



A comparative estimation of C.I. engine fuelled with methyl esters of punnai, neem and waste cooking oil

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Abstract

In this experimental study, performance, emission, and combustion characteristics of methyl esters of Punnai, Neem, Waste Cooking Oil and their diesel blends in a C.I. engine was experimentally examined. For the study, Punnai oil methyl esters (POME), neem oil methyl esters (NOME), and Waste Cooking Oil Methyl Esters (WCOME) were prepared by transesterification process. The Bio diesel-diesel blends were prepared by mixing 10%, 30%, 50%, and 70% of bio diesel with diesel. The effects of three methyl esters and their diesel blends on engine performance, combustion, and exhaust emissions were examined at different engine loads. Experimental results concluded that up to 30% of methyl esters did not affect the performance, combustion, and emissions characteristics. On the other hand, above B30 (30% Bio diesel with 70% diesel) a reduction in performance, combustion, and emission characteristics were clear from the study.

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Keywords: Combustion; Emission; Methyl ester; Performance; Transesterification.

1. Introduction

Recent days, copious use of fossil fuels has led to their fast lessening. Though, bio-diesel has emerged as a promising surrogate to diesel fuel, there are issues allied with them. Among those, the imperative one is higher viscosity. Viscosity of fuel plays an important role in the combustion characteristics because the direct injection of fuel through the nozzle and fuel spray pattern in the open combustion chamber decides the ease of thermal efficiency and combustion characteristics of the engine. Very low viscosity can result in excessive internal pump leakage and on the other hand, system pressure reaches an undesirable level that will affect the injection process during the spray atomization. The effect of viscosity is critical at low-speed or light load conditions [1]. Various methods such as blending, preheating, transesterification, and other super critical methods are available to treat the molecular structure of vegetable oils. Among those, transesterification process has been widely used to prepare bio diesels from vegetable oils and animal fats [2]. There is a reduction in viscosity and enhancement of fuel properties by the transesterification process [2-8].

Calophyllum inophyllum (punnai) is an ornamental evergreen tree belonging to Clusiaceae/Mangosteen family. It is native from eastern Africa, South coastal India to Malaysia, Australia, and Northwest coastal areas of Luzon Island in the Philippines. The fruit is a round, green drupe reaching 20-40mm (0.8 – 1.6

inch) in diameter, which has a single large seed. The kernels have very high oil content of around 75%, because for commonly used *Jatropha curcas* it ranges from 30 – 50% [9].

To give a brief note on Neem trees they have been commercially grown in more than 30 countries. Because of its climatic adaptability Neem trees are being used in many reforestation projects around the world. Oil extracted from the Neem seeds is light to dark brown in color and somewhat bitter tasting. In India, there is the potential to extract 83,600 tons of Neem oil per annum and out of which only 6% is being utilized for fertilizer and medical purposes [10].

Used frying oils could be treated and successfully utilised as a substitute for diesel fuel. Used oil often becomes thicker due to hydrogenation and has vegetable or animal fats from the foodstuffs [10]. Thorough cleaning is necessary to remove food particles and other contaminants that would quickly block fuel filters or damage the engine fuel system, since the injector pump is an expensive fuel system component, which is particularly susceptible to damage due to its fine construction and tolerances. To discuss about the present day scenario a not much attempt has been made to commercialize the use of esters of non edible oils as a replacement for diesel [10]. From all above facts, an effort has been made to test the performance, emission, and combustion characteristics of methyl esters of Punnai, Neem, and Waste cooking oil with the aid of Kirloskar single cylinder (water-cooled) diesel engine.

2. Materials and methods

2.1 Alkaline transesterification

The first and foremost step for bio-diesel preparation is the transesterification of vegetable oils. By this process the molecular size of the component (triglycerides) reduces. Such that the resultant esterified oil could be used in diesel engine for a prolonged period without any serious issues like carbon buildups, scum formation, etc. The transesterification process is as follows: one liter of Punnai/Neem/Waste cooking oil was taken in a round bottom flask and was heated up to 110 °C in order to remove the moisture content present in it. Base catalyst NaOH (7.5 g approx.) was dissolved in methyl alcohol (200 ml) and maintained at the reaction temperature of around 65 °C for a period of 60 minutes. The reaction products were allowed to settle under gravity in separating funnel for 24 hours to separate methyl esters and glycerol. Due to the higher density of glycerol it settled at the bottom of the funnel and obviously methyl esters occupied the top surface. The methyl ester was then washed with warm water to remove un-reacted methanol, catalyst, and impurities. The washed methyl ester was again heated to 110 °C to remove the moisture content. Various bio diesel-diesel blends (B10, B30, B50, and B70) were prepared for the experimental work. The inherent properties of POME, NOME, and WCOME are listed in Table 1. Basically, the fuel properties depend upon the structure and type of fatty acid esters present in the bio diesel. Thus, the physical properties of the three bio diesel samples were evaluated as per the ASTM standards. The relevant physical properties are experimentally evaluated and compared with the base diesel. It was clearly proved that the specific gravity, viscosity, and flash point of B100 blends are higher than the base diesel. On the other hand, the calorific values of B100 blends were lower than diesel. This may be due to the larger molecular mass, high relative density, and higher flash point of bio diesel.

Table 1. Properties of punnai, Neem and waste cooking oil methyl esters compared with diesel

S.no	Properties	Diesel	POME	NOME	WCOME
1	Specific gravity	0.84	0.91	0.89	0.87
2	Viscosity (cSt)	4.7	5.1	6.8	4.9
3	Calorific value (kJ/kg)	43,500	39,708	39,495	40,203
4	Flash point °C	50	175	168	130

2.2 Engine experimental set up and procedure

A single cylinder, direct injection, four stroke, water-cooled, Compression Ignition (C.I.) engine was used in the experimental study. The technical specification of the engine is given in Table 2. The engine was loaded by eddy current dynamometer. The fuel flow rate was measured by noting down the time taken for the consumption of a known quantity of fuel (50cc) from a burette. The viscosity of raw as well as esterified oil was measured by red wood Viscometer (ASTM D445), density by hydrometer (ASTM D1298), calorific value by bomb calorimeter (ASTM D420), flash and fire point by open cup method

(ASTM D93). AVL-444 DI Gas analyzer was used to record the exhaust tail pipe emissions such as HC, CO, CO₂, and NO_x. The smoke opacity was measured with the aid of AVL 437 standard smoke meter. Initially, before starting experimental tests, the engine was made to run under ideal condition as warm up phase and then the tests were conducted. The engine was started and allowed to warm-up for about 10 minutes. The engine was tested under five discrete part load conditions Viz; 0%, 25%, 50%, 75%, and 100%.

3. Bio diesel production unit

A small batch type unit used for bio diesel production was designed and fabricated in the laboratory. The features of bio diesel production unit are as follows:

The variable speed D.C motor was used to vary the speed of the stirrer from 200 to 900 rpm. The speed of the stirrer was monitored using digital speed sensor along with digital speed indicator. The automatic temperature controller was provided in the unit to vary the temperature of oil from 30°C to 250°C. This feature is highly useful for pre-treatment, transesterification, and evaporation of water molecules present in the bio diesel after bubble washing. The unit consists of eight numbers of stainless steel blades at an angle of 45° rotating in a clockwise direction to produce the centrifugal effects to separate the fatty acids from the oil more effectively. The capacity of the tank is six liters and it has the ability to produce maximum of five liters within 90 minutes or minimum of two liters within the same period. The photographic view of bio diesel production unit is shown in Figure 1.

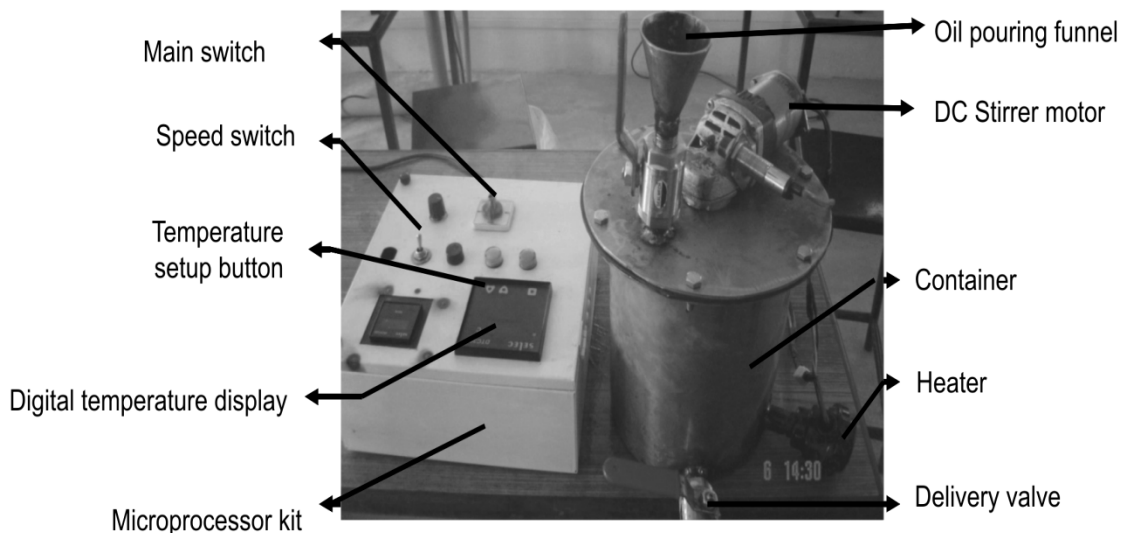


Figure 1. Photographic View of bio diesel production unit

4. Result and discussion

4.1 Brake thermal efficiency (performance parameter)

The variations of brake thermal efficiency with respect to brake power for diesel, bio diesel-diesel blends of Punnai, Neem, and used Cooking Oil are expatiated in the following sections.

Figures 2 to 4 show the variation of brake thermal efficiency with respect to brake power for POME, NOME, and WCOME and its diesel blends. The brake thermal efficiency indicates the ability of the combustion system to accept the experimental fuel and provides comparable means of assessing how efficient the energy in the fuel can be converted into mechanical output. It was evident in the study that for all test fuels the brake thermal efficiency increased with increase in brake power. Among B10, B30, B50, B70, and B100 bio diesel, bio diesel blends up to B30 has a maximum brake thermal efficiency of 30.37%, 30.13%, and 31.32%, respectively, for POME, NOME, and WCOME at full load conditions. It could be clearly seen from the plots that the brake thermal efficiency up to B30 blends is almost closer to that of base diesel (31.34%) at full load conditions. The brake thermal efficiency of B30 has increased by 3.33%, 3.57%, and 3.48% for POME, NOME, and WCOME when compared to that of B100 bio diesel operation. This may be due to better spray characteristics and dissolved oxygen in esters of B30 blends of POME, NOME, and WCOME in the combustion chamber, which lead to effective utilization of air

resulting in complete combustion and additional lubricity of the B30 blend. It is also evident from the plots that the brake thermal efficiency gradually decreased with increasing percentage of blends of esters from B50 to B100.

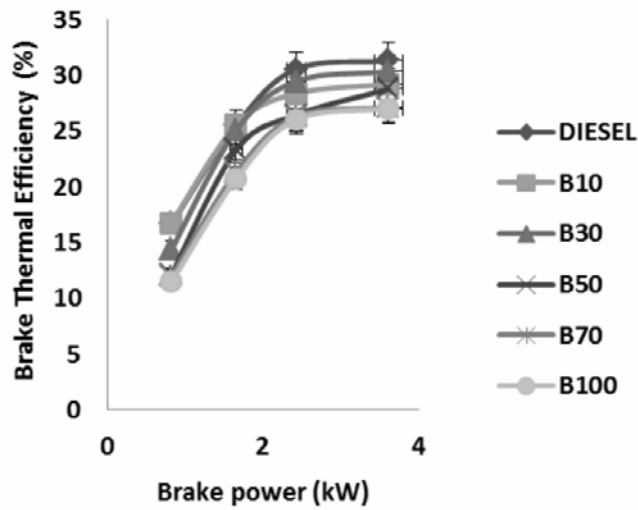


Figure 2. The Variation of Brake Thermal Efficiency for POME

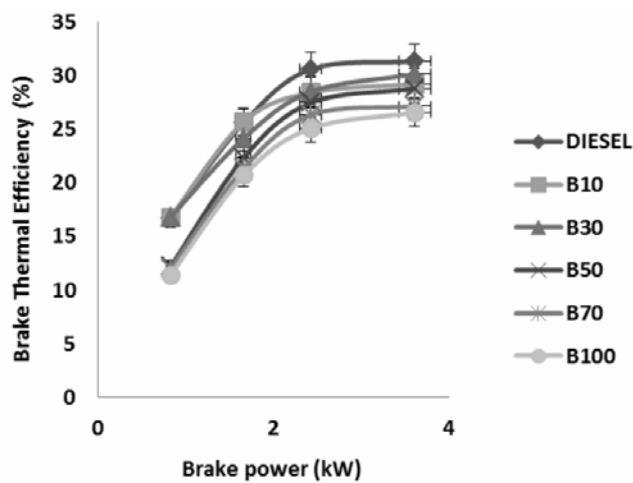


Figure 3. The Variation of Brake Thermal Efficiency for NOME

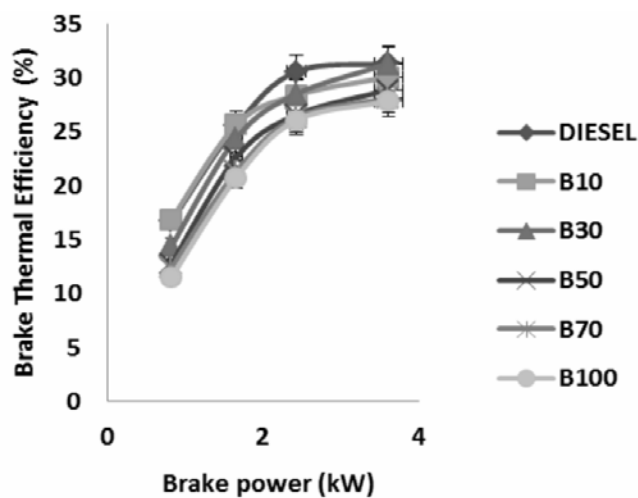


Figure 4. The Variation of Brake Thermal Efficiency for WCOME

The lowest value of brake thermal efficiency was noted with B100 bio diesel operation. This may be due to the large amount of bio diesel supplied to the engine when compared to diesel in order to maintain the equal energy input to the engine. The high viscosity of the blended fuels inhibits the proper atomization, fuel vaporization, and combustion. This trend is also due to the combined effect of lower calorific value, higher density, and viscosity of the blended fuel. These results are in accordance with experimental work done by the previous researchers [11-14].

4.2 Brake specific fuel consumption (BSFC)

Figures 5 to 7 show the qualitative pictures of Brake specific fuel consumption with brake power for diesel and bio diesel-diesel blends of POME, NOME, and WCOME.

The minimum BSFC was obtained for diesel (0.28 kg/kWh) in comparison with all other bio diesel-diesel blends used in the experimental study. It is evident from the graphs that the curves of B10 and B30 show an optimum BSFC and their values were very similar to neat diesel. With an increase in bio diesel blends the value of BSFC also increased. At maximum load, BSFC of B100 blend increased by 0.11 kg/kWh, 0.20 kg/kWh, and 0.13 kg/kWh for POME, NOME, and WCOME compared to diesel.

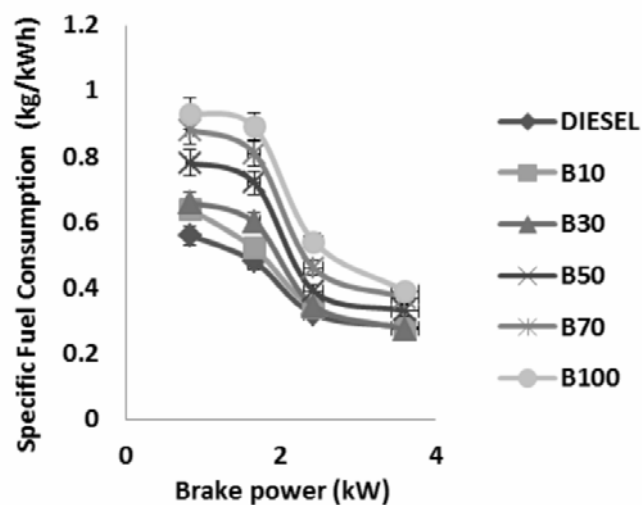


Figure 5. The Variation of Specific Fuel Consumption for POME

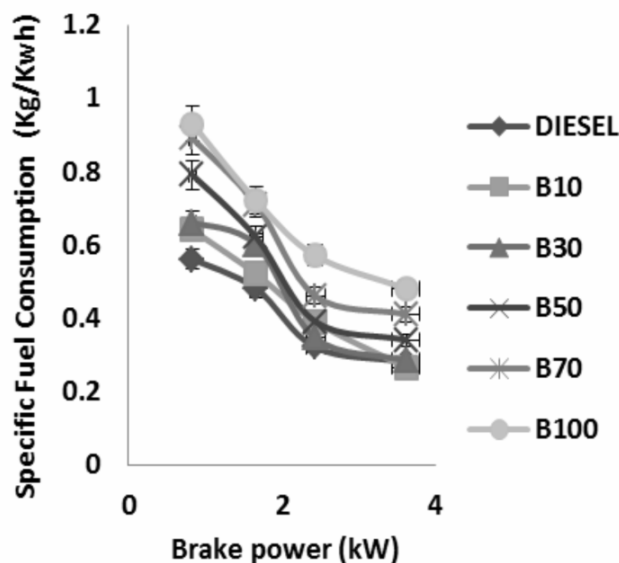


Figure 6. The Variation of Specific Fuel Consumption for NOME

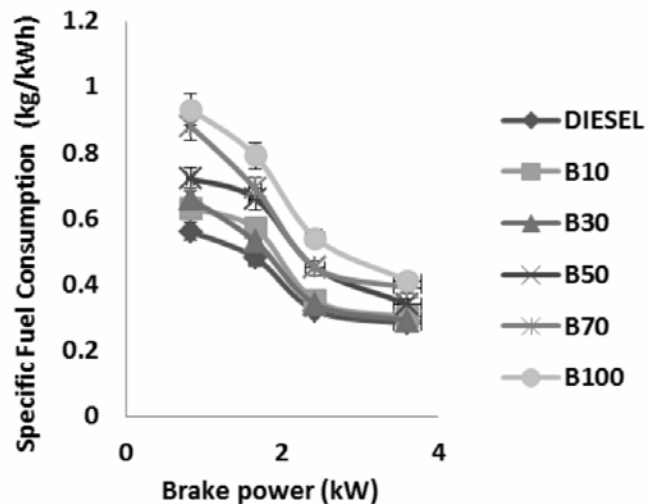


Figure 7. The Variation of Specific Fuel Consumption for WCOME

The maximum fuel consumed was noted for B100 bio diesel operation than any other bio diesel-diesel blends. The primary reason for this increase in BSFC with increase in fuel blends is the additional consumption of bio-diesel fuel by the test engine in order to maintain constant power output. On the other hand, the fuel pump of the engine delivers fuel in volumetric basis. Since the density of blended fuels is higher than that of diesel, the plunger in the injection pump discharges more blended fuel compared to that of diesel to maintain constant output power. This trend could be as a result of lower calorific value and higher density of the blended fuels. Among these properties, the calorific value is one of the most important properties of a fuel, because it drastically affects the thermal efficiency of the system. The practical diesel engine combustion chamber systems are only suitable when the calorific value of the fuel is high. This tends to reduce the fuel quality being handled by the system and maximizes the equipment operating range. It is always desirable for the vegetable oils have a calorific value closer to that of diesel as stated by Murugesan et al. [15]. Since the calorific value up to B30 blend of POME, NOME, and WCOME were closer to that of diesel, lesser fuel consumption were noted with these blends than the higher blends. Similar findings were noted with BSFC in the experimental study conducted by Purushothaman and Nagarajan [16] and Tsolakakis et al. [17].

4.3 Exhaust emissions

CO, CO₂, HC, NO_x, and smoke are considered to be the major exhaust emissions from C.I. engines. From the above-mentioned emissions, NO_x and smoke are the most significant emissions from a diesel engine that has to be controlled efficiently due to higher flame temperature and diffusive combustion in the combustion chamber. The diesel engine produces lesser amount of CO and HC emissions than spark ignition engines. Moreover, in case of bio diesel fueled engines, presence of airborne oxygen as well as its presence in the molecules of bio-diesel aids nearly complete combustion of fuel. From the above analysis, we have presented the NO_x and smoke emissions in the following sections.

4.4 Oxides of nitrogen emissions

The oxides of nitrogen in the exhaust emission are the combination of nitric oxide (NO) and nitrogen dioxide (NO₂). The formation of NO_x is highly dependent on in-cylinder temperature, oxygen concentration in the cylinder, and dependent on engine technology. Oxides of nitrogen are mostly created from the nitrogen in the air and in fuel blends. In addition to nitrogen atoms, the fuel may contain Ammonia (NH₃) and Hydrogen Cyanide (HCN), which would contribute to a minor degree in the NO_x formation. In general, the NO_x concentration varies linearly with the load of the engine. As the load increases, the overall fuel-air ratio increases resulting in an increase in the average gas temperature in the combustion chamber and thus higher NO_x. The variation of oxides of nitrogen emissions with respect to brake power is depicted in Figures 8 to 10 for diesel and bio diesel-diesel blends. Figures 8 to 10 show the variations of oxides of nitrogen (NO_x) emission in parts per million (ppm) with brake power for POME, NOME, and WCOME, and its blends. The NO_x emission of diesel at maximum load was noted to be 960 ppm, whereas for B100 of POME, NOME, and WCOME it was noted to be 823 ppm, 890

ppm, and 840 ppm, respectively. This reduced NO_x emission for B100 bio diesel when compared to diesel may be due to the reduced premixed combustion rate leading to lower NO_x emissions for B100 bio diesel operation. Moreover, B100 fuel had exhibited high viscosity during tests in comparison to other fuel blends, which primarily resulted in a lower amount of air entrainment and to poorer combustion leading to lower combustion temperatures. Similar results were observed in the previous research findings of Agarwal and Agarwal [18], and Patterson et al. [19].

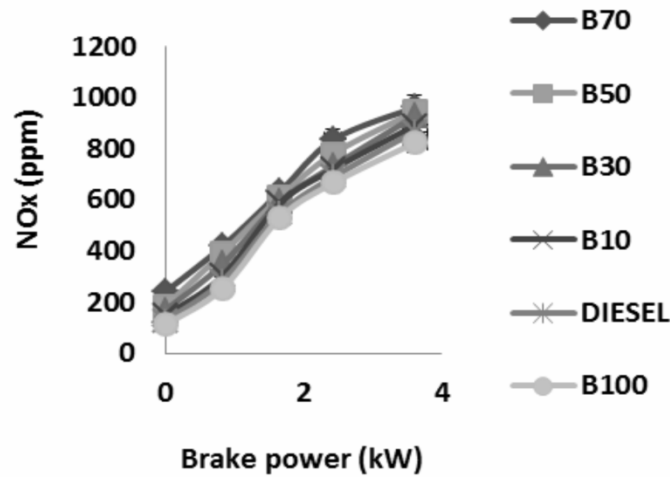


Figure 8. The Variation of NO_x Emissions for POME

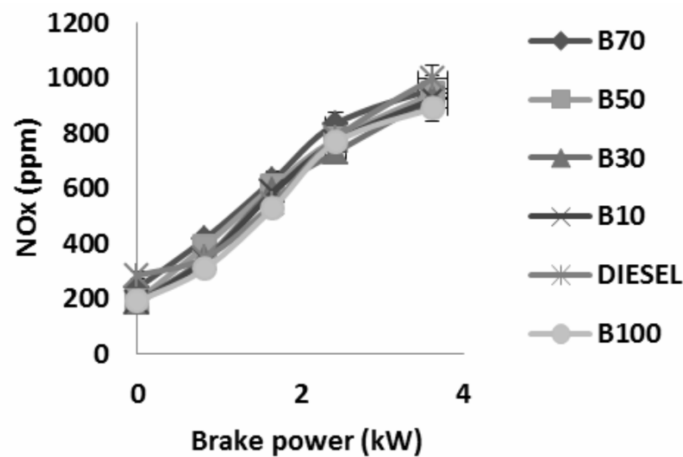


Figure 9. The Variation of NO_x Emissions for NOME

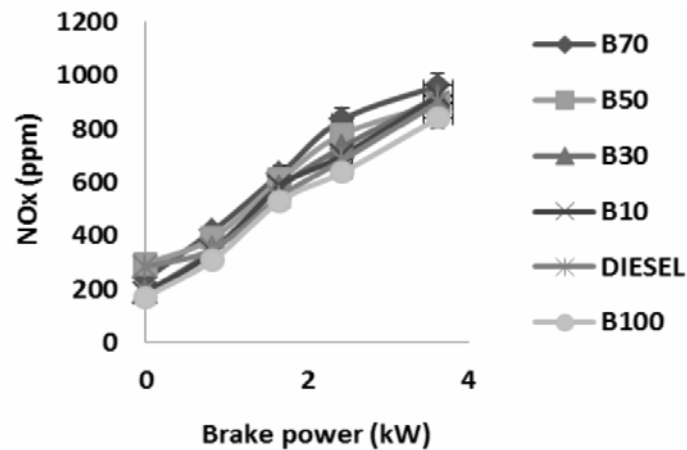


Figure 10. The Variation of NO_x Emissions for WCOME

However, emissions were noted to be higher for blended fuels compared to B100 and diesel at full load. When the blend ratio increases NO_x emissions also increased. This increase in NO_x is attributed to differences in the compressibility of the diesel fuel and bio diesel blends, which results in inadvertent advance in dynamic injection timing when bio diesel blends are used in the engine. Apart from this, the bio diesel has longer combustion duration compared to diesel resulting in higher exhaust temperature. The disassociation of NO_2 into N_2 and O_2 is suppressed by the higher temperature leading to formation of higher quantity of NO_x in bio diesel blends fuelled engines. These results are in good association with the earlier studies reported by Patterson et al. [19]. Some of the researchers like Qi et al. [20] found lower NO_x emissions for bio-diesel fuelled engines due to the variations in the engine geometry, compression ratio, the less reaction time, and temperature found with bio-diesel. In addition to this, studies conducted by Saleh [21], Khalid Al-Qurashi et al. [22], Rajasekar et al.[23] Pradeep and Sharma [24] and Deepak Agarwal et al.[25] suggested that the Exhaust Gas Recirculation (EGR) technique can be incorporated with C.I. engines to effectively reduce NO_x emissions without disturbing performance characteristics.

4.5 Smoke emissions

The smoke opacity of the diesel engine exhaust is said to be a visible indicator of the combustion process. Compared to other harmful and invisible emissions, smoke is more irritating and could cause nuisance. The variations of smoke emissions with respect to brake power are depicted in Figures 11 to 13 for POME, NOME, and WCOME, and their blends with diesel. The variations of smoke emissions are given in Hartridge Smoke Unit (HSU). For all test fuel blends, the smoke emission increased with increase in brake power. The high smoke emission is a suggestive of an incomplete combustion and the amount of smoke present in the exhaust gas is measured to quantify the particulate matter present in the exhaust gas [26].

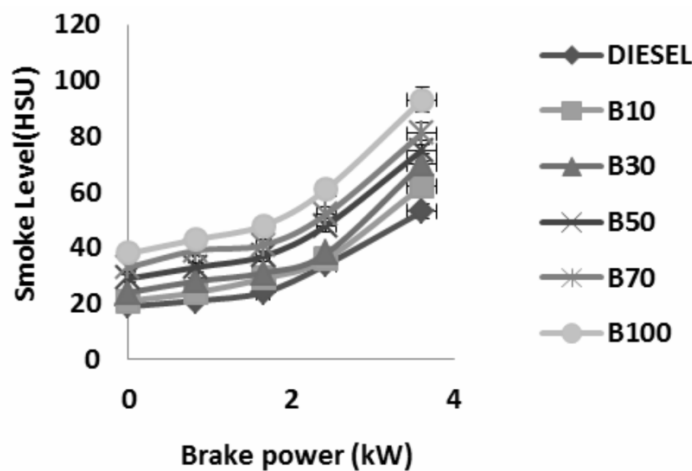


Figure 11. The Variation of Smoke Opacity for POME

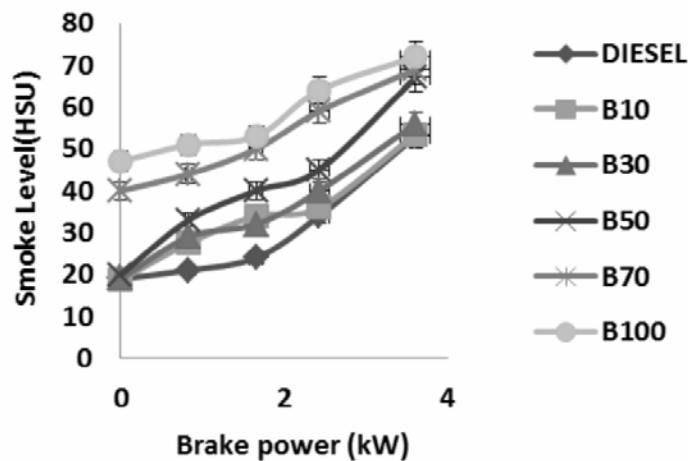


Figure 12. The Variation of Smoke Opacity for NOME

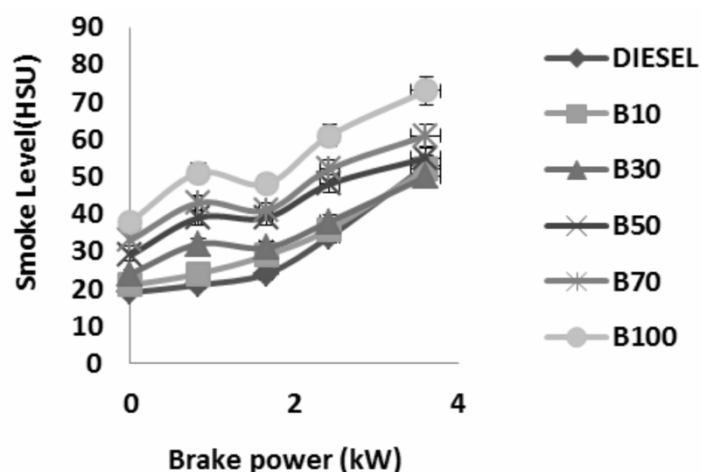


Figure 13. The Variation of Smoke Opacity for WCOME

The smoke emission of diesel at maximum load is 53 HSU, whereas for B100 of POME, NOME, and WCOME it was 93 HSU, 72 HSU, and 73 HSU, respectively. This increased smoke emission for B100 in comparison with neat diesel may be due to higher viscosity and lower volatility resulted in poor mixture formation, causing higher smoke emissions. Another possible reason is that the unblended bio diesel (B100) has a heavier molecular structure, which leads to poor atomization of fuels, thereby increasing smoke emissions. Yet, another reason is a higher viscosity of B100, which decreases the fuel jet Reynolds number, leading to larger mean fuel droplet size and decrease in fuel-air mixing rate, thereby increasing the emission at higher blend (B100) as noted by Barsic and Humke [27]. Similar findings for increase in smoke opacity were revealed by Devan and Mahalakshmi[28]. However, in the experimental study the smoke emissions were lower for the blended fuels as compared to B100 at full load. When the blend ratio decreased, smoke emissions also decreased due to better combustion of fuel. This may be due to the lower viscosity of blended fuels, which lower the smoke emissions as noted by Banapurmath et al. [29] and Kalam et al. [30].

Table 2: Engine technical Specification

Make	Kirloskar AV 1
Type	Four stroke, Single cylinder, vertical, Water cooled.
Bore	80 mm
Stroke	110 mm
Speed	1500 rpm
Power	3.7 kW (5 h.p).

5. Combustion analysis

The combustion analysis of diesel and bio diesel-diesel blends was carried out with the assistance of pressure transducer (AVL/GM12D Air Cooler), combustion analyzer (AVL 619 Indimeter), and software (Indwin-software version 2.2). The experimental observations of performance and emission analysis have proved that the prepared bio diesel can be used in the form of blends up to 30% with diesel. On the other hand, an optimum characteristic value was noticed up to B30 WCOME fuelled engine than B30 NOME and POME. Based on the above particulars, the combustion analysis is focused on B30 WCOME and the noted readings are presented here.

Figures 14 and 15 depict the variation of cylinder pressure and instantaneous heat release rate for diesel, B30, and B100 WCOME at full load and at standard injection timings (23° BTDC). One could observe from the plots that the highest peak pressure (66.182 bar) and higher premixed combustion heat release rate ($57.496 \text{ kJ/m}^3 \text{ deg.}$) are evident for diesel, whereas B30 WCOME operation in the engine exhibited a combination of lower maximum pressure rise (63.4 bar) and relatively slow heat release rate (51.67

kJ/m³deg.) when compared to diesel. However, the curves of in-cylinder pressure and heat release rate for B30 bio diesel are closer to diesel curve. In contrary, the observed values for B100 are noted to be lower than B30 blend and diesel. One possible explanation for this reduced pressure and heat release rate for B100 bio diesel is its lower heating value and larger molecular mass when compared to diesel. Another possible reason for this trend could be the lower mechanical stress induced in the crank drive due to the slow burning rates promoted by blended fuel.

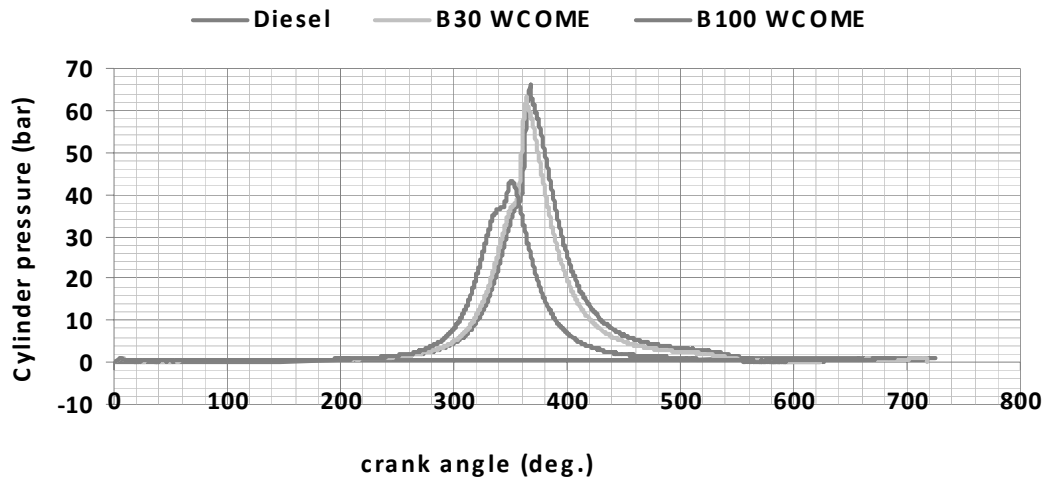


Figure 14. The variation of cylinder pressure with crank angle

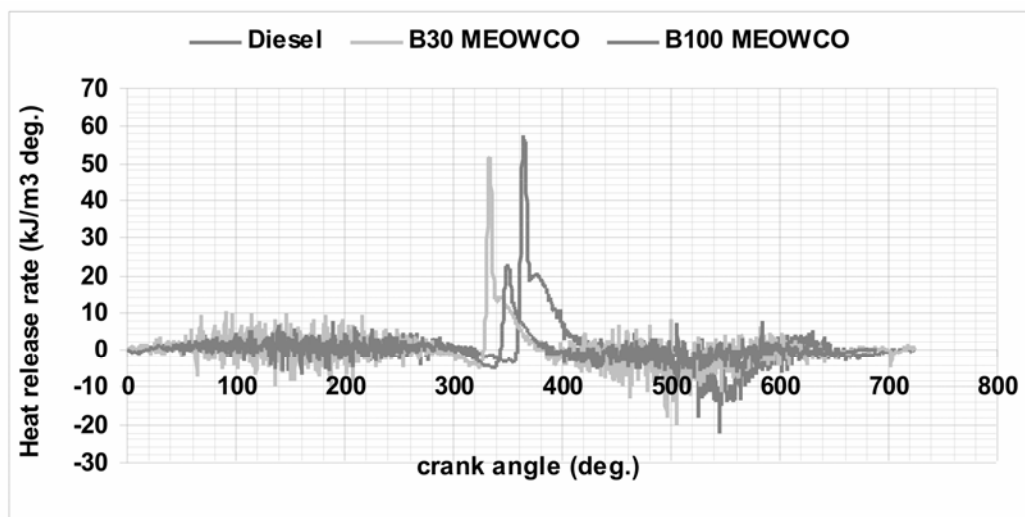


Figure 15. The variation of heat release rate with crank angle

6. Conclusion

The experimental results proved that up to B30 blend of bio diesel-diesel blends, the performance and emission characteristics were not much affected. When the blend ratio increased, incomplete combustion takes place because of less time available for mixture formation, which leads to a reduction in the brake thermal efficiency of the engine as well as an increase in the emission level. Based on the experimental work the following key points have been derived,

- The fabricated bio diesel production unit has the ability to produce the bio diesel yield of about 80 to 96% based on the nature of the oils and reactants.
- Nearly same power output was noticed in all blends with slightly reduced brake thermal efficiency because of the lower heating values of bio diesel fuels.
- The engine performance with all three bio diesel up to B30 blend is nearly similar to that of diesel.
- Methyl esters of Punnai, neem, and waste cooking oil can be directly used as fuel for diesel engine in the pure form (B100) without much modification for short-term only, because there is a drastic increase in smoke emission as compared to diesel fuel.

- The NO_x emission of B100 bio-diesel operation showed lower values for all three methyl esters compared to neat diesel and other blended fuel. Though, B100 bio diesel operation in engine showed lower NO_x emissions, it cannot act as a better surrogate to diesel fuel since use of B100 as fuel possess problems like poor fuel atomization, ring sticking, engine liner scuffing, etc., due to its higher viscosities.
- The combustion analysis revealed that the overall combustion characteristics of B30 bio diesel blends were closer to diesel than pure bio diesel.
- Overall, the methyl esters of waste cooking oil proved improvements in performance and emission characteristics than the methyl esters of Punnai and Neem due to its closer physical and thermochemical properties to neat diesel.

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