Performance evaluation of a diesel engine fueled with waste cooking oil methyl ester

Tushar R. Mohod, Rahul S.Tadse, Iftekhar A. Pathan.

Abstract— In this investigation, waste cooking oil methyl ester (WCOME) was prepared by transesterification using potassium hydroxide (KOH) as catalyst and was used in four stroke, single cylinder variable compression ratio type diesel engine. Tests were carried out at a rated speed of 1500 rpm at different loads. Straight vegetable oils pose operational and durability problems when subjected to long term usages in diesel engines. These problems are attributed to high viscosity, low volatility and polyunsaturated character of vegetable oils. The process of transesterification is found to be an effective method of reducing vegetable oil viscosity and eliminating operational and durability problems. The important properties of waste cooking oil methyl ester (WCOME) are compared with diesel fuel. The engine performance was analyzed with different blends of biodiesel and was compared with mineral diesel. It was concluded that the lower blends of biodiesel increased the break thermal efficiency and reduced the fuel consumption. The exhaust gas temperature increased with increasing biodiesel concentration. The results proved that the use of biodiesel (produced from waste cooking oil) in compression ignition engine is a viable alternative to diesel.

Keywords—Biodiesel, Diesel engine, Transesterification, Waste cooking oil,

I. Introduction

Rising petroleum prices, increasing threat to the environment from exhaust emissions and global warming have generated intense international interest in developing alternative non-petroleum fuels for engines. The use of vegetable oil in Internal Combustion engines is not a recent innovation. Rudolf Diesel (1858–1913), inventor of the diesel cycle engines, used peanut vegetable oil to demonstrate his invention in Paris in 1900. In 1912, Diesel said, ''the use of vegetable oils as engine fuel may seem negligible today. Nevertheless, such oils may become, in the passing years, as important as oil and coal tar presently." Nowadays, it is known that oil is a finite resource and that its price tends to increase exponentially, as its reserves are fast depleting [1].

It has been reported that in diesel engines, crude plant oils can be used as fuel, straight as well as blended with the diesel [2]. However, during extended operation of the engine, problems of injector coking, dilution of engine oil, deposits in various parts of engine, etc. have been reported. The major drawback with the vegetable oils as fuel is its high viscosity [3]. Higher viscosity of oils is having an adverse effect on the combustion in the existing diesel engines. In recent years, systematic efforts were under taken by many researchers to determine the suitability of vegetable oil and its derivatives as fuel or additives to the diesel [4-8]. Esterification is one of the methods to reduce viscosity of plant oils; it produces plant oil biodiesel commonly known as biodiesels. Several researchers [9] have used biodiesel as an alternate fuel in the existing CI engines without any modification.

In present study the biodiesel derived from waste cooking oil has been used. It is a triglyceride derived from ricinoleic acid, which constitutes 90% of fatty acids present in the molecule and 10% non-hydroxylated fatty acids, mainly by oleic and linoleic acids. Due to this particular chemical composition waste cooking oil becomes highly valuable for industrial purposes [10-12]. The demand of renewable combustible fuel derived from vegetable oils has increased in the last years, and has led to the development of a number of processes for transesterification of oils with methanol or ethanol, involving acidic [13,14] or basic catalysis [15,16]. To find out the performance of biodiesel prepared from waste cooking oil, testing was undertaken with single cylinder compression ignition engine at variable loads.

II. Esterification Of Waste Cooking Oil And Biodiesel Characterization

Waste cooking oil was converted into biodiesel through the alkaline transesterification reaction for which potassium hydroxide was used as catalyst with methanol. Two percent of the potassium hydroxide catalyst was dissolved in methanol (30% by weight) and mixture was added to the waste cooking oil. Then the prepared mixture was stirred at 60ºC for 30 min. Thereafter the reactant material was poured into transparent vessel and allowed for cooling at room temperature for 6–8 h.

It was allowed to settle for separation of glycerol as bottom layer.

The upper layer of biodiesel was put into another transparent vessel for washing with equal amount of water. The biodiesel was heated up to 110 ºC for 10 min to remove excess water. Then biodiesel was cooled down to room temperature before use, presenting a 94% yield. Transesterification, which is also called alcoholysis, is a process of substitution of the radical of an ester by the radical of one alcohol. Like hydrolysis, except for the fact of using an alcohol instead of water. The transesterification reaction is represented by the general equation [17].

$$RCOOR' + R''OH = RCOOR' + R'OH \quad (1)$$

Important properties of transesterified oil were evaluated for comparison with standard. These are given in Table1. The presence of a bigger content of hydroxyacid in the waste cooking oil is reflected in its colligative properties, such as high values viscosity and density [1].

Density of the fuel was found using density bottle, kinematic Viscosity of the oil was determined with the help of Redwood Viscometer No. 1 and flash point was obtained from electrically heated Pensky-Martens apparatus as per the standard test procedure of Bureau of Indian Standards (IS: 1448–1970). The gross calorific value of the waste cooking oil, waste cooking oil methyl ester and diesel were determined with the help of Bomb Calorimeter (IS: 1359–1959). The prepared waste cooking oil methyl ester (WCOME) was mixed with diesel in three different proportions i.e. 5%, 10% and 20% to prepare its blends i.e. B5, B10 and B20.

III. Experimental Methodology

The setup for the study consists of single cylinder, four stroke, variable compression ratio (VCR) diesel engine connected to eddy current type dynamometer for loading (see Plate 1). The detailed specifications of the engine used are given in Table 2. Windows based Engine Performance Analysis Software Package ''Enginesoft'' was taken for on line performance evaluation. The NOx emission by the combustion of biodiesel was measured by online flue gas analyser. The tests were conducted at the rated speed of 1500 rpm at different loads. The engine was started with standard diesel fuel and warmed up. The warm up period ends when cooling water temperature is stabilized. Then fuel consumption, brake power, brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency and exhaust gas temperature were measured. Same procedures were repeated for different blends of waste cooking oil methyl ester.

Iv. Results And Discussion

A.Brake power (BP)

The brake power developed by the engine on different load conditions starting from no load to 145.29 KN is presented in Fig 1. As the load increases the brake power developed by the engine increases for all blends of biodiesel. At maximum load i.e. 145.29 KN, the B10 blend developed 1.5%, 1.76% and 0.75% more BP when B0, B05 and B20 blends were used, respectively. From the results it is concluded that the biodiesel blend B10 developed more BP at higher loads.

TABLE1
FUEL PROPERTIES OF WASTE COOKING OIL AND THEIR BIODIESEL IN COMPARISON WITH DIESEL

Properties	WCO	WCO ME	Diesel
Density (g/ml)	0.96	0.913	0.830
Kinematic viscosity, cS at 38ºC	221.79	9.80	5.80
Gross calorific value (MJ kg^{-1})	36.50	39.80	46.22
Flash point (ºC)	312	145	47
Acid value (mg KOH/g)	1.642	1.008	0.00
Free fatty acid content (%)	2.8	1.86	0.00

Plate. 1 Variable compression ratio (VCR) engine test setup

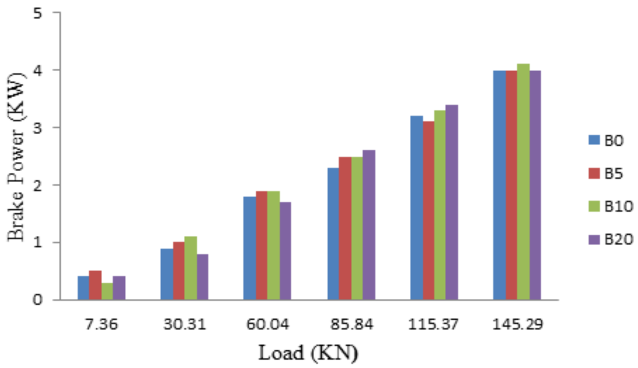

Fig.1. Brake power of biodiesel blends versus loads.

B. Total Fuel Consumption (TFC)

Fig.2 illustrates the relation between applied load and the fuel consumption. As the load increases no doubt the fuel consumption also increases, but during the study, fuel consumption on various loads was found lesser with B0 compared to blended fuel. It may be due to the decrease in overall calorific value of fuel by increasing percentage of blend. At the maximum load i.e. 145.29 KN, B10 shows 8.14%, 5.34% and 7.46% less fuel consumption as compared to B0, B05 and B20, respectively. In overall prospect, fuel consumption is improved at maximum load in blend B10.

TABLE 2
SPECIFICATIONS OF THE ENGINE USED

Make and model	Kirloskar diesel engine
General details	4-Stroke, water cooled variable compression ratio engine, compression ignition
Number of cylinders	Single cylinder
Bore	87.5mm
Stroke	110mm
Swept volume	661cc
Rated output	3.5kw at 1500rpm
Compression ratio	18
Rated speed	1500rpm
Temperature sensor	RTD PT 100 and K-type thermocouple
Load indicator	Digital range 0-490.5KN
Dynamometer	Type – eddy current, water cooled
Load sensor	Strain gauge load cell
Fuel flow transmitter	DP transmitter
Air flow transmitter	Pressure transmitter
Rotameter	Pressure transmitter

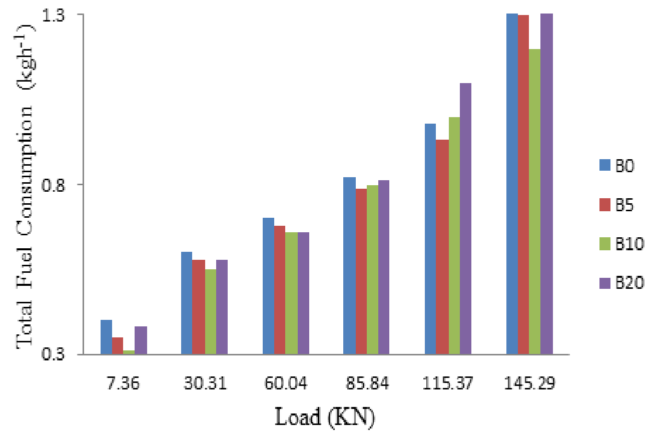

Fig.2. Total fuel consumption (TFC) of biodiesel blends versus loads.

C. Brake Specific Fuel Consumption (BSFC)

The variation of brake specific fuel consumption with respect to load is presented in Fig.3. For all blends tested, brake specific fuel consumption is found to decrease with increase in load. This is due to the higher percentage increase in brake power with load as compared to the increase in fuel consumption. But at no load conditions the developed brake power is less and hence the BSFC is more on that load for all blends. Using lower percentage of biodiesel in biodiesel–diesel blends i.e. B10, the brake specific fuel consumption of the engine is lower than that of diesel (B0) for all loads. In case of B20, the brake specific fuel consumption is found to be higher than of diesel (B0). With increase in biodiesel percentage in the blends, the calorific value of fuel decreases. Hence, the specific fuel consumption of the higher percentage of biodiesel in blends increases as compared to that of diesel (B0).

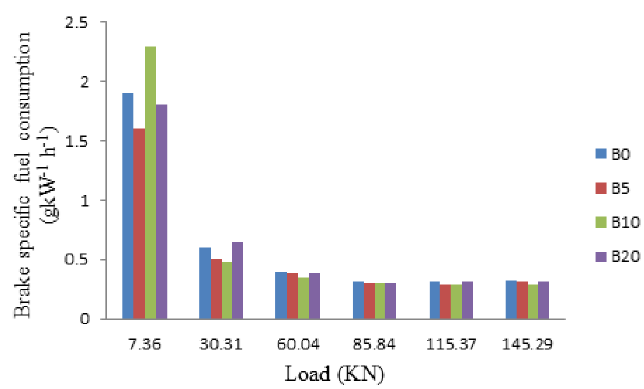

Fig.3. Brake specific fuel consumption (BSFC) of biodiesel blends versus loads.

D. Brake specific energy consumption (BSEC)

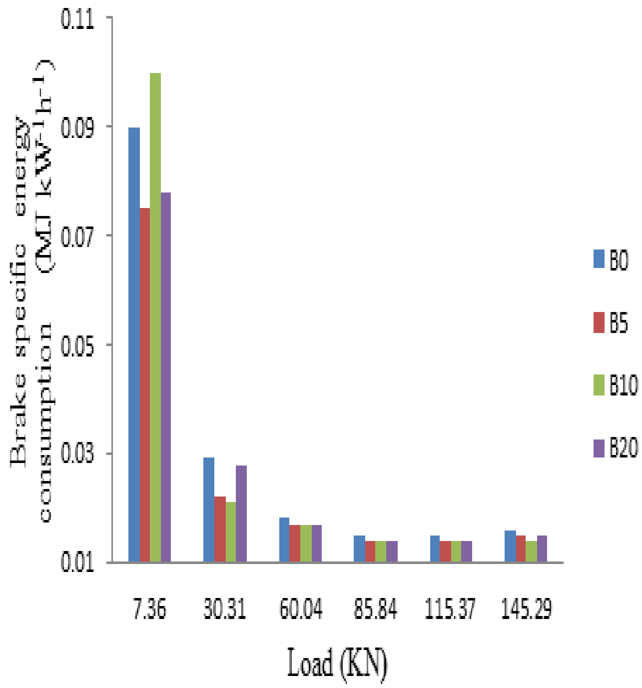

Fig.4. Brake specific energy consumption (BSEC) of biodiesel blends versus loads.

The variation of brake specific energy consumption with respect to load for different blends is presented in Fig.4. Brake specific energy consumption was almost similar for all blends. Brake specific energy consumption was also found lowest for B05 blend, it was 0.074, 0.023, 0.016, 0.014, 0.014 and 0.015 MJ $kW^{-1}h^{-1}$ for the no load, 7.36, 30.31, 60.04, 85.84, 115.37 and 145.29 KN load, respectively.

E. Brake Thermal Efficiency

Fig.5 shows the variation of brake thermal efficiency with respect to load for different blends. In all cases, brake thermal efficiency was having tendency to increase with increase in applied load. This was due to the reduction in heat loss and increase in power developed with increase in load. The maximum brake thermal efficiency at 145.29 KN load is about 28.89% for B10, which is 14.14% higher than that of B0. The maximum brake thermal efficiency was obtained as 26.14% and 26.66 while using B05 and B20, respectively, which was lower by 9.51% and 7.71%, respectively to B10. Hence B10 yields good thermal efficiency compared to B0, B05 and B20. Initially the thermal efficiency of the engine was improved with increasing concentration of the biodiesel in the blend. The possible reason for this is the additional lubricity provided by the biodiesel. The molecules of biodiesel (i.e. methyl esters of the oil) contain some amount of oxygen, which takes active part in the combustion process. It is noticed that after a certain limit with respect to diesel ester blend, the thermal efficiency trend was reverted and it started decreasing as a function of the concentration of blend. This lower brake thermal efficiency was obtained for B20 which could be due to the reduction in calorific value and increase in fuel consumption as compared to B10 [18].

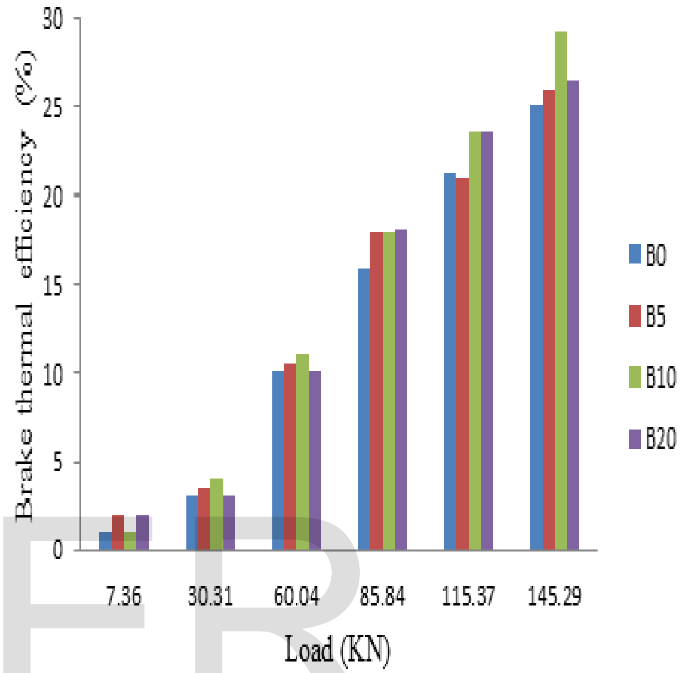

Fig.5. Brake thermal efficiency (BThE) of biodiesel blends versus loads.

E. Exhaust gas temperature (ExGT)

The variation of exhaust gas temperature with respect to applied loads for different blends is shown in Fig. 6. Up to B05 the exhaust gas temperature was lower; thereafter it increased with increasing blends. This reveals that the effective combustion is taking place in the early stage of strokes and there is reduction in the loss of exhaust gas energy. This fact is reflected in brake thermal efficiency and brake specific fuel consumption results as well. When biodiesel concentration is increased, the exhaust gas temperature increases by same value. The highest exhaust gas temperature is observed as 265°C in B20 blend at 145.29 KN load. The diesel mode exhaust gas temperature is observed as 187.7°C at 145.29 KN load. The higher exhaust gas temperature may be because of better combustion [19] of the waste cooking oil methyl ester as it contents oxygen molecule which helps in proper combustion.

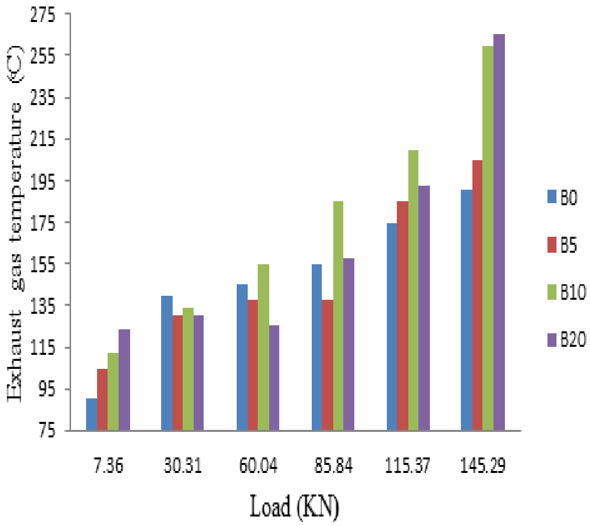

Fig.6. Exhaust gas temperature (ExGT) of biodiesel blends versus loads.

F. Nitrogen oxide (NOx) emissions

Fig.7 (a-f) shows oxide of nitrogen (NOx) emission for pure diesel (B0) and different biodiesel blends and relation with exhaust gas temperature. It is well known that vegetable based fuel contains a small amount of nitrogen. This contributes towards NOx production. In case of B10, NOx emission is lower than B0. NOx concentration increased with the increase in load and attains maximum at 145.29 KN load for all the blends. In case of B0, B05, B10 and B20, NOx emission recorded were 683, 686, 638 and 694 ppm, respectively, for the load 145.29 KN. It is found that the exhaust temperature increases with increase of WCOME in blends and is higher than that with diesel for all blends at all loads. Also a corresponding increase in NOx emission is observed. This may be due to higher combustion chamber temperature, which in turn is indicated by the prevailing exhaust gas temperature. With increase in the value of exhaust gas temperature, NOx emission also increased. That's why; biodiesel fuel has the potential to emit more NOx as compared to that of diesel fuelled engines [19-22].

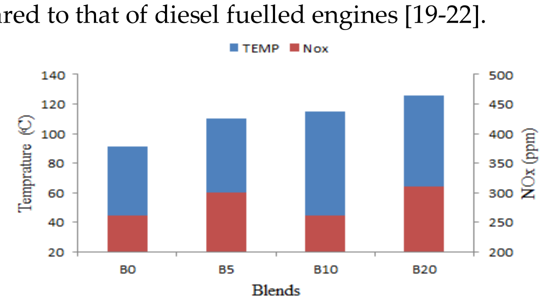

Fig.7(a) NOx emission at load 7.36 KN

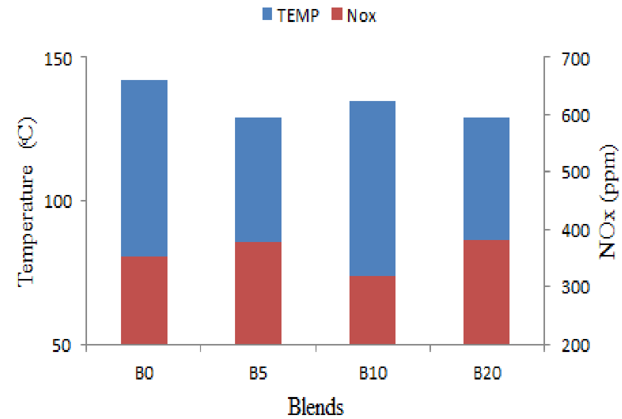

Fig.7(b) NOx emission at load 30.31 KN

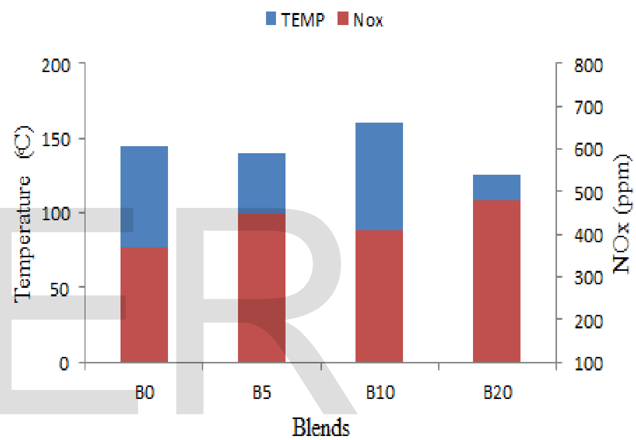

Fig.7(c) NOx emission at load 60.04 KN

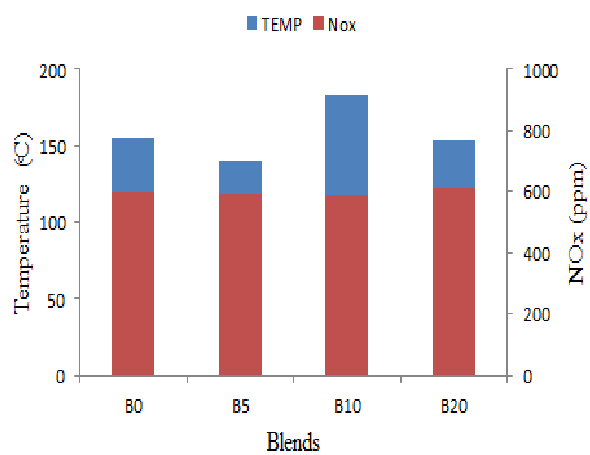

Fig.7(d) NOx emission at load 85.84 KN

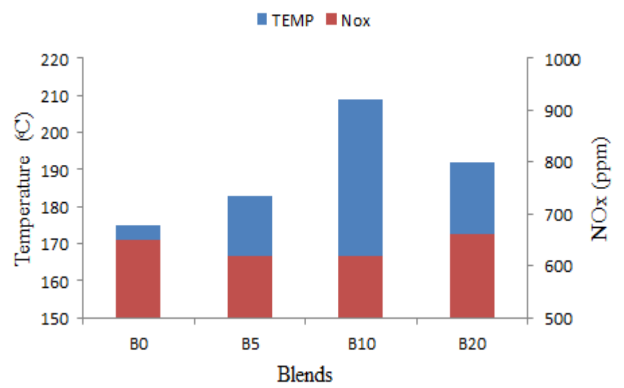

Fig.7(e) NOx emission at load 115.37 KN

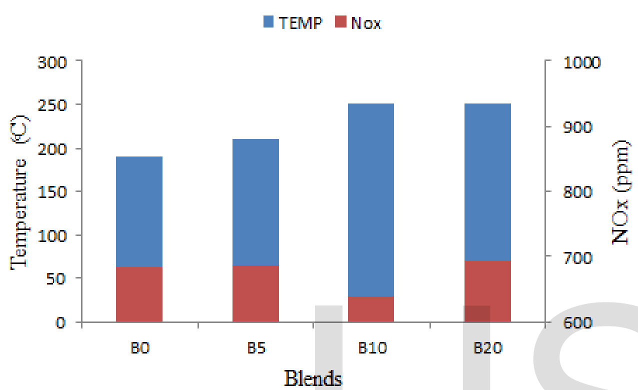

Fig.7(f) NOx emission at load 145.29 KN

V. Conclusions

Biodiesel is a clean burning fuel that is renewable and biodegradable. Waste cooking oil methyl ester (WCOME) blends showed performance characteristics close to diesel. Therefore waste cooking oil methyl ester blends can be used in CI engines in rural area for meeting energy requirement in various agricultural operations such as irrigation, threshing, etc. Although the calorific value of pure WCOME is lower that of diesel by about 15%. The blend B10 exhibits a calorific value about 45.50 MJ kg^{-1} that is only 2% lower than that of diesel. With this blend engine develops better power when compared with power output with diesel. High power output is reported in many other studies it may be due to better lubricity which reduces friction loss and better combustion of blends. The trends of NOx emission for WCOME are same as that of diesel at lower loads and slightly higher at full loads. Hence WCOME can be alternately used as fuel for diesel engine.

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