Effects of Mixing Two Non-edible Biodiesels on Performance and Emission of CI Engine

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1 Introduction

As a species, humanity has adapted remarkably well to the whims of the environment. We have been fortunate enough to inherit a world containing a ready source of fuel in the form of fossilized organic matter [1]. This buried treasure has enabled humankind to survive harsh environments and drastic climate changes. It has helped us prosper on the tide of cheap energy powering our lives [2]. Consumption of fossil fuels and their derived products is ruinous to the environment, economy, and therefore, every living being's health [3].

The supply chain dynamics of crude oil hold many countries hostage to the petroleum market's whims [4]. For example, at the time of this writing, we face a pandemic that prevents the free movement of products due to restrictions to slow the spread of infection in communities. The covid-19 pandemic currently affecting most of the world has revealed the fragile supply chains that most countries are dependent on [5]. Plant-based biodiesel is a better option among all available alternative fuels since it is renewable, biodegradable, environmentally friendly, and domestically available [6]. Hence, biodiesel is an excellent candidate for the same. Locally produced biodiesel can provide a fillip to agriculture, employment, and the local economy [7].

1.1 Non-edible Plant Seed Oil

Non-edible oils are considered second-generation feedstocks for the production of biodiesel [8]. An investigation regarding single biodiesel with diesel has been carried out and reported their potential to be alternative diesel fuel. Some of the non-edible seed oil sources explored by researchers are Karanja [9], Neem [10], Jatropha [11], Bilva, Cottonseed [12], Moha, Saemuruba [12]. There is minimal literature about mixing two biodiesels with diesel as a fuel blend in the CI engine. Inadequate investigations on dual biodiesel as an alternate fuel to diesel are worth reconnoitering.

The FFA content in non-edible seed oil is higher than in edible seed oil due to triglyceride molecules presence in a large percentage. Triglycerides are chemically treated to separate fatty acid esters (biodiesel) and glycerin using a two-phase catalytic reaction. The fatty acid compositions of biodiesel derived from these feedstocks presage desirable variations in their physicochemical properties. The percentage of FFA affects the fuel

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properties, considerably influencing engine performance and emission characteristics [10]. NO_x and CO_2 in biodiesel emissions appear in higher percentages than in diesel, but the more toxic HC, CO, and smoke were lower [13]. The utilization of biodiesel in an engine is reported to reduce engine wear by 30% because of their additional lubricity [14]. Based on the literature survey, the CI engine performance with biodiesel is on the negative side compared with diesel when used in the existing engine [8].

In the present investigation, the domestically available Pongamia pinnata (Karanja) and Neem seed oil extracts respective methyl esters. The physicochemical properties of vegetable oil-derived biodiesels are examined, and their suitability as fuels in a diesel engine is determined. The standard test procedures are followed for testing biodiesel and validated based on the values of the ASTM D6751 standard for biodiesel [15]. The results indicated that the mixture of two biodiesel exhibited favorable improvement in their properties like calorific value and density regarding single biodiesel [16]. Fuel blends B00, B10, B20, B30, B40, and B100, are prepared for experimentation, and their composition is as listed in Table 1. Engine performance is gauged based on the amount of fuel consumed by the engine at different loading conditions while maintaining a constant speed. Furthermore, the engine performance is justified by heat generation after air-fuel combustion. Engine exhaust analyzer is used to detect emissions like NO_x, CO and HC in the exhaust gas.

Table 1 Dual biodiesel fuel blends

Blends	Blend composition (% volume)		
	Pongamia pinnata biodiesel	Neem biodiesel	Diesel
B00	0	0	100
B10	5	5	90
B20	10	10	80
B30	15	15	70
B40	20	20	60
B100	50	50	0

2 Experimental Setup and Procedure

The production procedure of biodiesel and the properties of biodiesel blends produced are estimated to check their feasibility as fuel in an engine according to ASTM Standard testing method are discussed in this section. And the experimental setup of the CI engine test rig used for the present investigation.

2.1 Production of Biodiesel and Properties of Biodiesel

Oil extracted from the Pongamia pinnata and Neem seeds is dense as it has an FFA content of more than 4%. A two-step catalytic reaction can reduce the density of crude seed oil [17]. The first step is to treat the crude seed oil with methanol and an acid catalyst. This pretreatment of seed oil with an acid catalyst is called esterification. Step two involves chemical modification of pretreated oil by transesterification to produce fatty acid methyl esters (FAME) or biodiesel. The FAME extracted from Pongamia Pinnata seed oil is called Pongamia methyl esters or Pongamia biodiesel. Furthermore, the esters extracted from Neem seed oil are called Neem methyl esters or Neem biodiesel.

After the transesterification process, FAME derived from plant seed oil has a much lower viscosity, making it capable of replacing petroleum [18]. The triglyceride present in oil reacts with alcohols like methanol to produce FAME, called transesterification. A base catalyst like sodium hydroxide is used to speed up the reaction to form fatty esters and glycerin [19]. Figure 1 represents a triglyceride composed of three long-chain fatty acids with a glycerin base. The number of these FFA determines the characteristics of the produced biodiesel.

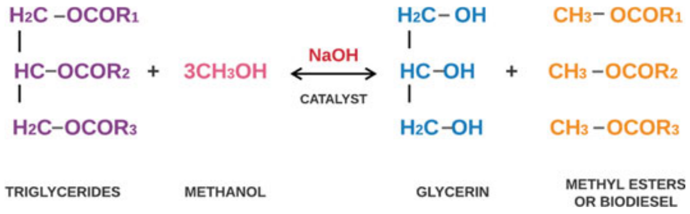

Fig. 1 Representing chemical reaction in the transesterification process

The estimated properties of biodiesels and diesel with the help of the test methods approved by ASTM standards are listed in Table 2. The blends are prepared with different compositions of Neem biodiesel and Pongamia pinnata biodiesel with diesel. The properties of dual biodiesel blends like the flashpoint and calorific value are improved, as shown in Table 2.

2.2 Engine Specification

It consists of a single-cylinder CI engine, cooled using water, and computerized to capture data. An eddy current dynamometer is employed to vary the torque and achieve different loading conditions.

The test rig used for this experiment is represented in Fig. 2, and its specification is listed in Table 3. The engine was kept in running condition for around 20 min before taking the readings with every fuel blend. The exhaust gas analyzer indicates the different engine exhaust emissions.

3 Results and Discussion

3.1 Engine Performance Analysis

The analysis of the subject engine's performance is characterized based on a speed of 1500 rpm is maintained at different load conditions. A variety of fuel blends are used

Table 2 Physiochemical properties of diesel and biodiesel with ASTM D6751 fuel standard

Fuel name	Density (kg/m^3)	Flashpoint (°C)	Kinematic viscosity cSt at 40 °C	Calorific value (kJ/kg)
Pongamia biodiesel	876	178	6.72	37,000
Neem biodiesel	870	76	5.64	35,010
B00 or pure diesel	824	50	2.30	42,850
B10	828	53	2.85	41,500
B20	833	56	3.22	41,880
B30	837	58	4.37	41,120
B40	842	60	5.35	39,400
B100	873	110	6.24	36,100

to collect data relating to performance and efficiency. Fuel consumption and thermal efficiency of prepared blends were compared with diesel as a benchmark. There were three iterations of this experiment for all fuel modes to ensure accuracy, and the error bars are included while plotting the results.

Brake-Specific Fuel Consumption (BSFC). Figure 3 demonstrates the impact on BSFC for the six fuel modes at all load conditions. The BSFC is higher at a lower engine load due to high engine speed and lower in-cylinder temperatures [20]. The higher in-cylinder temperature results in increased atomization of fuel and a better air-fuel mixture, thereby decreasing BSFC.

Fig. 2 Photographic view of the test engine's rig

Table 3 Test engine specifications

Particulars	Specifications
Make	Kirloskar
No. of cylinder	1
Bore	80 mm
Stroke	110 mm
Injection pressure	190 bars
Compression ratio	16.5:1
Dynamometer	Eddy current
Type of cooling	Water-cooled
Rated speed	1500 rpm
Rated power	3.75 kW

From Fig. 3, the BSFC decreases with an increase in engine loading and tends to stabilize for all fuel modes at maximum load. The BSFC of the CI engine for fuel blend B00 (100% diesel) was observed to be 0.39 kg/kW-hr at full load condition. The BSFC with dual biodiesel blends B10 and B20 was 0.37 kg/kW-hr and 0.36 kg/kW-hr, lower than diesel. The higher cetane number and fire point of dual biodiesel blends reduce the physical ignition delay during the combustion phase [21]. The BSFC with blend B30

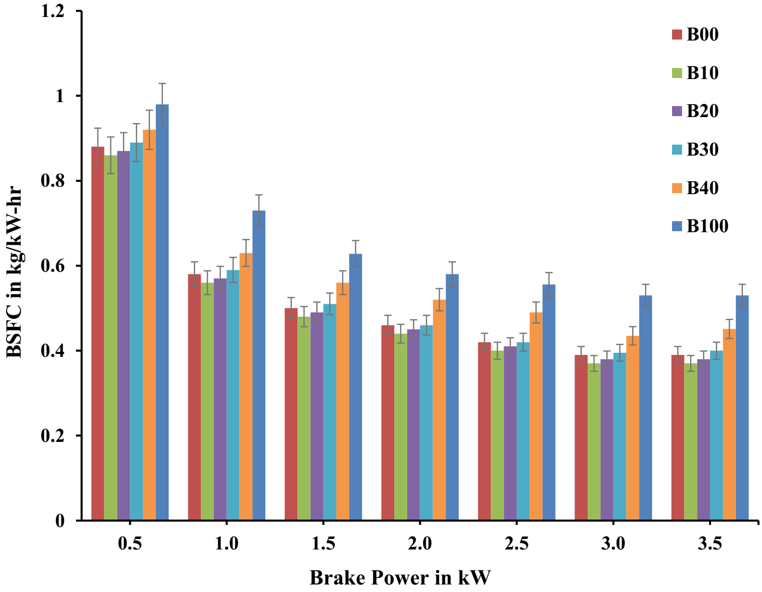

Fig. 3 BSFC for all the prepared blends versus brake power

was observed to be 0.40 kg/kW-hr, marginally higher than diesel. This might be due to the lower calorific value of the B30 blend when compared with diesel [22]. The lower energy content of the esters in biodiesel increases the BSFC of the engine.

Further, with the increase of biodiesel percentage in the fuel blends, the BSFC increases. BSFC for blends B40 and B100 was 0.45 kg/kW-hr and 0.58 kg/kW-hr, higher than diesel due to the ester's lower energy content. The dual biodiesel blend can be used in CI engine for up to 30% of diesel without any engine modifications.

Brake Thermal Efficiency (BTE). The impact of brake power on the BTE of an engine under all load conditions is represented Fig. 4. BTE is lower at lower loads due to higher engine speed and BSFC [23]. BTE is higher at higher loads because of the increased temperature inside the combustion chamber.

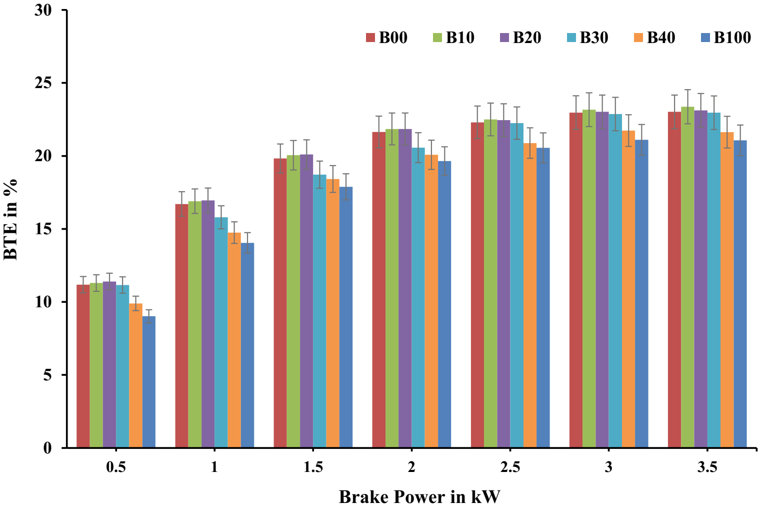

Fig. 4 BTE for the prepared fuel blends

The BTE was 23.02% with blend B00 or diesel at full load condition. The BTE of blends B10 and B20 is 23.21% and 23.17%, marginally higher than diesel due to oxygenated biodiesel in the fuel blend. When blended with diesel, the oxygenated biodiesel enhances the fuel's complete combustion ability and increases the BTE with a drop in BSFC. The BTE of blend B30 was 22.56%, slightly lower than diesel. The BTE of blends B40 and B100 was 21.63% and 20.07%, respectively. The diesel dilution in the higher biodiesel blends results in lower energy release due to the burning of low energy biodiesel esters. Lowering the energy released after combustion will lower the in-cylinder temperature and peak pressure, causing reduced BTE [24].

3.2 Engine Emissions

The significant components of emissions from diesel engines such as NO_x, CO, and unburnt HC that have exited out of the combustion chamber are graphically represented for different fuel modes at various load conditions.

NO_x Emission. The influence of brake power on the emissions of oxides of nitrogen with dual biodiesel blends is represented in Fig. 5. The graph demonstrates the presence of NO_x in the engine exhaust at different loads. The NO_x emission increases with increasing load for each dual biodiesel blend [20]. It is clear from the graph that the dual biodiesel blends tend to emit higher levels of NO_x. Higher exhaust gas temperature and oxygen in fuel with dwelling time at higher load conditions contribute to higher NO_x emissions in the blends.

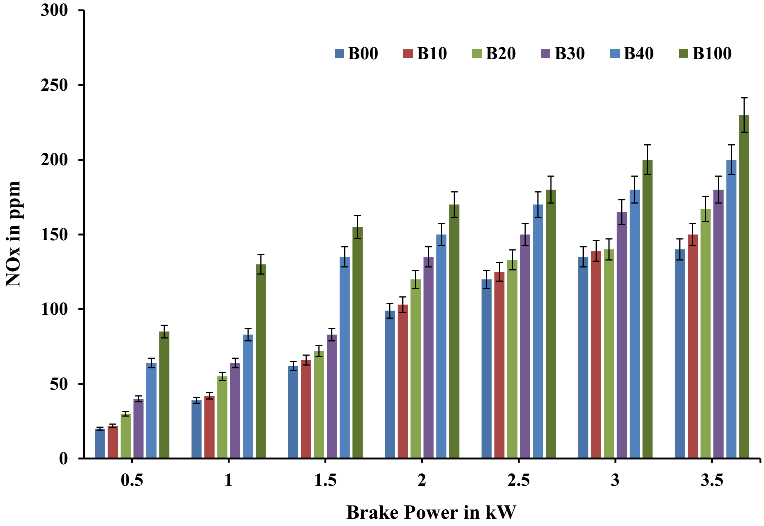

Fig. 5 NO_x emissions in exhaust versus brake power

CO Emission. The effect of brake power deviation on carbon monoxide emission at all load condition is shown in Fig. 6. CO content present in engine exhaust increases with an increase in load conditions. An increase in engine load leads to a corresponding rise in combustion temperature and increases CO emissions. A paucity of oxygen and lowered cooling time leads to partial combustion and generates CO.

HC Emission. The variant brake power effect on unburnt hydrocarbon emission is as shown in Fig. 7. HC emission is directly proportional to load, brake power, and indirectly proportional to temperature and oxygen availability [16]. Longer ignition delays mean that fuel combustion time is lowered, and HC emissions display an uptick. At part-load condition, HC emissions are 55 ppm for B00 or diesel, 45 ppm for B10, 40 ppm for B20, 38 ppm for B30, 35 ppm for B40, and 37 ppm for B100. HC emission in comparison to diesel is dropped in 18.18% with B10, 27.27% with B20, 30.9% with B30, 36.36% with

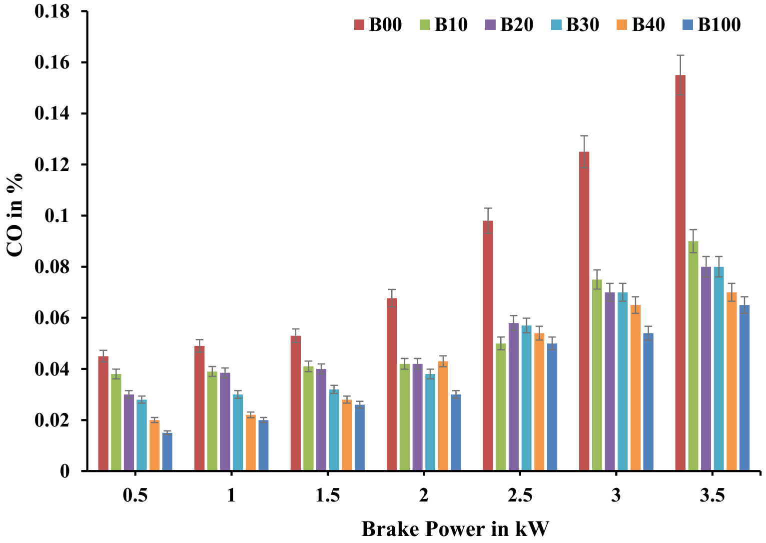

Fig. 6 Impact of CO emission with brake power

B40, 32.7% with B100. When compared with biodiesel blends, a diesel fuel exhibits a longer ignition delay.

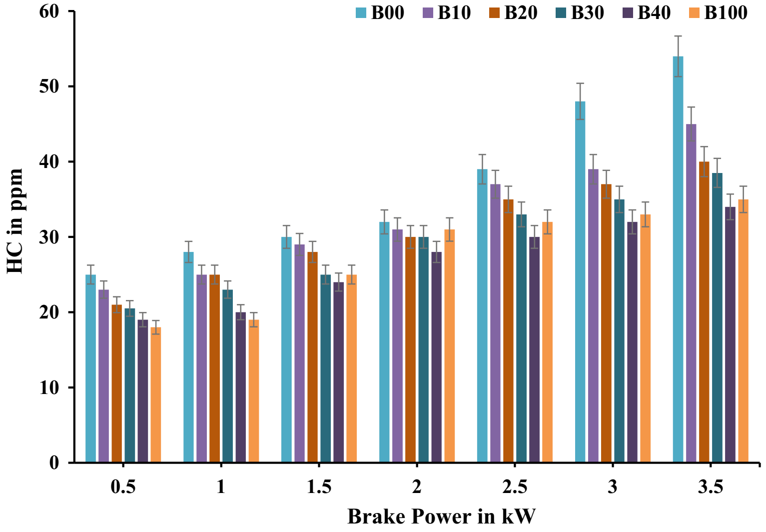

Fig. 7 Variant brake power effect on unburnt HC emission at different fuel modes

4 Conclusions

Dual biodiesel blends of Pongamia pinnata, Neem and regular diesel are used as fuel in a single-cylinder diesel engine. The results obtained are subject to analysis for their performance and emission characteristics.

- No modifications to the diesel engine were necessary to accommodate the utilization of a dual biodiesel blend.
- Properties of Pongamia pinnata and Neem biodiesel after chemically modified with transesterification are in the range of ASTM standards and can be used as an alternative to replacing fossil fuel.
- From the experimental analysis, dual biodiesel blends B10, B20, and B30 have BSFC and BTE values strikingly close to those of the diesel.
- The dual biodiesel blends have lesser CO and HC emissions than that diesel at all load conditions.
- The emission of NO_x from dual biodiesel blends was higher than that of diesel.

From this investigation, it could be summarized that biodiesel derived from Pongamia pinnata and Neem oil blended with diesel has the potential to be fuel in a conventional diesel engine. Dual biodiesel can be used as a substitute to diesel in the ratio of up to thirty by volume, which is B30 could be used without significant compromise to the engine performance and emissions. It also provides the opportunity to combine the biodiesels and not limit ourselves to one feedstock of biodiesel.

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