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PERFORMANCE ANALYSIS OF DIESEL ENGINE WITH MIXTURES OF WASTE FRIED OIL AND METHANOL MOLAR (BIODIESEL)

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ABSTRACT

This experimental investigation focuses on production of biodiesel from Waste Fried Oil (WFO) by changing oil to methanol molar ratios and performance analysis of it in diesel engine. High viscosity and poor volatility are the major limitations of waste fried oil for utilization as a fuel in diesel engine. The oil to methanol molar ratios considered for transesterification were 3:1, 6:1 and 9:1. The cost of biodiesel production is presented in this paper and found more economical than mineral diesel. It satisfies the important fuel properties as per ASTM specification of biodiesel.

This paper discusses the performance of biodiesel in a single-cylinder, four-stroke, direct-injection, diesel engine. The performance of engine with mineral diesel has been considered as base line. Biodiesel B50 with molar ratio of 6:1 yielded the highest thermal efficiency 30.2% closer to mineral diesel (31.6%) at rated load. The brake specific fuel consumption for B50 was 0.31 kg/kWh as against 0.29 kg/kWh of diesel. The highest exhaust gas temperature was observed for molar ratio of 3:1 and it was 31°C higher than that of diesel. For daily 6 hours operation for 300 days, it is possible to save Rs 21606 by running the engine on B50(6:1) mode.

1. INTRODUCTION

Biodiesel derived from vegetable oil by transesterification with alcohol like methanol and ethanol is recommended for use as a substitute for petroleum-based diesel mainly because biodiesel is an oxygenated, renewable, biodegradable and environmentally friendly bio-fuel with similar flow and combustion properties including low emission profile [1-2]. The used vegetable oil classified as waste is increasingly attracting much interest because of its great potential to be used as diesel substitutes known as bio-diesel [3]. Study has shown that vegetable oil based fuels can significantly reduce exhaust gas emissions, including carbon monoxide, carbon dioxide, particulate matter and sulfur dioxide [4-6].

As compared to petroleum-based diesel, the high cost of biodiesel is a major barrier for its commercialization. Approximately 70%–85% of the total biodiesel production cost arises from the cost of raw material [7]. Everywhere in the world, there is an enormous amount of waste lipids generated from restaurants, food processing industries and fast food shops everyday. Reusing of these waste greases not only reduces the burden of the government in disposing the waste, maintaining public sewers and treating the oily wastewater, but also lowers the production cost of biodiesel significantly. Furthermore, biodiesel fuel has been demonstrated to be successfully produced from waste edible oils by an alkali-catalyzed transesterification process [8-11]. Literature review indicates that there is need of conversion of WFO from kitchen waste into biodiesel using transesterfication process. The economics of production of biodiesel from waste fried oil waste fried oil methyl esters (WFOME) with mineral diesel in different compositions.

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2. METHODOLOGY

2.1 Preparation of biodiesel for different oil to methanol molar ratios

The raw material (WFO) was collected from different hotels in Goa, a tourist destination in India. The used fried oil was filtered to remove food residues and solid precipitate by using double layer of cheesecloth in a funnel. In order to avoid soap formation due to water, the filtered fried oil was dried at 60°C for 10 minutes using microwave oven. In preheated mixture of waste fried oil and methanol, NaOH was added. The amount of potassium hydroxide needed was 7.7 grams per liter by titration with waste fried oil. This solution was stirred at 600 rpm for 15 minutes and glycerin was allowed to settle for 24 hours. The ester layer was separated from the glycerol layer in a separating funnel. Crude ester layer consisted of methyl ester, unreacted oil and methanol of glycerol, catalyst residue, and small amount of produced soap. In the separating funnel, this layer was washed with hot water, until the washings were neutral. This ester was dried and filtered. The transesterification process followed for biodiesel production is shown in Figure 1

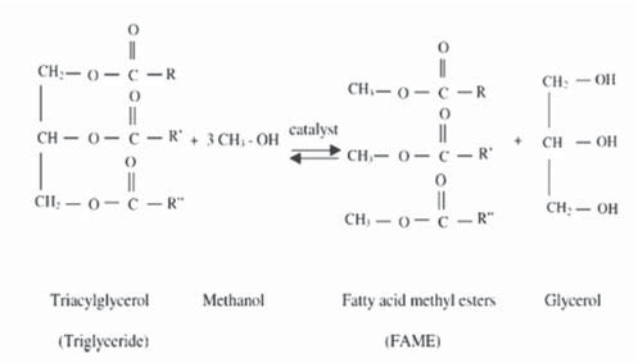

Figure 1 : Transesterification process

The molar ratios used to find out amount of methanol used are tabulated in Table 1. Figure 2 shows three batches of biodiesel with different waste fried oil to methanol molar ratios.

Table 1 : Molar ratio for biodiesel preparation

Batch	Molar ratio	Total volume ratio Methanol:WFO (ml/ml)
Batch 1	3:1	96:950
Batch 2	6:1	192:950
Batch 3	9:1	288:950

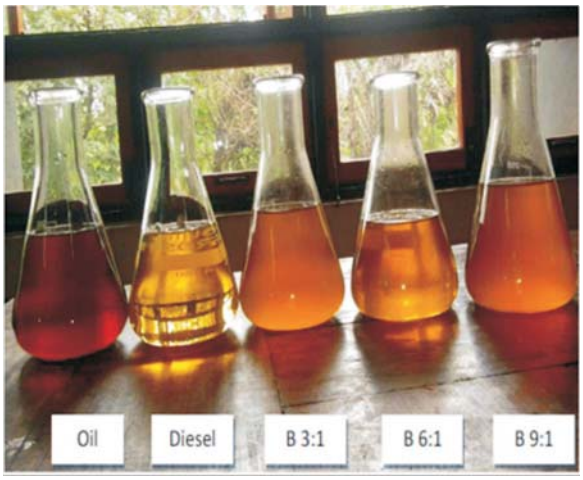

Figure 2 : Biodiesel with different molar ratios

2.2 Economic Analysis of Conversion

For the conversion of waste fried oil, methanol and potassium hydroxide are available at a rate of Rs 50/ litre and Rs 250/litre respectively. The cost of waste fried oil considered was almost zero because it's treated as discarded waste, harmful to the environment. Biodiesel cost will depend greatly on methanol prices and economy can be achieved by varying the grade of methanol used. By-product of transesterification is industrial grade glycerin which has industrial use and can be sold with or without processing, as it is an important constituent in chemical, pharmaceutical and cosmetic industry. The cost of production of 1 liter biodiesel for molar ratio of 1:6 is presented in Table 2. It can be seen from Table 2 that the production cost of biodiesel is substantially lower than market price of mineral diesel.

Table 2 : Cost of biodiesel production from waste fried oil

Biodiesel from WFO	Cost (Rs/lit.)	Cost (USD/lit.)
Waste fried oil	Nil	-
Methanol (192 ml)	10.00	-
Reagents	1.00	-
KOH (7.7 gms)	2.00	-
Electricity	0.40	-
Purification	0.50	-
Labour	1.40	-
Collection and transportation	4.00	-
Sub total	19.30	-
Revenue from by product sales	3.00	-
Total (cost less revenue)	**16.30**	**0.35**
Cost of Diesel	**40.00**	**0.86**

2.3 Fuel Properties

Viscosity of WFO and biodiesel was determined with help of redwood viscometer. The transesterfication of WFO provided a significant reduction in viscosity. At 40°C, the reduction was from 64.60 cSt to 10.75 cSt. The addition of WFOME increased the viscosities of blends by 10.75 cSt and 7.535 cSt for B100 and B50 respectively. Calorific value (38900 kJ/kg) for biodiesel for molar ratio 6:1 was estimated with help of bomb calorimeter and found lower than that of mineral diesel (43000 kJ/kg). The flash point temperature was found out by flash point apparatus and it is more than 93°C which is minimum requirement for biodiesel based on ASTM D 6751- 09. The properties of different fuels with Indian Standards used are given in Table 3. It can be seen from Table 3 that the properties of biodiesel produced from different molar ratios are in the acceptable ranges.

It is observed that with increase in molar ratio there was increase in calorific value and flash point temperature. Viscosity of biodiesel from molar ratio 6:1 was found closer to mineral diesel.

Table 3 : Comparison of fuel properties

Properties	WFO	Diesel No2	Biodiesel			Standard
			3:1	6:1	9:1	
Viscosity at 40°C (cSt)	64.14	4.320	12.20	10.75	11.51	IS: 1448 (P:25)-1976
Specific gravity	0.897	0.830	0.858	0.843	0.845	IS:2720 (Part III/Sec I)-1980
Calorific Value (kJ/kg)	31000	43000	34700	38900	42300	IS:1350 Part II – 1970
Flash point Temperature °C	180	70	110	125	136	IP-34 ASTM-D93-58

3. EXPRIMENTATION

The experimental set up consisted of a single cylinder diesel engine, engine test bed, fuel and air metering equipment, exhaust gas analyzer and digital temperature indicator. The specifications of engine are given in Table 4. The schematic diagram of test setup is shown in Figure 3.

Table 4 : Engine specifications

Make	**Laxmi Industries Kolhapur (India)**
Rated Power	3.78 kW
Rated Speed	1500 rpm
Number of cylinders	1
Bore X Stroke	80 mm X 110 mm
Combustion Chamber	Direct injection with bowl in piston
Standard injection timing	27^0 BTDC
Standard injection pressure	190 bar

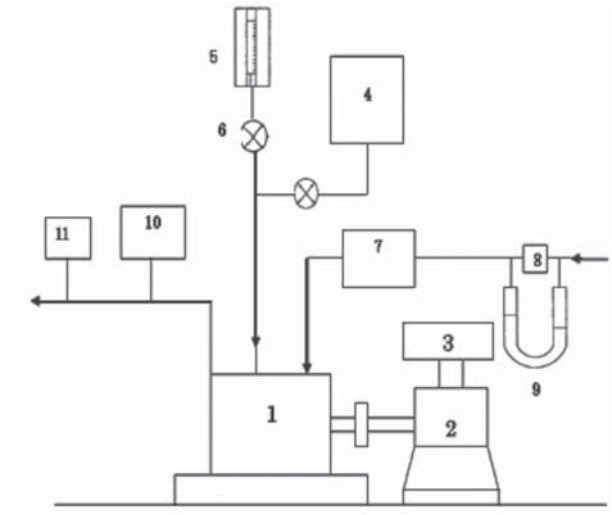

Figure 3 : Schematic diagram of experimental setup (1) Engine (2) Alternator (3) Electrical Load Bank (4) Fuel tank (5) Burette (6) Two way control valve (7) Air box (8) Orifice plate (9) U tube manometer (10) Exhaust Gas Analysis (11) Exhaust gas thermocouple

All tests with different fuels were conducted for constant engine speed 1500 rpm and varying load on engine. Tests were carried out for 190 bar original fuel injection pressure and injection timing 27°C before top dead centre. The engine was coupled with a single phase, 220 V AC alternator. The alternator was used for loading the engine through a resistive load bank. The load bank consisted eight heaters of 500 W each. The load was varied from 0.5 kW to 4 kW in step of 0.5 kW. The engine was first tested with diesel for no load and 20 minutes at rated speed of 1500 rpm until lubricating oil temperature reached to 80°C. Same conditions were maintained throughout the experiment for different fuels. After the baseline test with diesel, no load test was conducted for three batches of biodiesel prepared with different molar ratios 3:1, 6:1 and 9:1. For testing of each batch fuel the blends were prepared on volume basis just before the experimentation. The fuel prepared from each batch for testing purpose were B50 (50% biodiesel + 50% mineral diesel), B70 (70% biodiesel + 30% mineral diesel) and B100 (100% biodiesel).

The specific fuel consumption was calculated by measuring the time required for a fixed volume of fuel to flow into the engine. The torque was measured using swinging field electrical dynamometer. The engine speed (rpm) was measured by electronic digital counter. The performance parameters break thermal efficiency and brake specific fuel consumption were calculated from measured data. The exhaust gas temperature was measured by using an electronic digital indicator with iron-constantan thermocouple. The exhaust gas temperature was measured by using an iron-constantan thermocouple with accuracy of ±1°C. The results from the engine with biodiesel from different oil to methanol ratios were compared with the baseline test.

4. RESULTS AND DISSCUSSION

4.1 Brake thermal efficiency (BTE)

The variation of brake thermal efficiency with molar ratios 3:1, 6:1 and 9:1 for different blends B50, B70 and B100 for varying load conditions is shown in Figure 4 to 6. In all cases the thermal efficiency of biodiesel was less than that of diesel at all power outputs. The baseline brake thermal efficiency for diesel was 31.6%. The maximum brake thermal efficiency for B50 with molar ratio 6:1 was 30.2% and for other two molar

ratios, it varied in the range 28.7% to 28.5%. The maximum brake thermal efficiency for B70 varied in the range 25.8% to 29.8%. For B100 the maximum thermal efficiency was in the range 23.8% to 25.7%. Lower thermal efficiencies may be due to lower heat content, higher density, higher viscosity and poor volatility of biodiesel compared to diesel. Significant improvement in thermal efficiency was observed with increase in diesel percentage in the blends.

For higher molar ratio, higher the conversion of methanol was observed. However using too low molar ratio results in less conversion of methyl esters resulting in presence of un-removed glycerin and higher molar ratio with excess methanol can obstruct glycerin formation, all these can lead to higher viscosity and poor volatility of the fuel.

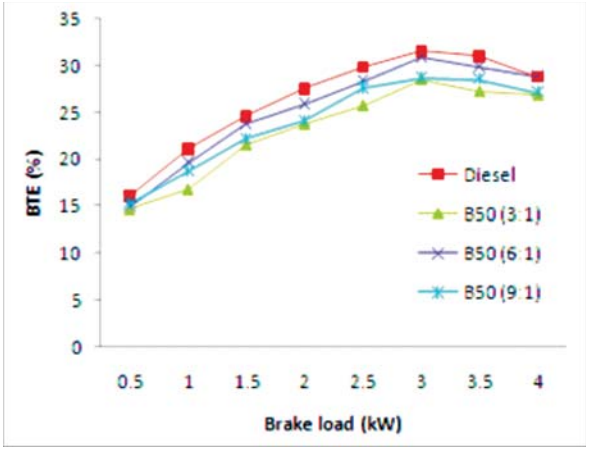

Figure 4 : Brake thermal efficiency at break load (B50)

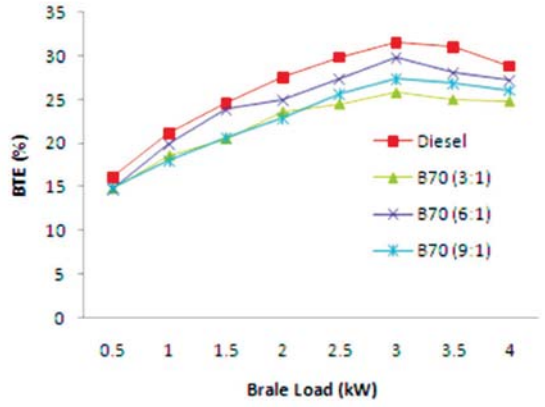

Figure 5 : Brake thermal efficiency at brake load (B70)

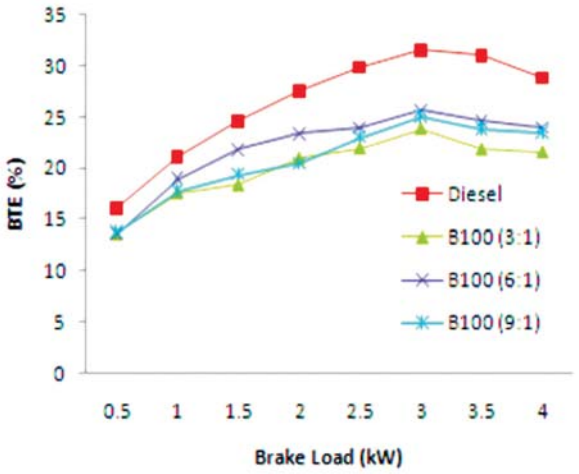

Figure 6 : Brake thermal efficiency at brake load (B100)

4.2 Brake specific fuel consumption (BSFC)

Figure 7 to 9 show the variation brake specific fuel consumption with load on engine for diesel and different biodiesel blends.

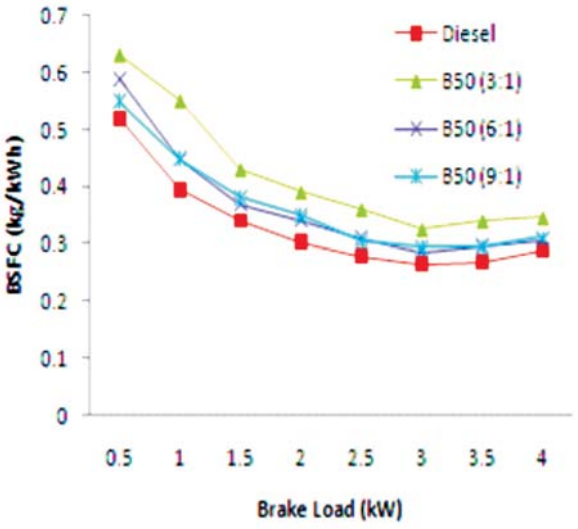

Figure 7 : Brake specific fuel consumption at brake load (B50)

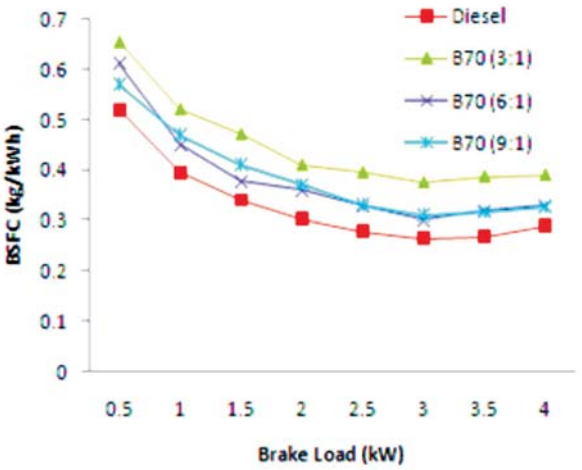

Figure 8 : Brake specific fuel consumption at brake load (B70)

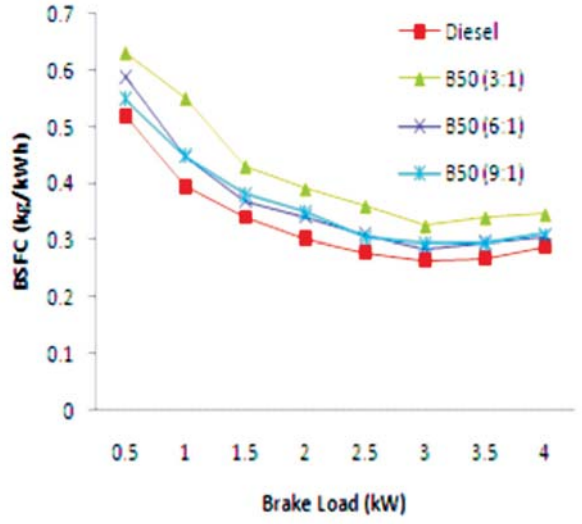

Figure 9 : Brake specific fuel consumption at brake load (B100)

The minimum brake specific fuel consumption was observed at rated power output for all fuels. In all cases the brake specific fuel consumption of biodiesel is higher than that of diesel. The minimum BSFC for B50 with molar ratio 9:1 was 0.284 kg/kWh as against 0.27 for diesel. The minimum BSFC for B70 with different molar ratios varied in range 0.375 kg/kWh to 0.301 kg/kWh. For B100, the minimum BSFCs were in the range 0.435 kg/kWh to 0.340 kg/kWh. The reasons for increase in BSFC with increase in percentage of biodiesel in mixture may be increase in viscosity and poor spray atomization.

For daily 6 hours running for 300 days a year, engine running with 50% biodiesel will consume 972 kg (1153 lit) of biodiesel and 972 kg (1168 lit) of diesel compared to 1813 kg (2178 litre) of diesel alone. Running cost of engine with 50% biodiesel will be Rs 65514 per year compared to Rs 87120 with diesel. Annual saving of Rs 21606 is possible by running the engine with B50.

4.3 Exhaust gas temperature

Figure 10 to 12 show the variation exhaust gas temperature with load on engine for diesel and different biodiesel blends. It was observed that the exhaust gas temperature increases with load because more fuel is burnt at higher loads to meet the power requirements. For B50 (6:1), it increased from 127°C to 300°C. It was also observed that the exhaust gas temperature increases with percentage of biodiesel in the test fuel for all the loads. For B50 (6:1), the maximum exhaust gas temperature was 300°C and same was 320°C for B100 (6:1). This is because biodiesel constitutes of poor volatility, which burns during the late combustion phase. For molar ratio 3:1, exhaust gas temperature found was the highest 341°C followed by 325°C for 9:1 and 320°C for 6:1.

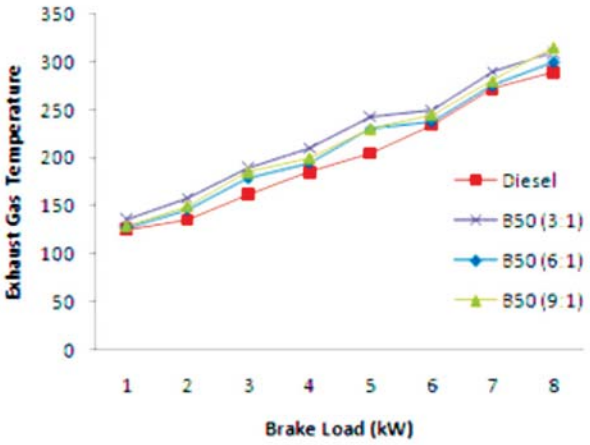

Figure 10 : Exhaust gas temperature at brake load (B50)

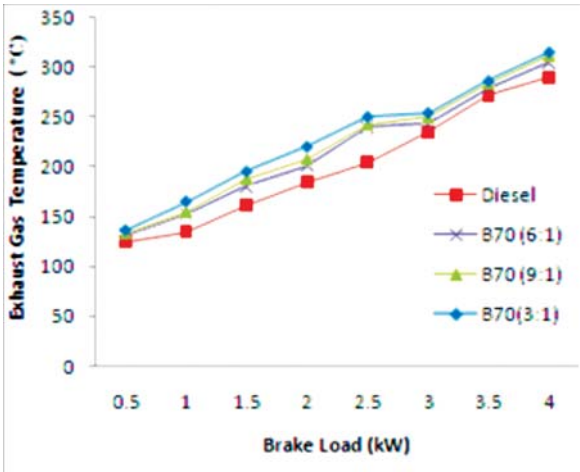

Figure 11 : Exhaust gas temperature at brake load (B70)

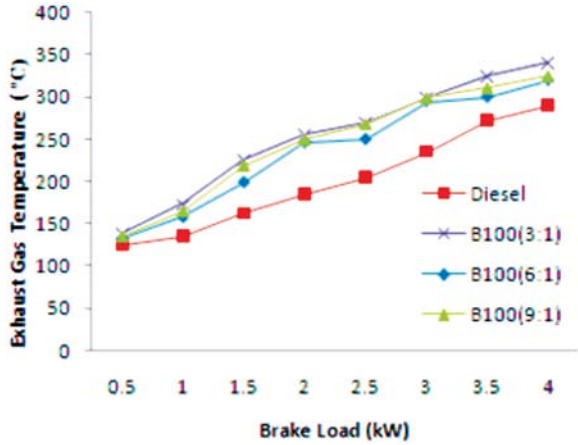

Figure 12 : Exhaust gas temperature at brake load (B100)

5. COLCLUSIONS

The prospect of waste fried oil based fuel production looks very attractive for energy conversion in a developing country like India. Cost of conversion of biodiesel from waste fried oil was Rs. 16.3 per liter compared with subsidized market price of diesel approx. Rs. 40 per liter. Waste fried oil to methanol molar ratio of 6:1 for transestrification satisfies the important fuel properties as per ASTM specifications of biodiesel. Based on the experimental investigation on the performance of biodiesel in a diesel engine, the following conclusions could be drawn.

1. Biodiesel B50 with molar ratio of 6:1 yielded the highest thermal efficiency 30.2% closer to mineral diesel (31.6%) at rated load.
2. For biodiesel B50 with molar ratio of 6:1, the lowest brake specific fuel consumption was 0.284 kg/kWh compared with 0.27 kg/kWh of diesel.
3. The highest exhaust gas temperature was observed for molar ratio of 3:1(341°C) followed by 9:1(325°C) and 6:1(320°C) and mineral diesel (290°C).
4. For daily 6 hours operation for 300 days, it is possible to save Rs 21606 by running the engine on B50(6:1) mode. For biodiesel B50 with molar ratio of 6:1, the lowest brake specific fuel consumption was 0.284 kg/kWh compared with 0.27 kg/kWh of diesel.

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