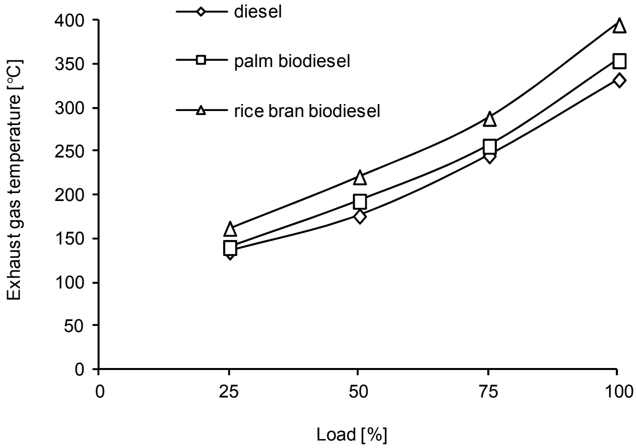

Fig. 4. Dependence of exhaust gas temperature on load

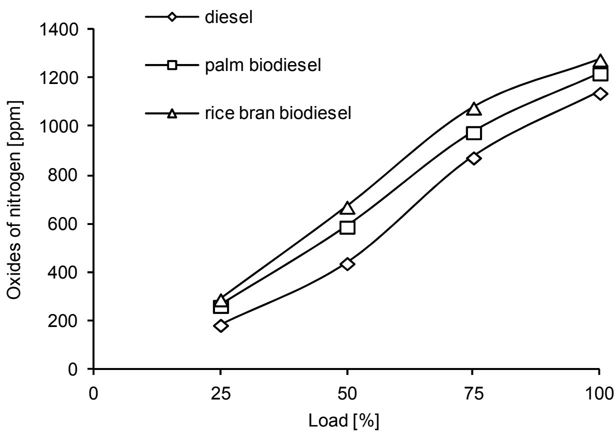

Fig. 5. Dependence of nitrogen oxides emission on load

The variation of nitrogen oxides (NO_x) with load is depicted in Fig. 5. It can be seen that NO_x of biodiesel derived from rice bran oil is higher than that of diesel and palm biodiesel. Between rice bran and palm biodiesel, the former shows higher NO_x emission than the later. This increase in NO_x emission could be due to the presence of higher amounts of polyunsaturated fatty acids in rice bran biodiesel compared to palm biodiesel. Also increasing density may increase NO_x content because fuel injectors inject a constant volume, but larger mass of more dense fuels. Since a larger mass of fuel is burned, more NO_x is produced. From Table 4, it can be seen that diesel has lower density compared to palm biodiesel; similarly, the density of palm biodiesel is lower than that of rice bran biodiesel. As compared to diesel, the increase in NO_x emissions were found to be 7% for palm biodiesel and 12% for rice bran biodiesel at full load operation.

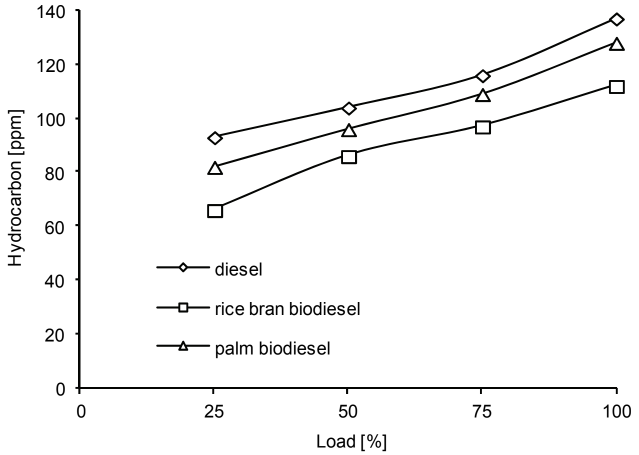

Fig. 6. Dependence of hydrocarbons emission on load

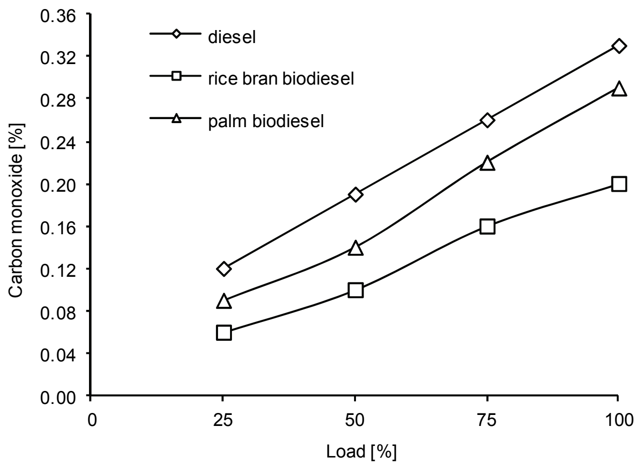

Fig. 7. Dependence of carbon monoxide emission on load

Figures 6 and 7 show the dependences of emissions of hydrocarbons (HC) and CO on load, respectively, for the fuels under investigation. Hydrocarbon emission occurs due to incomplete combustion of fuel molecules. This is an effect of wall quenching. The study of HC emissions is essential since they contribute to photochemical smog. From Figure 6, it can be seen that HC emissions of all the fuels are lower at partial load, but tend to increase with load due to fuel-rich mixture at elevated loads. At all loads, diesel shows higher HC emissions compared to biodiesel fuels. The reduction in HC emission with palm and rice bran biodiesel fuels could be believed due to the oxygen content of biodiesel, which may lead to better combustion. However, rice bran biodiesel shows higher HC emission compared to biodiesel derived from palm oil. As compared to diesel, palm biodiesel has 18% lower; while rice bran biodiesel has 6.6% lower HC emissions at full load operations. Similarly, CO emissions result from the lack of oxygen and low combustion temperature, resulting in incomplete oxidation of CO to CO_2. CO emissions from diesel engines are generally low as they operate on lean mixtures.

From Figure 7, it can be observed that CO emissions increase with loads for all the test fuels. As compared to diesel, rice bran and palm biodiesels exhibit lower CO content at all loads. As like HC emissions, the decrease in CO emission could be an outcome of improved oxidation of carbon monoxide to carbon dioxide due to additional oxygen content in the biodiesel. It can be noted that the biodiesel chain has oxygen molecules by about 10–11% which results in better combustion. At full load, the CO emissions are 0.33%, 0.20%, and 0.29% for diesel, palm, and rice bran biodiesels, respectively.

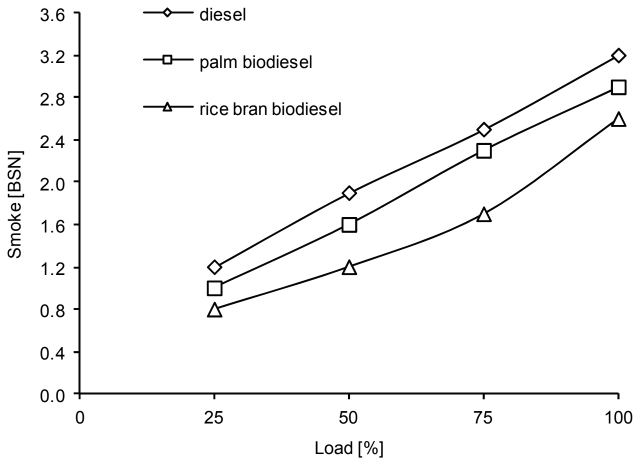

Fig. 8. Dependence of smoke on load

The dependence of smoke in Bosch smoke number (BSN) on load is shown in Fig. 8. Smoke is emitted as a product of incomplete combustion, particularly at elevated loads. The smoke emission increases upon increasing load for all the test fuels. Only a marginal difference in smoke could be found between the test fuels at part loads. However a considerable difference was observed at elevated loads. At full load, the smoke densities for diesel, palm, and rice bran biodiesels are 3.2, 2.9, and 2.6 BSN respectively. The reductions in smoke density are 18.8% and 9.3% with rice bran and palm biodiesels, respectively, compared to diesel at full load. This reduction in smoke emission can be due to the presence of additional oxygen in the fuel molecules. Due to the additional oxygen, smoke may be reduced at the rich mixture of fuel spray and the cooler part of spray impingement of combustion chamber wall. Smoke can be related to stoichiometric air-fuel ratio, as well. Fuel with higher air-to-fuel ratio needs more air for complete combustion than the fuel that has a lower stoichiometric air-to-fuel ratio in a given time. The reported values [26, 27] of stoichiometric air-to-fuel ratio for biodiesel derived from palm, coconut, and rapeseed oils were found to be lower than that of diesel. However, compared to palm biodiesel, rice bran biodiesel shows lower smoke density at full load.

4. CONCLUSIONS

Experiments were carried out to investigate the environmental emissions and performance of a stationary type diesel engine fuelled with biodiesels derived from two different feedstocks: one is more unsaturated (rice bran biodiesel) and the other one more saturated in nature (palm biodiesel), and to compare with petrodiesel. From the results and discussion, the following conclusions are drawn. The NO_x emissions are higher with biodiesel fuels. Compared to diesel, the increase in NO_x emissions were found to be 7% for palm biodiesel and 12% for rice bran biodiesel at full load. The HC and CO emissions of palm biodiesel were lowest among the other test fuels. Compared to diesel, palm biodiesel has 18% lower; while rice bran biodiesel has 6.6% lower HC emissions at full load operations. At full load, the CO emissions are 0.33%, 0.20%, and 0.29% for diesel, palm, and rice bran biodiesels respectively. The smoke emission of rice bran biodiesel was the lowest compared to the rest of the fuels. The reductions in smoke density are 18.8% and 9.3% with rice bran and palm biodiesels, respectively, compared to diesel at full load. At all loads, diesel exhibits higher brake thermal efficiencies than the remaining fuels. From the present study, the authors conclude that the biodiesels derived from palm and rice bran oils with their different fatty acid composition, show lower exhaust emissions except NO_x, and closer performance characteristics to that of diesel. However, compared to palm biodiesel, rice bran biodiesel showed slightly inferior performance and emission results. Therefore, future studies should be done consisting in blending rice bran biodiesel with palm biodiesel in various ratios in order to realize better emission results and performance from rice bran biodiesel.

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