Performance and Emission Characteristics of a Direct Injection Diesel Engine Fuelled With Diesel/Rice-Bran Oil Blend

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Abstract

The present experimental investigation aims to depict the effect of using diesel/rice-bran oil blend as fuel on the characteristics of a small agricultural engine. Characterization for major properties of test fuel was conducted. Series of short-term tests were conducted on a single cylinder, 3.7 kW, water cooled, stationary diesel engine and performance and emission characteristics were determined using diesel/rice-bran oil blend and compared with those of diesel.

The maximum brake thermal efficiency (BTE) decreased marginally by 7.36%, while the brake specific fuel consumption (BSFC) increased slightly by 11.6%, at full load and rated engine settings. Significant reduction in carbon monoxide and hydrocarbon emission were observed. CO and HC in exhaust emissions reduced by up to 25 %, while the CO_2 emissions increased marginally by only 3.19%.
The use of lower blends of rice-bran oil even at rated engine settings results in minimum loss of efficiency and generates higher environmental benefits.

KEYWORDS: Diesel/rice-bran oil blend, Diesel engine, Performance, Emissions.

I. Introduction

Diesel engines have high efficiency, durability, reliability and low operating cost making them the most preferred engines. But, they are also the largest contributor to environmental pollution.

Environmental impact and potential fuel savings were predicted by implementing the fuel economy standard program for light duty vehicles in Iran. Around 3.81 billion litres of fuel is expected to be saved, along with huge emission reduction from 2013 to 2018. (Mohammadnejad et al. 2014; Resitoglu et al. 2014)). Fuels of bio-origin promise energy conservation, efficiency and environmental preservation. They are renewable in nature and can provide a feasible solution to the energy crisis, with reduced dependence on fuel import. (Hayek et al. 2013).

Research in USA, Europe, India, Germany, Philippines and South East Asia has established the possibility of using vegetable oils like soybean, canola, sunflower, coconut, castor, palm, cottonseed, etc. in diesel engines. The various studies conducted thus far have aggregately shown that the use of bio-fuels could potentially reduce major pollutants typical of diesel engines (Ramadhas et al. 2004; Sonar et al.2014; Sonar et al. 2015; Sharma et al. 2009).

In rural and remote areas of developing countries where grid power is not available, locally available vegetable oils can play a vital role in decentralized power generation. But, high viscosity of vegetable oils is a major hindrance in using it as a fuel in diesel engines. To lower the viscosity, transesterification is well accepted method but this adds to complexity and extra cost of processing, apart from logistics problem in rural settings. Engines running on neat oils with the integration of such sub-systems could perform effectively for around 250 hours. Vegetable oils and blends have shown performance characteristics close to diesel. Due to improved combustion, emission values decrease with positive effect on engine parts. However, modified maintenance schedule may be adopted to control carbon deposits formed during long term usage of vegetable oil. (Agarwal D et al. 2008; Agarwal AK et al. 2008; Ramadhas et al. 2004; Reddy and Ramesh 2006; Sayin et al. 2012; Kannan and Anand 2012; Biona and Licauco 2009; Pradhan et al. 2014; Sidibe et al. 2010; Misra and Murthy 2010)

Straight vegetable oils (SVO) can be produced on small-scale in local cooperatives through pressing, filtering and conditioning processes which are much simpler than the ones required for biodiesel (BD) production. A comparative life cycle assessment of small-scale SVO and large-scale BD was performed to assess environmental advantages of SVO vis-a-vis its BD. Moreover, energy return on investment index and an energy conversion ratio were evaluated. Results showed a clear preference for SVO as compared to BD. The main differences in terms of impacts and energy appear due to the fact that the production of BD requires more complex processes than the SVO production. Also, the obtained results show the environmental benefits of using SVO instead of BD (Esteban et al. 2011).

India is producing a host of non-edible oils such asjatropha, linseed, castor, mahua, rice bran, karanj, neem, palash, kusum, etc. Not much attempt has been made to usethese non-edible oils as substitute for diesel exceptJatropha and Karanja (Agarwal et al. 2008).

Rice bran oil (Oryzasativum)

Non-edible Rice bran oil is a post-harvesting agricultural by-product obtained from outer layer of brown rice kernel. Estimated yield potential of crude Rice bran oil is about 8 million metric tons globally.

Rice grain consists of the edible portion covered with an outer layer called husk or hull. After removing the protective husk, a thin bran layer is seen surrounding the starchy white rice kernel. The rice milling process produces rice husk and rice bran as by-products. The Rice Bran is about 10% of the weight of rough rice.

Rice plant (paddy) and its seed are shown in Fig 1.

Fig 1 Rice plant (paddy) and its seed

Crude rice bran oil is a non-conventional, inexpensive, low-grade vegetable oil, and can be used as a feedstock for biodiesel. However, its use has not been standardized, although it has a potential as a fuel because of its mineral diesel like properties.

Advantages of rice bran as fuel are: generally non-edible, local and widely available, no large distance transportation needs, no large processing infrastructure required, cheaper fuel source, etc. Its main limitations are high density, viscosity and presence of suspended particulates. Efficient dewaxing and degumming is very necessary for its use as fuel. (Ju YH. etal. 2005; Prasad BR et al. 2012; Sundaram PK et al. 2015)

Crude rice-bran oil (RB100) has been selected for this experimental investigation. The specific objectives of this study are to evaluate the performance and emission characteristics of the diesel engine using crude rice-bran oil and to compare these results with those of baseline diesel.

Materials and methods

The quality of expelled oils depends largely on the storage conditions of seeds and the oils. Fresh oils from properly stored seeds have better characteristics. The crude rice bran oil that was freshly extracted was procured from the local market. It was filtered with cloth and also with filter paper mainly to remove dirt. High speed diesel was procured from pump station of Indian Oil Corporation in Jaipur. It was used as reference fuel for comparison of performance and emission characteristics of the engine with the test fuel. 20% cude rice bran oil was thoroughly mixed with 80 % diesel to make the R20 fuel.

Experiments

Series of short-term tests were conducted on a single cylinder,3.7 kW, water cooled, stationary diesel engine and performance and emission characteristics were evaluated using diesel/rice-bran oil blend (R20) as well as diesel.

Characterization for major properties of test fuel was done.

Detailed specifications of the engine are given in Table 1and the schematic layout of test setup is shown in Fig. 2.

Specifications of diesel engine

1. Name of the engine – Kirloskar Oil Engine Model AV1
2. Type of engine – Four stroke cycle, single cylinder, water cooled, direct injection, 1,500 rpm, C.I. engine
3. No. of cylinders – 1
4. IS rating at 1,500 rpm kW 3.7
5. Bore/stroke mm 80/110
6. Cubic capacity litres 0.553
7. Compression ratio – 16.5:1
8. Recommended fuel – Diesel as per IS: 1460
9. Fuel injection pressure (rated) kgf/cm2 (bar) 200 (196)

10. Fuel injection timing (rated) Crank angle 23_ BTDC

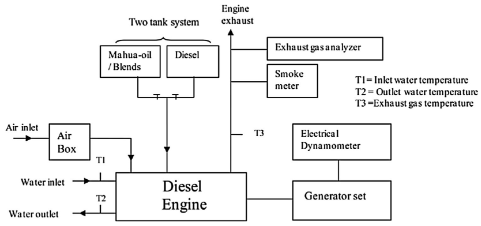

Fig. 2 The line diagram of experimental setup

Experimental setup and measurements

Tests were conducted over the entire range of engine operation. Results were compared with baseline data of diesel fuel. The test engine was directly coupled to a Kirloskar make electrical alternator. An electric dynamometer was installed to determine the brake power. Flow rate of air was measured by means of a manometer. Chromel-Alumel thermo couples were used to measure various temperatures. Two fuel tank system was used, one each for diesel and crude rice-bran oil/blends. The mass flow rate of intake air was measured with an orifice meter coupled to a manometer. An air box was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. A duly calibrated standard burette (100 ml volume with 1 ml division) and a digital stopwatch were employed for the fuel flow measurements. Engine rpm was measured using a battery-operated handheld standard tachometer. The emissions such as CO and HC were measured using AVL 4,000 Light exhaust gas analyser.

The tests were carried out using diesel andR20 on the engine with manufacturer recommended fuel injection pressure of 196 bar and injection timing of 23^{o}bTDC and at a rated speed of1, 500 rpm. The engine tests were carried out at 0, 1, 2, 3 and 3.7 kW loadings. To overcome the problem of high fuel viscosity, the engine was always started and run for 20 min, using diesel fuel and then switched to vegetable oil. Similarly, while shutting down, reverse was done to ensure that only diesel fuel was left inside the fuel system.

At each load, after the engine reached the stabilized condition, the performance and emission parameters we rerecorded. The experiment was replicated three times and average values were taken. Each reading was also averaged for values during loading and unloading.

Result and discussion

Fuel properties

The physico-chemical properties of bio-fuels are highly sensitive to the variety of feedstock used (Agarwal et al.2008). Depending on the nature of the oil-bearing biomass from which SVOs are obtained, and on extraction and drying conditions, SVOs display highly variable physicochemical characteristics and combustion properties (Sid beet al. 2010). Hence, a detailed characterization of fuel properties must be conducted before experimentations, if straight vegetable oils are used.

Fuel prope	Un it	Di e	R1 00	R 20	AST MD	Method /

rty		sel			6751	apparatus
Density at 15 ^{0}C	kg/m^3	832	918	851	*	Relative density bottle
Kin viscosity at 40^{0}C	mm^2/s	2.61	39.41	10.45	1.9–6.0	Redwood viscometer
Calorific value	MJ/kg	43.51	37.86	42.38	*	Bomb calorimeter

Table 2 Fuel properties of various fuels with ASTM limits and methods used

* Not mentioned

Fuel characterisation for major properties of test fuels was done as per ASTM standards in Biodiesel labs in Mechanical and Chemical Engineering Departments of MNIT Jaipur and the values are recorded in Table 2.

The lower calorific value of crude R100wasfound to be 37.86 MJ/kg, which is12.9 % less than diesel. This may be due to the difference in chemical composition, different percentage of carbon and hydrogen atoms and the presence of oxygen molecule in rice bran oil.

Performance characteristics

Engine performance

Brake thermal efficiency (BTE)

Figure 3 shows the variation of BTE for R20 oil and diesel. At full load and rated engine settings, the BTE of R20 was 7.36 %lower than diesel. There is a trade-off between reduced calorific value and increased oxygen content in the R20 blend. This slight decreased value might be attributed to lower energy content of the former. BTE in both cases increased with increase in load, probably due to reduction in heat losses and increase in power with load.

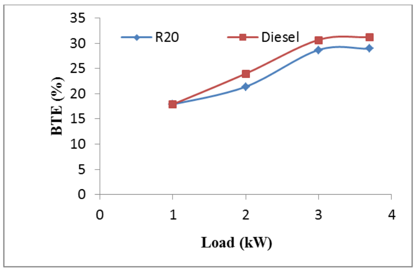

Fig. 3 Variation of BTE with load

Few of the researchers have reported BTE values of the SVO and their blends to be comparable with diesel with or even without modifications. In some cases, power and torque remain unchanged, often with a 5–10 % increase in engine power with vegetable oils and with minor modifications in engine (Sidibe et al. 2010). Engine power and torque of sesame oil diesel blend are close to diesel even without engine modifications (Behmus et al. 2008).

Maximum BTE at full load condition for Jatropha oil was29.15 % and that for diesel was 29.88 % (Pradhan et al.2014). Peanut oil has shown even higher efficiency than that of diesel regardless of preheat condition (Yilmaz andMorton 2011).

Brake specific fuel consumption (BSFC)

The BSFC of test fuels at rated settings is provided in Fig. 4.BSFC for R20 oil is generally higher than that of diesel. BSFC of the test fuel as well as diesel were lowest near full load.

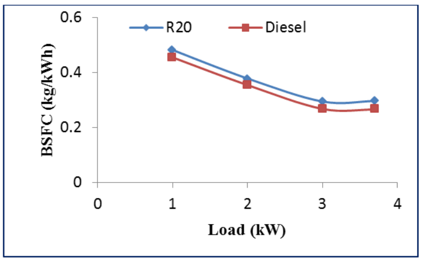

Fig. 4 Variation of BSFC with load

With increase in load, the brake power increases to rated value for the engine leading to better utilization of injected fuel. The increase in brake power is more as compared to the increase in fuel consumption resulting in lower BSFC.

BSFC is much higher for crude 100% vegetable oils than diesel at rated engine parameters and full load, since vegetable oils have lower CV and higher density, requiring more fuel to maintain the power output. As the BSFC was calculated on mass basis, obviously higher densities with higher mass injection for the same volume resulted in higher values for BSFC. Due to these reasons, the BSFC for crude rice-bran oil or its blend was higher than that of diesel.

But blends can reduce this difference to acceptable limits. At rated settings and full load, for R20, it was higher than that of diesel by only 11.6%.

Emission characteristics

Carbon Monoxide (CO)

Variation of CO emissions with load is shown in Fig. 5.

Diesel engine being lean burn engine emits significantly less CO emissions. Further lower values were observed for

R20 oil indicating more complete combustion. The reduction of up to 25 %in CO emission, and a reduction of 20% at full load was achieved with R20. Some of the CO produced during combustion ofR20 oil might have converted into CO2 by taking up the extra oxygen molecule present in the bio diesel chain and thus reduced CO formation.

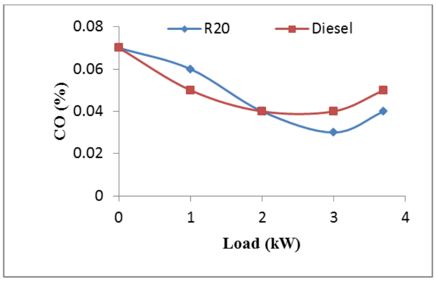

Fig. 5 Variation of carbon monoxide with load

CO initially decreased with load and later increased upto full load for the fuel blend tested. At no load condition, cylinder temperatures might be too low resulting in incomplete combustion. Temperatures increased with loading due to more fuel injected inside the cylinder, so performance of the engine improved with relatively better burning of the fuel resulting in decreased CO. However, on further loading, the excess fuel required led to formation of more smoke, which might have prevented oxidation of CO into CO2, consequently increasing the CO emissions again.

Un burnt hydrocarbons (HC)

The variation of unburnt hydrocarbons (HC) is shown in Fig. 6.Similar to CO, HC is the outcome of incomplete combustion. Increased oxygen content in the rice-bran oil promoted more complete combustion, which resulted in lower HC. At rated engine settings, maximum reduction in HC was observed to be 18.6% for R20, and such reduction at full load as compared to base case values for diesel was observed to be 5.17%.

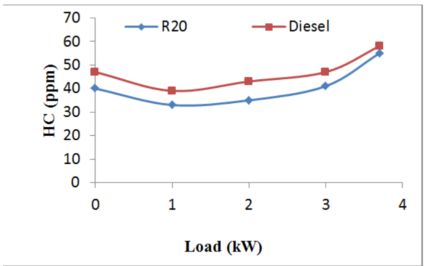

Fig. 6 Variation of unburnt hydrocarbons with load

Carbon Dioxide (CO_2)

The variation of carbon dioxide (CO_2) with load for R20fuel is shown in Fig. 6. There was not much variation in the release of carbon dioxide in R20 and diesel as fuel. The maximum variation was found to be 13.5 % at no load. There was an increase of only 3.19% at full load. CO_2 emission is the indicator of complete burning. The test fuel, viz R20 burns completely at full load due to high temperature and pressure conditions inside the cylinder at full load. Increased oxygen content in the R20 fuel promoted more complete combustion, which resulted in higherCO_2 than that for diesel.

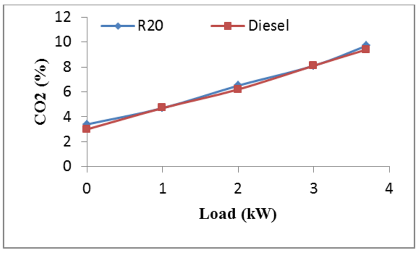

Fig. 7 Variation of carbon dioxide with load

Conclusion

The fuel properties of R20 blend was found to be similar to diesel, and largely within limits specified by the ASTM standards except viscosity. The maximum brake thermal efficiency (BTE) decreased marginally by 7.36%, while the brake specific fuel consumption (BSFC) increased slightly by 11.6% only at full load and rated engine settings.

CO and HC in exhaust emissions reduced by up to 25 % , while the CO_2 emissions increased marginally by only 3.19%.

It is concluded that lower blends of rice-bran oil could be safely used as fuel, and thus could be a suitable alternative fuel for diesel. Although the thermal efficiency is still slightly lower than diesel, emission parametersat rated engine settings are much better than diesel operation.

The use of lower blends of rice-bran oil even at rated injection pressure results in minimum loss of efficiencyand generates higher environmental benefits.

Scope for future work

Some investigation objectives listed below, though not exhaustive, may be considered as future scope of work:

- Engine stability, noise and vibrations characteristics with vegetable oils and biodiesels as fuel.
- Engine emissions like NOx and smoke may also be determined and analysed.
- Use of fuel additives like dimethyl carbonate, 2-EHN, etc. in plant oils used as fuel in diesel engines.
- Other modifications like injection pressure and timing, compression ratio, spray angle, etc. for improving performance, combustion and reducing emissions in an engine. Optimization techniques like Taguchi, Response surface methodology, artificial neural network, etc. may be employed.
- Durability tests and tribological investigation for long term operation of SVO fuelled engine.

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