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(Research Article)

Effect of engine load and higher blends of pongamia methyl ester on engine behavior

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Abstract

The diesel demand in the country is growing at an annual rate of 8%. It's also predicted that the supply of fossil fuels will not be able to meet this demand. The greenhouse gas (GHG) emissions of the transportation sector had increased 16.4% from 1990 to 2013. In biofuels, the country has a ray of hope in providing energy security and the use of higher biodiesel blends offer considerable GHG emission benefits over standard diesel. Therefore, the biodiesels become compelling in view of the tightening automotive vehicle emission standards to curb air pollution.

The main objective of these experiments is to attempts the use of commercially available pongamia biodiesel blends; hence the effect of increased engine load and the biodiesel proportion in the blend on engine performance and emissions in comparison with diesel fuel is most required. The various engine performance and emission parameters evaluated are BTE, BSFC and emission parameters like; O2, CO2, CO, UBHC, NOx, EGT and smoke opacity. The results revealed that, the lower blends results closer performance and emissions in comparison to diesel. The higher NOx emissions observed at higher loads for POME blends and diesel due to higher peak temperatures. Further, the increased biodiesel percentage in the blend with diesel increases the O2, EGT and NOx emissions at all engine operating conditions.

Keywords: Waste Heat Potential; Effect of Engine Load; Pome Blends; Engine Behavior.

1. Introduction

In the "World Energy Outlook 2008" report, the IEA had predicted the world energy demand to increase by 45% over the next 20 years. According to the International Energy Outlook 2013, the world energy consumption is projected to increase by 56 % over the next three decades. The half of total world energy consumption is attributed to China and India. The diesel demand in the country is growing at an annual rate of 8%. It's also predicted that the supply of fossil fuels will not be able to meet this demand, even when taking new and undiscovered fields into account. Further, the increased trend in the forecast of vehicle populations, India is expected to become the world's third largest passenger vehicle market by 2019 (consultant IHS Automotive estimates). Further, the transport sector vehicles accounts for 1/3rd of the total crude oil consumption and had been identified as a major polluting sector (Figure1).

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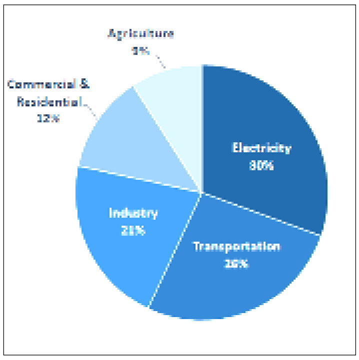

Figure 1 The world energy consumption sector wise

The emission reductions are directly proportional to the amount of biodiesel concentration in the blend. The B100 provides significantly reduced GHG emissions compared to B20 as shown in Figure 2. The analysis conducted by the NREL found that the GHG emissions for B100 could be more than 52% lower than those from diesel [1].

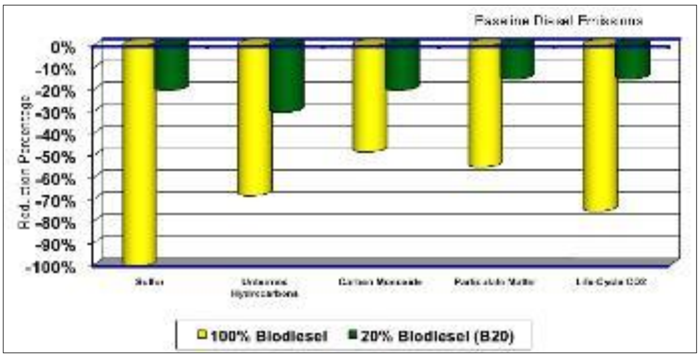

Figure 2 The comparative greenhouse gas emissions for B100 and B20

The increased biodiesel concentration in the blend enhances the viscosities and reduces the feasibility of direct use (Choudhury et al. [2]). Blending is the most common way to reduce the viscosity related issues. The most common ratio is B20; there have been numerous research works showing significant reduction in emission with the blends of smaller biodiesel concentration (Sigar P. [3]; Dilip Sharma [4]; Bari et al. [5]). In India, the demand for biodiesel increased every year nearly by 1-2 million tons (Dwivedi et al. [6]). The estimated million tones demand considering B20 observed from Table 1.

Table 1 The future biodiesel requirement in India

Year	Diesel demand (MT)	Biodiesel requirement (MT) BD20
2010-11	100.47	20.1
2011-12	106.00	21.2
2012-13	111.83	22.3
2013-14	117.98	23.6
2014-15	124.47	24.9
2015-16	131.31	26.2
2016-17	138.54	27.7
2017-18	146.16	29.2
2018-19	154.19	30.8
2019-20	162.67	32.5

The most recent works conducted on pongamia oil and its derivatives for optimum blending ratio are presented here. Jagadeesh Alku [7] reported that, the pongamia biodiesel up to 25% blend can be substituted for diesel without any engine modification. Balajee [8] investigated the utilization of POME blends and concluded that the B10 pongamia is safe to use as an alternative fuel.

Panigrahi et al. [9] investigated different blends of KOME. The viscosity of B20 and B40 blends were much closer to diesel. The maximum power was observed for B20 blend at full load and BSFC reduced with increased load. Nagarhalli et al. [10] tested KOME and recommended B40 blend as diesel substitute. Raheman and Phadatare [11] tested the blends of KOME and reported that, the B40 could replace diesel. Jahagidar et al. [12] carried experiments on KOME and found the power almost same for all the loads and reported the optimum performance with B40 & B60. Venkanna et al. [13] studied the higher blend ratios of honge oil, and found inferior to diesel. They suggested 20% honge oil in the blend as diesel replacement without any modification and without any adverse effects.

Ghosh et al. [14], Mahanta et al. [15], Sureshkumar et al. [16] and Nithyananda et al. [17] studied different oils and observed that 20% oil blended with diesel can yield the satisfactory results in terms of fuel efficiency and power developed.

a

b

c

d

Figure 3 (a) Pongamia tree (b) Pongamia flowers (c) Pongamia seeds and (d) Pongamia biodiesel

The most abundant oil sources in India are Mahua, Neem, *Pongamia* and Jatropha. Amongst the various renewable fuel, Jatropha and pongamia plant are considered as the sole resources that can meet the growing demand in India due to their high productivity and less maturity cycle. It's also seen that pongamia pinnata has higher productivity as compared to Jatropha and can becomes a good source of energy (Dwivedi et al. [6]). Thus, the pongamia oil appears as attractive renewable fuel for engines. The karanja (Pongamia Pinnata) oil is non edible and is easily available in many parts of the world including India and it is cheaper compared to other oils. The pongamia pinnata found as one of the most suitable non edible oil plant species in India (Dwivedi et al. [6]). Pongamia pinnata is originated from India and is planted in the humid tropical lowlands around the world. It's a medium sized tree of about 7-8 meters high with hemispherical crown of dark green leaves (Figure 3 (a)). Pink flowers (Figure 3 (b)), Elliptical pods usually contain a single or two seeds as shown in Figure 3 (c). The seeds of pongamia pinnata contain 30 to 40% oil which is thick and reddish brown in colour known as Pongam / Pongamol / Hongay oil which can be converted to biodiesel as shown in Figure 3 (d) by transesterification with methanol in the presence of KOH.

1.1. Properties of pongamia oil and its derivatives

The different thermo chemical properties like; density, flash and fire point temperature, viscosity and calorific value of pongamia oil and its derivatives were evaluated according to the ASTM methods in the fuel testing laboratory (Figure 4), College of Agriculture, Hanumanamatti (Haveri district).

Figure 4 Biodiesel testing laboratory

The various instrument used for the determination of biodiesel properties in the testing laboratory and the corresponding ASTM methods are tabulated in the Table 2.

Table 2 The instruments and ASTM methods used to measure properties of fuels.

Properties	Unit	Instrument used	ASTM methods
Kinematic viscosity	cSt	Red wood viscometer	D445
Density	gm/m^3	Hydrometer	D1298
Flash point and fire point temperature	ºC	Pensky Martens apparatus	D93
Calorific value	KJ/kg K	Bomb calorimeter	D240
Copper strip corrosion		Copper strip corrosion test bomb	D130

The Table 3, shows the Thermo-chemical properties of pongamia oil and its derivatives in comparison with diesel.

Table 3 Thermo chemical properties of pongamia oil and its derivatives

Properties	Unit	Diesel	PO	POME blends with diesel									
				10B	20B	30B	40B	50B	60B	70B	80B	90B	100B
Kinematic viscosity at 30 °C	cSt	2.2	41	3.7	3.8	4.2	4.7	5.1	5.7	6.2	6.5	6.7	6.8
Flash point temp	° C	65	206	91	94	97	102	110	117	124	128	147	174
Fire point temp	° C	71	223	98	103	107	113	119	128	134	139	156	185
Calorific Value	kJ/kg	43,800	36,425	42,150	41,618	40,200	39,380	38,650	38,100	38,020	37,880	37,510	37,150
Density at 30 ºC	kg/m^3	816	915	818	820	831	842	846	851	860	868	879	894

1.2. Materials used

- Computerized diesel engine test rig with all the necessary instrumentation.
- MRU make Flue gas analyzer and smoke meter.
- Lab view based software "IEAS" suitable for engine performance analysis.
- The data acquisition system.
- The complete workstation for data access, online data display and file storage.
- The commercially available pongamia biodiesel (POME) that conforms to the standards specified in ASTM D-6751.
- Pongamia oil (PO) and diesel fuel.
- POME blends: B10, B20, B30, B40, B50, B60, B70, B80, B90 and B100.

2. Experimental Setup

Figure 5 presents the schematic experimental test set up with heat exchanger assembly (9) and the necessary instrumentation for online data measurement. It consists of a stationary diesel engine (1), dynamometer (2), duel fuel tank, different sensors, data acquisition system, thermostat, a personal computer, panel board, flue gas analyzer, smoke meter and the temperature data logger etc.

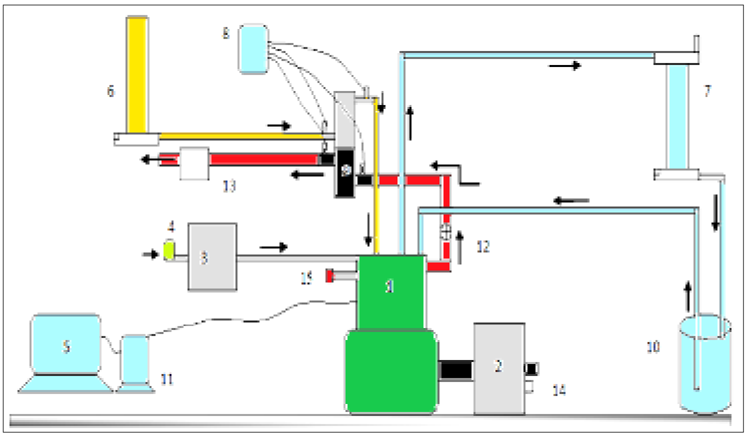

Figure 5 The schematic diagram of experimental test set up

1. Diesel Engine; 2. Eddy current dynamometer; 3. Air box; 4. Anemometer; 5. Personal computer 6. Fuel flow measuring load cell; 7. Water flow measuring load cell; 8. Temperature data logger; 9. Heat pipe heat exchanger; 10. Water storage; 11. Engine data logger; 12. Engine exhaust pipe; 13. Flue gas analyzer; 14. Torque sensor; 15. Pressure sensor

The complete facility for the present research work is established at Government Engineering College, Haveri. The Vision Group on Science and Technology (VGST) recognized and awarded the fund of rupees six lakh under the SMYSR scheme (Seed Money for Young Scientists) to set up engine research lab.

2.1. Experimental procedure

The entire set of experiments were conducted at a constant speed of 1500 rpm, injection timing of 23º BTDC and injector pressure of 200 bar for zero to full engine load. After applying the load on engine the required observations and subsequent reading are recorded and stored in the log file using the engine software. Simultaneously the data related to engine emissions and smokes are recorded. Each experimental run typically consist of the following procedure:

- Adjust the water flow to engine cylinder jacket and pressure sensor cooling circuit.
- Fill the sample of blend to be tested in the load cell based fuel measuring cylinder.
- All the instrumentations, data acquisition panel, engine and emission software of are kept in ON and live position in computer desktop for run.
- Switch on & allow gas analyzer & smoking meter to stabilize at room temperature.
- Then the engine started with zero load, wait for minute for steady state.
- Then each run of 180 seconds with increased load from 0-100% are experimented.
- All the data related to engine performance and emissions are recorded.

- First the engine is tested with diesel fuel at increased load from 0 to 100% of rated load (0%, 25%, 50%, 75% and 100%).
- The above procedure has been then repeated for B10, B20, B30, B40, B50, B60, B70, B80, B90 and B100 and PO.

2.2. Computerized single cylinder diesel engine

In India, almost all irrigation works, tractors, machinery and transportation are powered by diesel engines. They always been preferred widely due to the power developed, fuel consumption and durability. Keeping these features in mind, an engine system as shown in Figure 6, used widely in the agricultural sector, has been chosen. The technical specification of the engines is listed in the Table 4.

Figure 6 Single cylinder 4 stroke diesel engine

Table 4 Technical specification of the engine

Detail	**Specification**
Engine type	AV1 5hp, single cylinder, water-cooled, 4-stroke CI engine.
Make	Kirloskar
No. of cylinders	1
Bore x stroke (mm)	80 x 110
Compression ratio	16.5 : 1
Rated power	3.7(5)
Rated speed rpm	1500
Dynamometer and torque measurement	Air cooled eddy current dynamometer , load cell 0-40kg with digital indicator
Air flow measurement	Differential pressure transducer with digital indicator
Fuel measurement	Load cell based, loss in weight type with digital indicator
Water flow measurement	Load cell based, loss in weight type with digital indicator
Temperature measurement	Pt 100 sensors with indicator for low temperature measurement and k type thermocouple for high temperature measurement with indicator.
Speed measurement	Digital speed indicator with proximity sensor
Calorimeter	Pipe in pipe type with glass wool insulation and cladding
Communication	All the above mentioned indicators communicated with RS-232 output
Software	Lab view based software suitable for performance analysis

	(software "IEAS")
Crank angle measurement	TDC encoder is provided to measure crank angle having 1dg resolution.
Flywheel rotation	Clockwise
Engine start	Hand start
Governing	Class"a2/b1"
Fuel injection	Direct injection

3. Results and discussion

The results of tests performed at steady state, to analyze waste heat potential from exhaust gas and cooling water are discussed. Further, the test results of experiments conducted at increased engine load on diesel, POME blends: B10, B20, B30, B40, B50, B60, B70, B80, B90 and B100 and PO are discussed.

- Effect of load on engine performance with POME blends
- Effect on brake thermal efficiency (BTE)

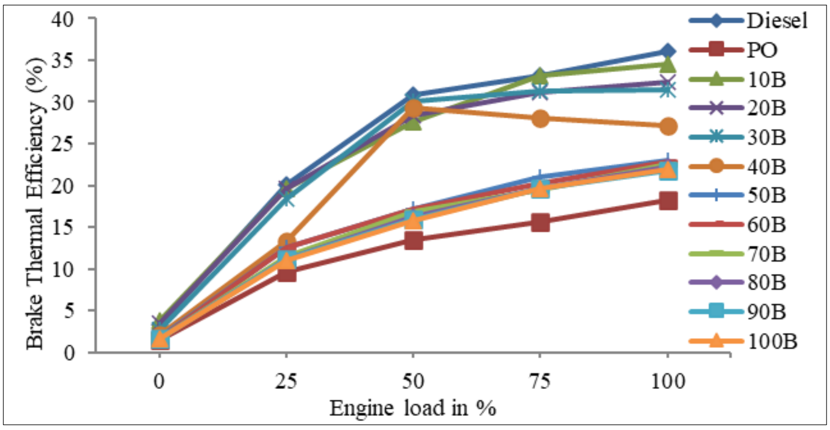

Figure 7 Variation of BTE at different load for pongamia oil derivatives

The BTE commonly termed as fuel conversion efficiency that indicates the percentage of fuel energy converted into useful energy. Figure 7 shows the variation in BTE at increased engine load fueled with diesel, pongamia oil (PO) and POME blends. The maximum BTE has recorded at full engine load for PO and its derivatives. The BTE is little closer and lesser than diesel for upto B30 at lower as well as at higher loads, while the higher blends above B50 shows lower efficiencies at all load conditions. The BTE for B100 and B50 are 21.95% and 22.93% respectively at full engine load. The decreased BTE with increased portion of biodiesel is greatly influenced by the SFC, high viscosity, poor volatility, lower calorific value and poor atomization of biodiesel.

3.1. Effect on brake specific fuel consumption (BSFC)

The BSFC is the amount of fuel consumed to produce 1 kW power output in an hour. The variation in BSFC with varied load and constant speed is shown in Figure 8. The POME blends exhibited similar deceased trend with increased load like diesel. It's also seen that the BSFC for POME blends are higher than diesel except for B10 which shows 4.945% lower than diesel. The increased load results in rapid decrease in BSFC for all POME blends, which is inversely to the engine efficiency. Further, all the blends experienced the higher BSFC than diesel due to the decreased calorific value and higher viscosity with increase in biodiesel percentage in the blend. It's also seen that the pongamia oil shows the highest BSFC at all engine loads.

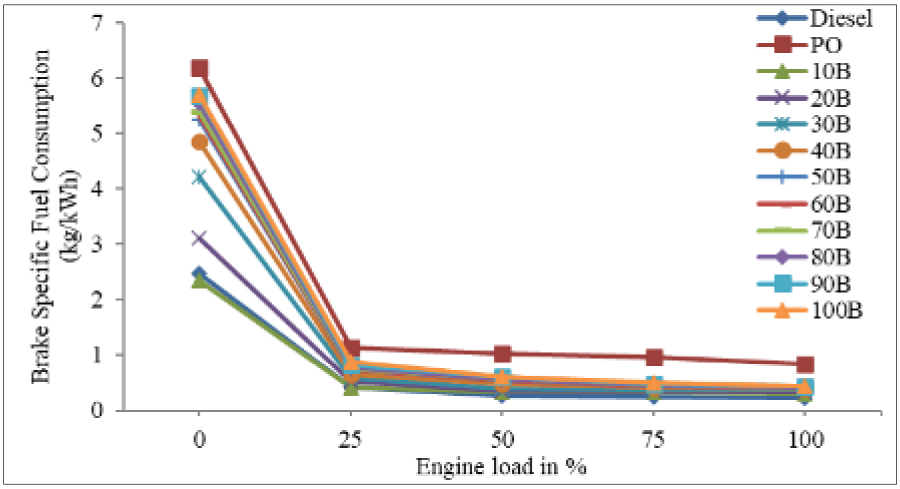

Figure 8 Variation of BSFC at different load for pongamia oil derivatives

3.2. Effect of load on engine emissions with POME blends

3.2.1. Effect on oxygen(O_2) emission

Figure 9 shows the results of engine load on O_2 emission for pongamia oil and its derivatives. It's seen from graph that the oxygen emission reduced with the increased load for all the blends, diesel and pongamia oil. The O_2 emission of all POME blends and pongamia oil found higher than the diesel. This is attributed to the higher oxygen content of biodiesels leads to the complete combustion.

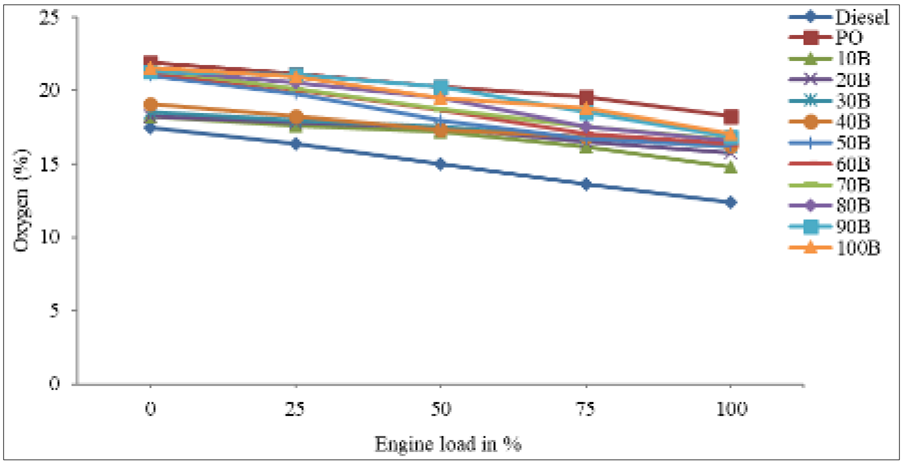

Figure 9 Variation of O_2 emission at different load for pongamia oil derivatives

3.2.2. Effect on carbon dioxide(CO_2) emission

The Figure 10 shows that the CO_2 emission of engine is directly related to the brake power produced and the efficiency of the corresponding fuel. The lowest CO_2 emission observed for all pongamia biodiesel blends than the diesel fuel and pongamia oil. This is due to complete combustion and lower carbon to hydrogen ratio. Further, the CO_2 emission of pongamia oil is significantly higher than diesel due to much lower heating value. Further, the higher biodiesel blends exhibit lower CO_2 emission. The lowest of 0.2 to 2.7% CO_2 emission observed with B100 from 0 to100% engine load.

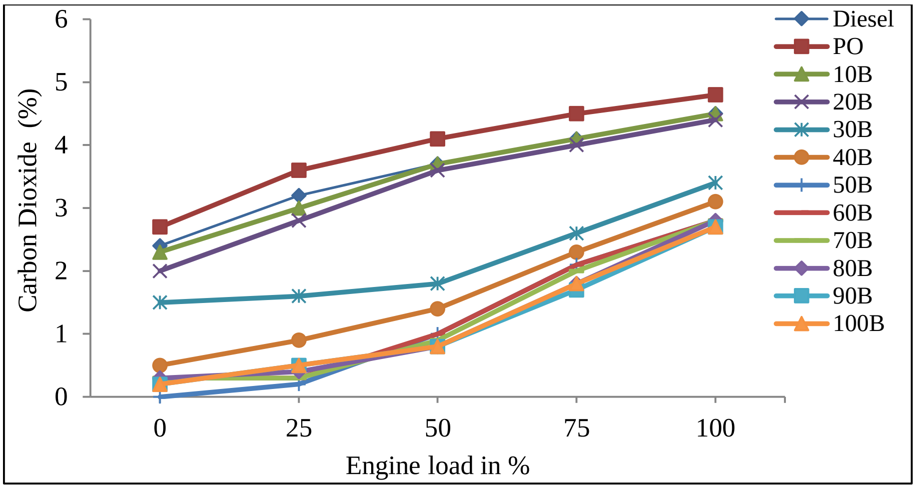

Figure 10 Variation of CO_2 emission at different load for pongamia oil derivatives

3.2.3. Effect on carbon monoxide (CO) emission

The Figure 11 indicates the results of engine CO emissions with increased engine load for different POME blends, pongamia oil and diesel fuel. The increased biodiesel concentration in the blend decreases CO emission. Further, all POME blends results lower CO than diesel due to higher oxygen content of biodiesels that result in complete burning and supplies the necessary oxygen to convert CO to CO_2. During the full load operation B50, B100 and PO respectively shows 25%, 43.75% and 75% lower CO emissions in comparison with diesel. The similar trend exhibited by all the POME blends with increased load from 0 to 100%. Further, the PO shows lowest CO emission of 0.02 to 0.04 % as load increased from 0 to 100%. The higher CO emissions observed with diesel fuel.

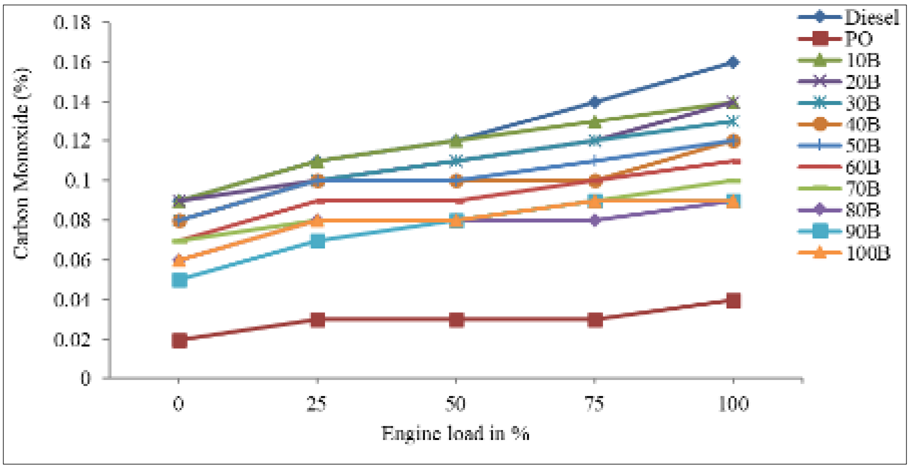

Figure 11 Variation of CO emission at different load for pongamia oil derivatives

3.2.4. Effect on nitrogen oxide (NO_x) emission

The higher NO_x emission is observed at higher load for POME blend, PO and diesel and is increased with increased load (Figure 12) due to higher peak temperatures. Further, the increased percentage of biodiesel in the blend increases the NO_x emission. The B50, B100 and PO respectively show 1.83%, 4.99% and 12.49% higher NO_x emissions in comparison with diesel. The similar trend exhibited by all the POME blends with increased load. The extremely undesirable emission in diesel engines is the NO_x. The higher combustion temperature, more oxygen content and faster reaction rate favor the NO_x formation.

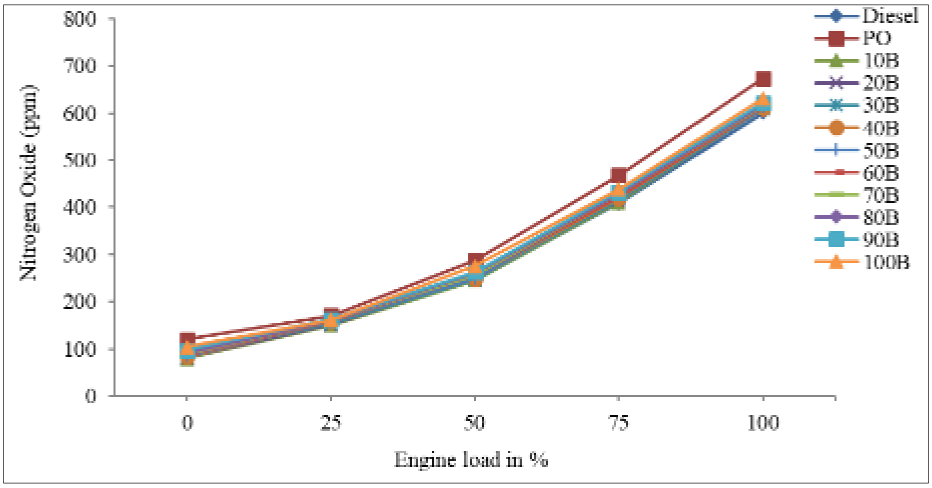

Figure 12 Variation of NO_x emission at different load for pongamia oil derivatives

3.2.5. Effect on unburned hydrocarbons (UBHC) emission

Figure 13 shows the results of UBHC emissions at varied load for different POME blends. The HC emissions found lower at part load and increased with load. This is attributed to the presence of less oxygen for the reaction at higher engine load. Further, the HC emissions reduced for higher biodiesel in the blend.

The POME blend emits lower UBHC than diesel fuel, due to better combustion with excess oxygen in the biodiesel blends as compared to diesel. The B50, B100 and PO respectively show 32.75%, 36.20% and 87.93% reduced HC emissions in comparison with diesel. The higher cetane number of POME blends results lower HC emission due to shorter ignition delay. The plot shows the HC emission of 19 to 37 ppm for increased load from 0 to100% when supplied with B100.

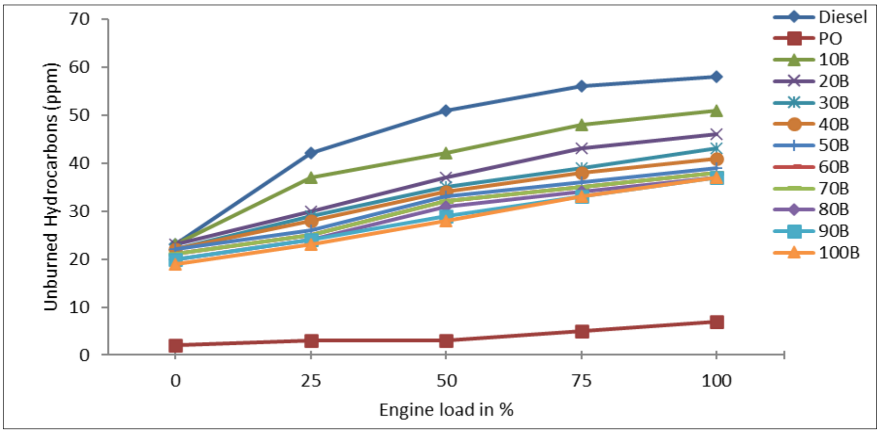

Figure 13 Variation of UBHC emission at different load for pongamia oil derivatives

3.2.6. Effect on smoke opacity

The effect of increased engine load and the increased biodiesel concentration on smoke emission indicated in Figure 14. The increased smoke emission observed with increased load for all the tested fuel samples; PO, diesel and POME blends. The increase in percentage of biodiesel in the blend decreases smoke opacity. The smoke formed is much lower for biodiesel and its blends as compared to diesel. This is attributed to the complete combustion of POME blends as compared to diesel. The maximum of 61%, 26% and 23% smoke opacity reported at higher load for diesel, B100 POME blends and PO respectively.

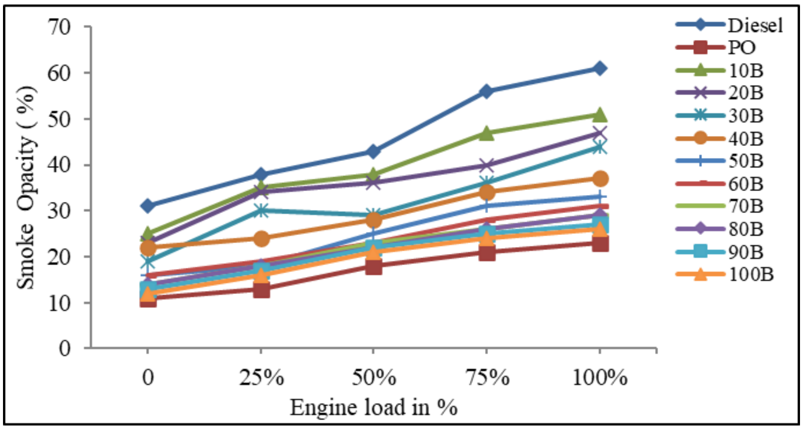

Figure 14 Variation of smoke opacity at different load for pongamia oil derivatives

3.3. Effect on exhaust gas temperature (EGT)

Figure 15 shows the variation of EGT with engine load for pongamia oil derivatives. All the POME blends including pongamia oil and diesel exhibit increased EGT with increased engine load. This is due to increased fuel consumption and temperature rise in the engine cylinder. Further, the EGT for all the POME blends are higher than diesel at all engine operating conditions. This confirms the lower efficiency with increased percentage of POME in the blend. The graph shows an increased EGT of 19.99%, 5.97% and 3.48% for PO, B100 and B50 respectively. Further, the higher EGT of 201 °C, 213 °C and 241 °C observed at full load for diesel, PO and B100 respectively.

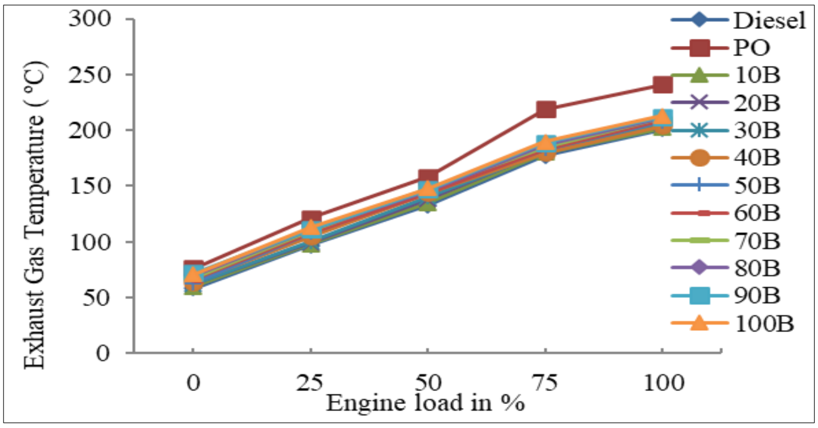

Figure 15 Variation of EGT at different loads for pongamia oil derivatives

4. Conclusions

The results revealed that, the lower blends results closer performance and emissions in comparison to diesel. However, for higher POME blends, the engine performance found marginally inferior. This is due to lower heating value and higher viscosity of biodiesel.

The engine BTE found closer to diesel for upto B30 at lower as well as at higher loads, while the higher blends above B50 shows lower efficiencies at all load conditions. This increase in brake power at increased load results the rapid decrease in BSFC for POME blends. Further, all the blends experienced the higher BSFC.

- The lowest CO_2 and CO emission observed for all POME blends than the diesel fuel and pongamia oil.
- The increased biodiesel percentage in the blend decreases HC, CO and smoke emissions.
- The higher NO_x emissions observed at higher loads for POME blends and diesel due to higher peak temperatures.
- Further, the increased biodiesel percentage in the blend with diesel increases the O_2, EGT and NO_x emissions at all engine operating conditions.
- The results revealed that, the increased biodiesel percentage in the blend decreases all the emissions.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have no conflict of interest to disclose.

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