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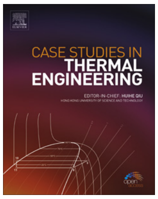

Performance and emission characteristics of a transportation diesel engine operated with non-edible vegetable oils biodiesel

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ABSTRACT

In this study, production, performance and emission characteristics of methyl esters of Oleander, Kusum and Bitter Groundnut oil in a transportation diesel engine were studied. Oleander oil methyl esters (OOME), Kusum oil methyl esters (KOME) and bitter Groundnut Oil Methyl Esters (BGOME) were prepared by transesterification process. The effects of three methyl esters on engine performance and exhaust emissions were examined at different engine speed and full load condition. Experimental results showed that the brake thermal efficiency of OOME is found higher and brake specific fuel consumption lower compared to KOME and BGOME. BGOME shows less emissions compared to OOME and KOME. In short, it may be concluded from the experimental investigations that biodiesel from different non-edible oils (Oleander, Kusum, and Bitter Groundnut) can become an alternative source of fuel in future.

1. Introduction

Many reports project that India will double its fuel consumption by 2030 [12]. Biodiesel from non-edible vegetable oils appears to be an attractive source of energy in India. Currently, more than 95% of the world biodiesel is produced from edible vegetable oils such as rapeseed, soybean, palm and sunflower oils [17]. Biodiesel production on a large scale is a cause of concern due to food vs. fuel competition in the long term [7]. Therefore the use of non-edible vegetable oils like Karanja, Mahua, Kusum, Oleander and Calophyllum inophyllum oil [10,22,27,29,30], can not only can skip the food vs. fuel concerns, but also decrease the final biodiesel cost.

Significant research work has been reported with regards to the production, and performance of biodiesel derived from a variety of vegetable oils. Dhar and Agarwal [10], reported maximum torque for 10% and 20% KOME blends which were higher than mineral diesel. Similarly, Raheman and Ghadge [27], found the comparable performance of Mahua biodiesel and its blends with petroleum-based diesel. Ong et al. 2014 [22], reported an optimum yield of C. inophyllum biodiesel at 9:1

Abbreviations: ; BGOME, bitter groundnut oil methyl ester; OOME, oleander oil methyl ester; KOME, kusum oil methyl ester; C.I, compression ignition; CO, carbon monoxide; UHC, unburnt hydrocarbons; NOx, oxides of nitrogen; BTE, brake thermal efficiency; BSFC, brake specific fuel consumption; ppm, parts per million; cSt, Centi Stoke; kW h, Kilo-Watt-Hour; rpm, rotations per minute

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methanol to oil ratio with 1 wt% NaOH catalyst at 50 °C for 2 h. The performance and emission of 10% C. inophyllum biodiesel blends (CIB10) gave a satisfactory result in diesel engines. Khiari et al. [15], reported a maximum increase of 3.1% at full engine load condition for Pistacia lentiscus biodiesel. Carbon monoxide and unburned hydrocarbon are significantly reduced whereas, higher NOx levels.

Yadav et al. [33], studied engine performance with used transformer oil and reported that the retarded injection timing of 20° before TDC resulted in decreased oxides of nitrogen, carbon monoxide and unburned hydrocarbon by 11.57%, 17.24%, and 10% respectively while the brake thermal efficiency and smoke increased under all the load conditions when compared to that of standard injection timing. Yang et al. [2] and Sharon et al. [28] carried out the investigations on diesel engine with methyl esters of Jatropha and used cooking oil as fuels. The efficiencies with the above said two biodiesels are lower than that of diesel fuels. Utlua and Kocak [19] conducted an experimental study on a four cylinder, direct injection, turbocharged, intercooled diesel engine using waste frying oil methyl ester and reported that the brake specific fuel consumption was 14.34% higher than that of diesel fuel. They concluded that the low heating value and the higher density of waste frying oil methyl ester were responsible for the increased fuel consumption rate.

Puhan et al. [25] noted a slight decrease in brake thermal efficiency with linseed biodiesel compared to mineral diesel. Lin et al. [18] observed that when fueled with various vegetable oil methyl esters; the smoke emission from the engine was reduced compared to petroleum diesel, due to the uniform air–fuel mixing and the extra oxygen content in vegetable oil. Kakati and Gogoi [14] reported that Kutkura fruit seed contains 35.45% oil with 3.1% FFA. Engine BTE and ITE were higher with the biodiesel blends and it was the maximum for B20 at all BMEPs. B10 and B20 produce less smoke compared to diesel fuel and the smoke was the minimum with B10.

It is found that there are about 300 varieties of oil seeds but only 10–15 varieties have been tapped so far, amongst which **"**Oleander", "Bitter Groundnut" and "Kusum", the non-edible vegetable oils can be considered as a potential alternative fuel for CI engines. These have been chosen in the present study to explore their possibility for use as fuel because no substantial work has been done on utilization of these oils as a fuel for CI engine. From literature review it is also found that many researchers have done work on edible oils or very costly oils. The higher price, in many countries is offset by legislative and regulatory incentives or subsidies in the form of reduced excise taxes. However, the higher price can also be (partially) offset by the use of less expensive feed stocks, which has sparked interest in oils such as "Oleander", "Bitter Groundnut" and "Kusum".

In India, diesel costs are about Rs.45 per liter. But in India, petro- diesel is a highly subsidized fuel due to its vast use in agriculture. If there were no subsidies given to diesel by the Government of India, the price of diesel would have jumped over the price of even petrol, which is around Rs.80 per liter now-a-days. On the other hand the cost of Oleander, bitter Groundnut and Kusum oil is less because they are generally treated as waste in India. This waste can be collected and oil is extracted at a very low cost. Biodiesel is then prepared and blended with petrol diesel, thus reducing the price of the fuel to about Rs.50 per liter.

From the literature it is found that most of the test have been done on stationary diesel engines [1,3,9,12,14,15,18,25,27,28]. Stationary diesel engine is usually designed for optimum/constant speed as the load in such case is usually fixed. Stationary engines are used largely in rural areas for irrigation. Very less work has been done on "Transportation Engine" [8,10]. In transportation engine the loads vary w.r.t. loading condition of the vehicle. Loading of vehicle may be fully loaded/half loaded or move empty. To achieve the variation of power required the speed of a transport engine has to be varied. So the present investigation focuses on the experimental study on Transportation Engine.

Oleander is a very drought resistant poisonous plant found throughout India especially in Assam. An Oleander plant produces, more than 400 – 800 fruits annually (Fig. 1a). The plant has annual seed yield of 52.5 t/ha and about 1750 L of oil can be obtained from a hectare of waste land. It has high oil content which is around 60% in its kernel [3]. Hence, it can be used to produce bio-diesel on large scale. India ranks second in Groundnut production in the world next to China. It produces an average 3,00,000 t of groundnut oil every year. Out of this, approximately 10% could not be utilized due to its

Fig. 1. Picture of (a) Oleander Seed (b) Bitter Groundnut Seed and (c) Kusum Seed.

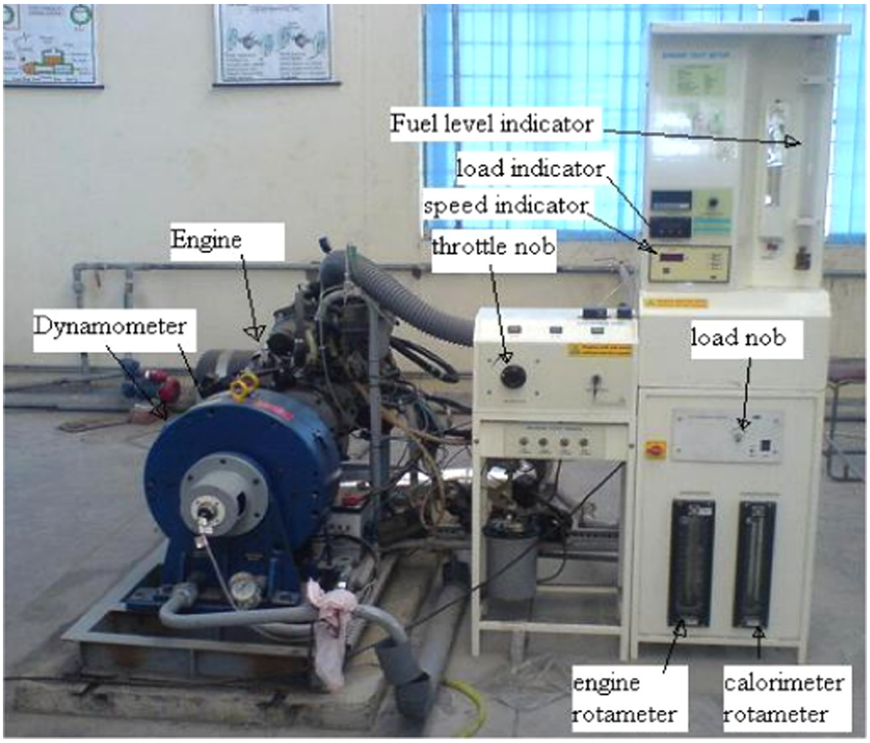

Fig. 2. Tata Indica diesel engine test rig.

bitterness and is generally treated as waste, which is can be used as novel feedstock for biodiesel production. The production of Kusum seed (Fig. 1c) is 66,000 t per year in India. It is mainly produced in sub-Himalayan tracts in the north, central parts of eastern India. It contains about 51–62% oil [29]. The objective of the present study is to investigate performance and emission characteristics of a transportation engine operated with biodiesel derived from Oleander, Kusum and bitter Groundnut oil (Fig. 2).

2. Materials and method

2.1. Materials

The Oleander and Kusum seed used in the present study for biodiesel production were collected from their plants available on the campus of Delhi technological university and bitter Groundnut collected from an oil mill available locally. Oil from the seeds was obtained by means of mechanical extraction. Anhydrous methanol (99.8% min.) and Potassium hydroxide (85% min.) were purchased from a local chemical store.

2.2. Production and characterization of biodiesel

Chemical transesterification of Oleander/Kusum/bitter Groundnut oil was done, to produce their methyl esters (biodiesel) and physico-chemical properties of the all the three biodiesel samples were evaluated experimentally and compared with that of base diesel.

2.3. Experimental engine setup

The setup consists of four cylinders, four stroke Diesel engine connected to eddy current type dynamometer for loading. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. Windows-based engine performance analysis software package “Engine soft” is used for on-line performance evaluation. An AVL DIX Emission diagnostic system was used for engine exhaust measurement. Specification of test engine and Emission

Table 1
Technical specification of the test engine and emission diagnostics system.

Make	Telco, Model Tata Indica,		
Type	4 Cylinder, 4 Stroke, Diesel water cooled,		
Rated Power	39 kW at 5000 rpm,		
Torque	85 Nm at 2500 rpm,		
Cylinder volume	1405 cc		
Compression ratio	22:1		
Dynamometer	Type eddy current, water cooled, with loading unit		
Load sensor	Load cell, type strain gauge		
Software	Engine soft Lab view, Engine performance analysis software		
Emission diagnostic			
Make	AVL; model: DI-Gas 480		
Exhaust Emissions	Measurement range	Resolution	Accuracy
CO	0–10 vol%	0.01 vol%	< 0.6 vol% .: ± 0.03 vol%
HC	0–20,000 ppm > 2000: 10 ppm	< 2000: 1 ppm vol.	< 200 ppm vol.: ± 10 ppm vol. P200 ppm vol.: ± 5% of ind. val.
CO_2	0–20 vol%	0.1 vol%	< 10 vol% : ± 0.5 vol%
NO	0–5000 ppm	1 ppm vol.	< 500 ppm vol.: ± 50 ppm vol.
Opacity	0–100%	0.001	± 2%

Table 2
Range, accuracy and uncertainty of measurements.

Measurements	Instrument	Range	Accuracy
Engine load	Strain gauge type load cell	0–25 kg	± 0.1 Kg
Speed	Speed sensor	0–10000 rpm	± 20 rpm
Time	Stop watch	–	± 0.5%
Exhaust temperature	K-type thermocouple	$0–1000^0$C	± 1 °C
Smoke density	Smoke meter	0–100%	± 2%
Calculated results			**Uncertainty**
Engine power	–	0–8 kW	± 1.0%
Fuel consumption	Level sensor	–	± 2.0%
Air consumption	Turbine flow type	–	± 1.0%
BTE	–	–	± 1.0%
BSEC	–	–	± 1.5%

diagnostic system is shown in Tables 1 and 2 with present range, accuracy and uncertainty of measurements.

3. Results and discussion

3.1. Physico-chemical properties

Physico-chemical properties of different biodiesel and diesel fuel are presented in Table 3.

3.2. Fatty acid composition

Fatty acid composition of different oil used in this work were determined by Gas chromatography (GC) analysis, in Intertek India Pvt. Ltd. Chemical Testing Lab (Food Services), and shown in Table 4.

Table 3
Properties of Oleander, Kusum and Bitter Groundnut oil methyl esters compared with diesel.

Properies	Biodiesel			Diesel	ASTM Limit
	OOME	KOME	BGOME		
Density at 15 °C (g/cc)	0.874	0.857	0.866	0.840	0.86 –.90
Viscosity at 40 °C (cst)	4.2	4.5	4.1	3.0	2.52 – 7.5
Flash point (°C)	175	138.5	148	51	Min 130
Fire point (°C)	186.2	147	152.8	58	Min 53
Pour Point (°C)	3	−2	6	−6	−15 to 16
CFPP (°C)	7	4	5	−9	Max 19
Cetane number	75	52.4	49	50.3	Min. 47
Calorific Value (MJ/kg)	42.35	39.07	41.05	44.47	Min. 33

Table 4
Fatty acid composition of different selected oils.

Type of fatty acids	**Oleander Oil**	**Bitter Groundnut Oil**	**Kusum Oil**
Myristic (14:0)	–	–	–
Palmitic (16:0)	23.88	10.42	6.73
Stearic (18:0)	7.46	1.9	5.81
Palmitoleic (16:1)	–	1.2	2.88
Oleic (18:1)	44.23	49.3	48.51
Linoleic (18:2)	21.82	33.76	6.57
Linolenic (18:3)	0.48	1.4	0.21
Arachidic (20:0)	1.8	1.1	27.21
∑ **Saturated fatty acids**	**33.14**	**4.4**	**40.64**
∑ **Unsaturated fatty acids**	**66.53**	**94.88**	**58.17**

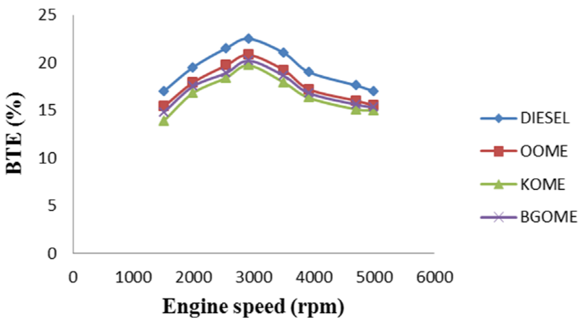

Fig. 3. Variation of Brake thermal efficiency (BTE) with Engine speed.

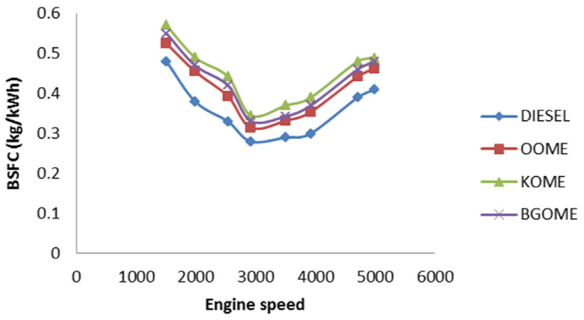

Fig. 4. Variation of Brake specific fuel consumption (BSFC) with Engine speed.

3.3. Engine performance

Figs. 3 and 4 show the percentage change in the performance parameters with respect to engine speed considering diesel as a baseline. All observations are taken in the speed range of 1500–5000 rpm with an increment of 500 rpm. Brake thermal efficiency is a vital engine performance parameter. It is the ratio of mechanical work obtained at the engine shaft and the total energy supplied by the injected fuel, which is the product of fuel heating value and mass flow rate [16]. The variation of the engine BTE obtained for all the tested biodiesels and diesel fuel with respect to engine speed is shown in Fig. 3. For all biodiesels brake thermal efficiency is lower as compared to pure diesel over the entire range of engine speed at full load. This was attributed to increased brake power and reduced wall heat losses at higher engine loads [6]. The BTE in general, was found to decrease with increased volume fraction of biodiesel in the blends. This is due to a number of factors like lower heating value, higher viscosity and density of the biodiesel resulting in poor atomization/vaporization, and increased fuel consumption. Among the tested biodiesels, KOME showed the least BTE (19.7%), while OOME the maximum efficiency (20.20%) at a speed of 2900 rpm. compared to diesel (22.5%). Further increase in rpm decreases the brake thermal efficiency for a wide range of engine rpm. These results are supported by literature [10,13,14,16,21,22].

The BSFC of diesel engine depends mainly on the relationship between fuel density, viscosity and energy content [26]. The variation of brake specific fuel consumption for OOME, KOME and BGOME compared to diesel fuel is shown in Fig. 4. The BSFC initially decreases sharply with an increase in rpm up to 2900 and then increases suddenly with an increase in speed. The BSFC for all biodiesels and pure diesel is least at 2900 rpm. OOME, however, showed less brake specific fuel consumption compared to KOME and BGOME. The brake specific fuel consumption values were 0.314, 0.331 and0.345 kg/kWh for OOME, BGOME, and KOME, respectively, and with diesel fuel, it was 0.221 kg/kWh at a speed of 2900 rpm. Similar trends of BSFC with different biodiesel blends were also reported by other researchers [10,22]. The reason for the higher BSFC of biodiesels blends is mainly due to the higher density and lower energy content of biodiesel-diesel blends [20]. Any fuel is delivered to the engine on a volumetric basis. For the same fuel volume, an increase in fuel density would imply a larger mass flow rate to the cylinders and this would increase the BSFC to produce the same power [31]. KOME showed least brake thermal efficiency (19.7%) compared to OOME and BGOME due to high viscosity and low volatility. The biodiesels exhibited more brake specific fuel consumption compared to diesel fuel, as calorific value is less hence, more fuel is needed for the same power output. At higher speed beyond 2900 rpm, BSFC goes on increasing for all tested fuels.

3.4. Engine emissions

Figs. 5–8 shows emission characteristics of different biodiesels and diesel at different engine speed. The amount of CO produced by using diesel, OOME, KOME, and BGOME is shown in Fig. 5. Carbon monoxide (CO) is a toxic gas formed due to the incomplete combustion of any fuel which does not contain oxygen. Several factors such as engine speed, air-fuel ratio, injection pressure, injection timing and type of fuel used have an effect on CO emission. A similar trend was found for CO in biodiesel blends and diesel fuel, which steeply decreased as the engine speed increased from 1500 rpm to 2900 rpm and then increases up to 5000 rpm. It was noticed that CO emissions of diesel fuel are higher than all the biodiesel fuels at all speed of the engine. This was due to biodiesel containing more oxygen element, which gave better combustion. Therefore, as the percentage of biodiesel increases in the blend, the higher oxygen contents of biodiesel allow more carbon molecules to burn and combustion is completed. Moreover, low aromatics in the blends may be an additional reason for reducing CO emission. Ong et al. [22] claimed that there was lower CO emission during combustion using biodiesel as compared to the diesel fuel. OOME, on the other hand, exhibited higher CO emissions compared to KOME and BGOME at maximum speed (5000 rpm), due to incomplete combustion. CO emissions of diesel, OOME, KOME, and BGOME were 0.19%, 0.15%, 0.14%, and 0.13% at rated speed.

Fig. 6 shows a variation of HC emissions for OOME, KOME, BGOME and diesel with engine speed. The HC emissions were less compared to diesel fuel at all speeds. For efficient combustion of a fuel, the fuel has to atomize, mix with air and ignite properly. Atomization and mixing of fuel depends on the physical property of the fuel. Viscosity and surface tension affect

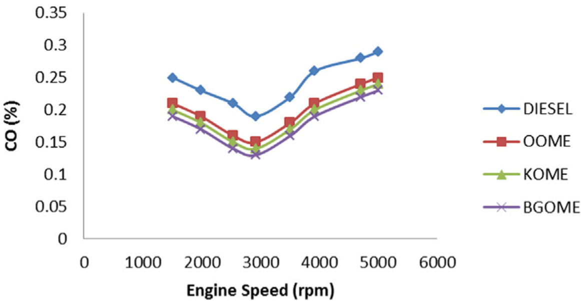

Fig. 5. Variation of carbon mono oxide (CO) with Engine speed.

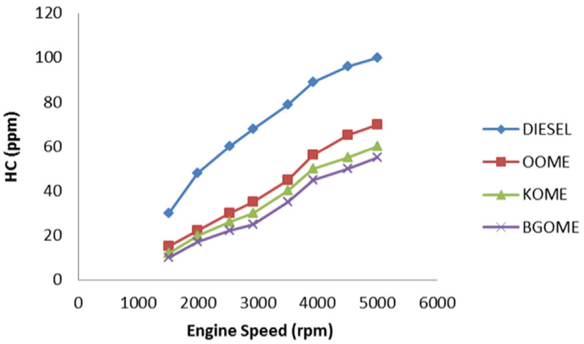

Fig. 6. Variation of hydrocarbon (HC) with Engine speed.

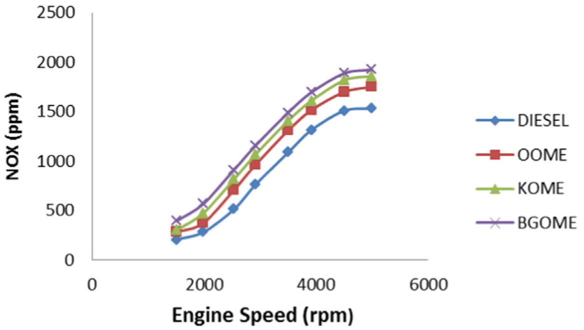

Fig. 7. Variation of oxides of nitrogen (NO_X) with engine speed.

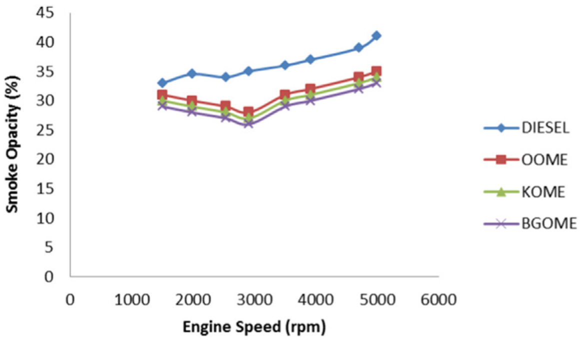

Fig. 8. variation of smoke opacity with engine speed.

the penetration rate, maximum penetration and droplet size of the fuel. Cetane number of the fuel plays a vital role in ignition process. As cetane number of biodiesel is higher than diesel, it exhibits a shorter ignition delay period and permits the fuel for better combustion. The oxygen content of biodiesel enhances the combustion process. Therefore the net result of oxygen content and cetane number of the biodiesel is low HC emission compared to diesel. The lowest UHC emission was observed for BGOME. The HC emission increases as speed increases for all tested fuels. The decreased trend of HC emission for all biodiesel fuel compared to diesel might be due to the presence of oxygen molecules in the biodiesels that helped for complete combustion [8].

Among the tested biodiesels, the HC emissions were 70, 60 and 55 ppm for OOME, KOME and BGOME, respectively, compared to a value of 100 ppm for diesel at maximum speed. This is in line with the findings reported by many other researchers [8,22] while fueling diesel engines with different biodiesels. The variation of nitrogen oxides (NOx) emissions w.r.t engine speed is shown in Fig. 7. The presence of oxygen in biodiesel blends caused higher NOx formation and it is indicated that exhaust gas temperature was increased as well [4]. Furthermore, Ozsezen and Canakci [23] mentioned that the oxygen content is affected in NOx formation due to high exhaust gas temperatures caused excess hydrocarbon oxidation. Lin et al. [18] observed that higher EGT leads to increase in NOx emission. In general, NOx formation depends on temperature and presence of oxygen [1]. It was observed that NOx emissions were higher for all biodiesels, compared to diesel fuel. NOx emissions were 1923, 1887, and 1750 ppm for BGOME, KOME and OOME and respectively, compared to a value of 1532 ppm for diesel. Similar results are reported by previous researchers [8,10].

Smoke opacity is a measure of soot content in the exhaust gases. Fig. 8 shows the variation of opacity vs. speed for OOME, KOME and BGOME in comparison to pure diesel. It was observed that smoke opacity for OOME, KOME and BGOME was 28.2%, 27.3% and 25.9% respectively at 2900 rpm. However, the highest smoke opacity was found 35.3% for diesel fuel at the same speed. The trend regarding the variation of opacity with respect to speed is almost similar for all type of fuels. However, the highest smoke opacity was 41.4% for diesel fuel at 5000 rpm. The BGOME has lower smoke opacity than diesel because of the oxygen content present in biodiesel fuel [9]. This is agreed by Raheman and Ghadge [27], who reported that smoke emissions for biodiesel blends decreased due to increase of oxygen content in the fuel. Moreover, many researchers were agree that the higher oxygen content in biodiesel reduces smoke opacity [5,24]. Another reason of smoke emissions reduction for biodiesel is the lower carbon to hydrogen ratio and absence of aromatics compounds. The lower carbon and higher oxygen content decrease the tendency of fuel for soot production and thus reduce smoke opacity (2010). It was agreed by Gumus and Kasifoglu [11] that biodiesel rich in oxygen can decrease smoke formation. On the other hand, Zhang et al. [34] observed that start of combustion for biodiesel blends is earlier than diesel. The early start of combustion for biodiesel blends and advanced injection timing can reduce the smoke emission. On other hand, high smoke opacity of diesel fuel was due to higher sulfur content compared to biodiesel [32].

4. Conclusions

Biodiesels were produced by chemical transesterification and different properties of biodiesel were determined. The performance and emission characteristics were studied for a transportation engine. The biodiesels such as oleander oil (OOME), Kusum oil (KOME) and bitter Groundnut oil (BGOME) show poor performance compared to diesel fuel. The CO, HC emissions and smoke opacity of OOME, KOME and BGOME were found to be slightly less than that of diesel fuel. The NOx emissions were slightly more than that of diesel. Overall engine operation with all three biodiesels (OOME, KOME, and BGOME) was smooth. All tested biodiesels (OOME, KOME, and BGOME) exhibited reduced brake thermal efficiency and exhaust emissions (CO and HC and smoke opacity) except NOx. The engine could be operated with these biodiesels without major modifications.

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