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Engine Performance Test Evaluation of Biodiesel Blends from Castor Seed Oil at Varying Mixture Ratios and Engine Speed

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ABSTRACT
The global demand for petroleum products, coupled with concerns over environmental impact and the instability of the oil market, necessitates exploring alternative fuels from renewable sources. This study investigates the engine performance of biodiesel blends derived from castor seed oil, focusing on varying mixture ratios and engine speed. With its renewable and environmentally friendly characteristics, castor oil is explored as a potential substitute for mineral oil in industrial applications. The study includes the trans-esterification process of castor oil into biodiesel and assesses the engine performance parameters using a single-cylinder diesel engine. Blends of pure castor oil methyl ester (COME) and diesel fuel ranging from B10 to B50 were investigated, complying with ASTM specifications. Results indicate that higher engine speed corresponds to increased brake power (BP) and improved brake thermal efficiency. Notably, the B20 blend demonstrated superior BP at high speeds. Blend composition influenced the fuel consumption rate (FCR), with B20 exhibiting better performance at maximum speed. Also, brake thermal efficiency peaked at B20 due to enhanced lubricity and oxygen content. Exhaust gas temperature (ExGT) and nitrogen oxide (NOx) emissions were assessed, revealing lower NOx emissions in B20 and a correlation between ExGT and NOx levels. The study underscores the potential of castor oil-based biodiesel blends as viable alternatives in sustainable energy solutions.

Keywords: Engine efficiency, Biodiesel, Blend, Fuel Consumption rates, Gas emission

INTRODUCTION
Energy has a great and major effect on every socio-economic activity. However, the rapidly growing global, industrial and domestic demand for petroleum products, the consequent depletion of crude oil reserves, adverse environmental concerns and the unstable nature of the international oil market make the need to explore alternative fuel options from locally available renewable resources to become imperative (Al-Widyan and Al-Shyoukh, 2002). For this reason, a deliberate diversification to achieve a wider energy supply mix will no doubt ensure greater energy security for Nigeria (Oyewunmi, 2017) and the world at large. Consequently, the search for environmentally friendly materials that can substitute mineral oil in various industrial applications is currently considered a top priority in fuel and energy management research. This is largely due to the rapid depletion of world fossil fuel reserves and increasing awareness of environmental pollution from excessive mineral oil use and its disposal. A renewable resource such as vegetable oil is considered a potential replacement for mineral oil base stocks in certain fuel applications where immediate contact with the environment is expected. The non-toxic and biodegradable characteristic of vegetable oil is that it is

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environmentally friendly due to its less effect and danger to human health and the entire environment, particularly as a result of emission from automobile exhausts and oil spillage during disposal (Mobarak et al., 2014; Srivastava and Sahai, 2013).

Bio-based oil is the most valuable form of renewable energy that can be used directly in petrol or diesel engines. It is a substitute for or an additive to diesel fuel that is derived from vegetable seed oil such as Castor seed, Jatropha seed, Soyabean seed, Cotton seed, Neem seed, Sunflower seed etc. (Demirbas, 2009)

Intensive production and commercialisation of biodiesel from edible-grade sources have raised some critical environmental concerns. Alternative oilseeds are being investigated as biodiesel feedstocks to mitigate these environmental consequences. Castor (*Ricinus communis L.*) is one of the most promising non-edible oil crops due to its high annual seed production and yield and since it can be grown on marginal land and in semiarid climates. Still, few studies are available regarding its fuel-related properties in its pure form or as a blend with Petrodiesel, many of which are due to its extremely high Ricinoleic acid content (Berman et al., 2011). In this study, the specifications in ASTM D6751 and D7467, which are related to the fatty acid composition of pure castor methyl esters (B100) and its blend with Petro diesel in a (10-50) % vol ratio (B10-B50)) were investigated.

Several studies have considered biodiesels and their corresponding influence on engine performance. Examples included the studies of Kaisan et al. (2021) and Sulaiman et al. (2023). The research gap, however, stills lies in the lack of comprehensive investigation into the engine performance and emissions characteristics of castor oil-based biodiesel blends, particularly focusing on the interaction between blend composition, engine speed, and various performance parameters.

METHODOLOGY

Materials and Reagents

All chemicals and reagents used in this study were analytical grades. The castor seeds were obtained from National Research Institute for Chemical Technology (NARICT). The seeds will represent the local Nigerian breed of castor (small seed type). Before oil extraction, seeds were oven dried at 70 °C for 72 hr to remove excess moisture. Castor oil was attained by cold-pressing castor seeds with an industrial press. The unrefined castor oil was filtered with a plate filter of pore size 0.5 mm). B10-B50 blends were achieved by blending 10% vol pure Castor oil Methyl Esther (COME) in 90% Diesel fuel and 50% vol pure COME in 50% diesel fuel, respectively, at 10% vol intervals.

Methods

Trans-Esterification

Trans-esterification is a way of converting Castor oil to biodiesel. The Castor oil undergoes three stages of trans-esterification reaction to overcome its high acid value. During trans-esterification, potassium hydroxide (KOH) was added to methanol in a mixer and stirred for 10 to 15 minutes until completely dissolved. It was then mixed with the castor oil in a reactor equipped with a heater and magnetic stirred at 70 °C. Stirring was continued, and the product was placed in a separating funnel and left for 24h for glycerin to settle to the bottom of the funnel and then removed in a measuring cylinder. The impure methyl ester (biofuel) was washed with Sulfuric acid (98% concentration) and distilled water to remove impurities such as diglyceride and monoglyceride, catalyst, soap, and excess methanol before drying in the furnace at 150 °C for two hours. Lastly, the biodiesel was kept in a beaker and sealed with aluminum foil to prevent contamination. This is similar to the methodology adopted by Alleman et al. (2016) and Demirbas (2009).

Engine Experimental Runs

A four-stroke single-cylinder diesel engine with mechanical rope brake loading was used for this study. It is a single-cylinder, four-stroke, vertical, water-cooled engine having an engine specification as shown in Table 1. It has a provision for loading through a rope brake dynamometer. The inlet valve opens at 50 degrees before the top dead centre and closes at 35.50 degrees after the bottom dead centre; the exhaust valve opens at 35.50 degrees before the bottom dead centre and closes at 4.50 degrees after the top dead centre. The engine was tested with pure diesel and prepared blends of castor biodiesel at different loading and speed variations. The engine was started with commercial diesel fuel and warmed up. The warm-up period ends when the cooling water temperature is stabilised. Fuel consumption, brake power, brake thermal efficiency, and exhaust gas temperature was measured along with CO_2, CO, SO_2 and NO_x for pure diesel and various blends of castor methyl ester with diesel. Three (3) runs each was carried out for the pure diesel control and various blends B10-B50 at different speed of (1000, 1200 and 1400) revolution per minute (rpm). The gas analyser was connected to the engine's exhaust with the aid of a pipe which fits into the exhaust. When the machine switched on, it was left to recalibrate before the engine started. This method is in line with the method employed by Panwar et al. (2010).

Table 1: Engine Specification

BHP	5
Rated Speed	1500rpm
Number of cylinders	One
Compression ratio	16.5:1
Bore	80mm
Stroke	110mm
Orifice diameter	20mm
Type of ignition	Compression ignition
Method of loading	Rope brake
Method of starting	Crank start

RESULTS AND DISCUSSION

Brake Power (BP)

The brake power developed by the engine on different speed conditions, from 1000 rpm to 1400 rpm, is presented in Fig. 1. As the speed increases, the BP developed by the engine increases for all biodiesel blends. At maximum speed, i.e. 1400 rpm, the B20 blend developed 7.14% more BP when control, B10, B30, B40 and B50 blends were used, respectively. The results concluded that the biodiesel blend B20 developed more BP at higher speeds.

The observed increase in brake power for the B20 blend can also be linked to the oxygen content in biodiesel. Biodiesel molecules contain oxygen, which can enhance combustion by promoting complete fuel oxidation (Hoang, 2021). This property contributes to improved energy release and, consequently, higher brake power. However, it's important to note that biodiesel's oxygen content and other chemical characteristics can vary based on feedstock and production methods, which may influence the extent of power improvement observed (Venu et al., 2021).

Fuel Consumption Rate (FCR)

Fig. 2 illustrates the relation between applied speed and the fuel consumption rate. As the speed increases, the fuel consumption rate decreases, but during the study, the fuel consumption rate at various speeds was found to be lesser for control than blended fuel. It may be due to the decrease in the overall calorific value of fuel by increasing the blend percentage. At the maximum speed, i.e. 1400 rpm, B50 shows 42.5%, 21.3%, 21.3%, 12.8% and 6.4% more fuel consumption rate than control, B10, B20, B30, and B40, respectively. In overall prospect, the fuel consumption rate is improved at maximum speed in blend B20.

One possible explanation for this phenomenon is related to the overall calorific value of the fuel. As the blend percentage of biodiesel increases, the calorific value of the fuel may decrease due to the lower energy content of biodiesel compared to diesel (Sudalaiyandi et al., 2021). This decrease in energy content could result in a higher fuel consumption rate for blended fuels than pure diesel, as observed in the study and also observed by Elkelawy et al. (2021)

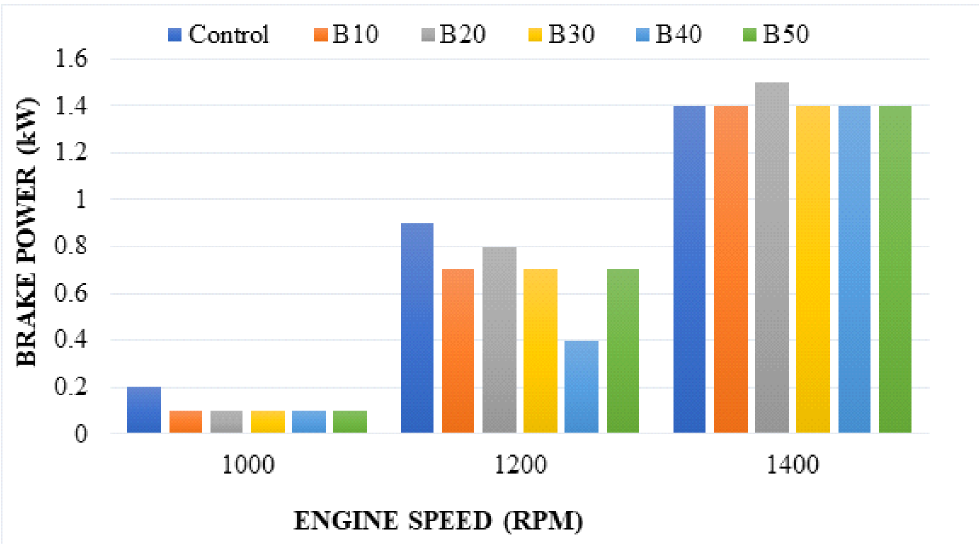

Fig. 1: Variation of Brake Power of COME-Biodiesel blend against Engine speed.

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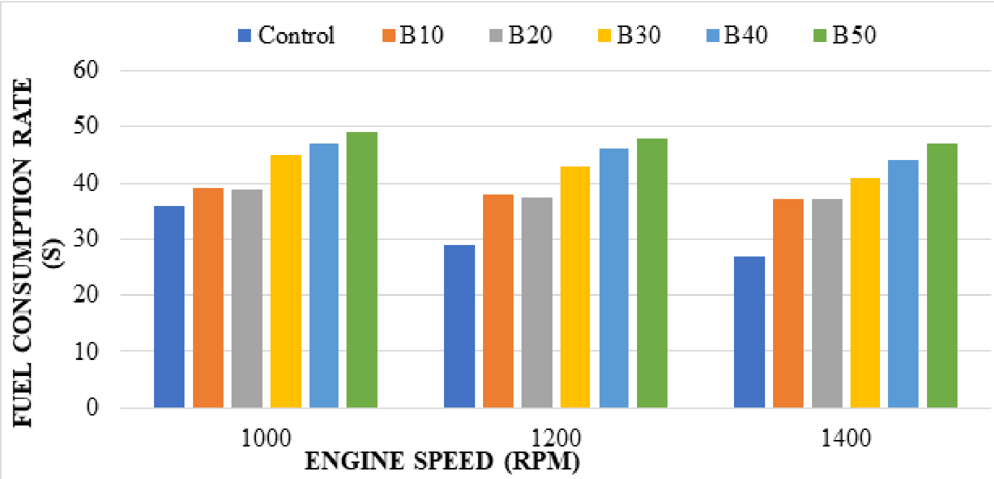

Fig. 2: Variation of fuel consumption rate of COME-Biodiesel blend against

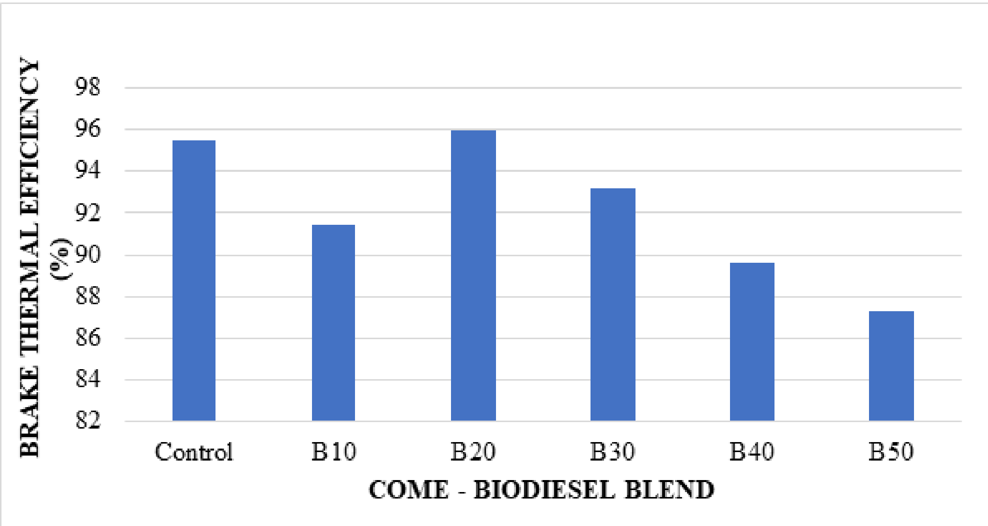

Fig 3: Variation of Brake thermal efficiency against COME-Biodiesel blend at 1400 rpm

Brake Thermal Efficiency

Fig. 3 shows the variation of brake thermal efficiency with respect to speed at 1400 rpm for different blends. The maximum brake thermal efficiency at 1400 rpm speed is about 96 % for B20, which is 0.5%, 4.6%, 2.8%, 6.4% and 8.7% higher than that of control, B10, B30, B40 and B50, respectively. Hence B20 yields good thermal efficiency compared to control, B10, B30, B40 and B50. Initially, the engine's thermal efficiency was improved with increasing concentration of the biodiesel in the blend. The possible reason for this is the additional lubricity provided by the biodiesel. This aligns with the studies of Awang et al. (2021) and Suthisripok and Semsamran (2018), who observed that the molecules of biodiesel (i.e. methyl esters of the oil) contain some amount of oxygen, which takes an active part in the combustion process. It is noticed that after a certain limit of B20 for the diesel ester blend, the thermal efficiency trend was reverted, and it started decreasing as a function of the concentration of the blend. This lower brake thermal efficiency was obtained for B50, possibly due to reduced calorific value and increased fuel consumption compared to B20 (Ramadhas et al., 2005).

Exhaust gas temperature (ExGT) and Nitrogen gas (NOx) emissions

Fig. 4 shows nitrogen oxide (NOx) emission for pure diesel (control) and different biodiesel blends in relation to exhaust gas temperature. It is well known that vegetable-based fuel contains a small amount of nitrogen. This contributes towards NOx production. In the case of B20, NOx emission is lower than control by 18.8%. NOx concentration increased with the load and attained a maximum of 39 parts per million (ppm) at B50.

It is found that the exhaust temperature (ExGT) increases with an increase of COME in blends and is higher than that with diesel for all blends at 1400 rpm. Also, a corresponding increase in NOx emission is observed. This may be due to higher combustion chamber temperature, indicated by the prevailing exhaust gas temperature. With an increase in exhaust gas temperature value, NOx emission also increased. That is why biodiesel fuel has the potential to emit more NOx as compared to that diesel-fueled engines (Kadu and Sarda, 2011; Chhina et al., 2005; Lapuerta et al., 2008; Deshmukh and Bhuyar, 2009).

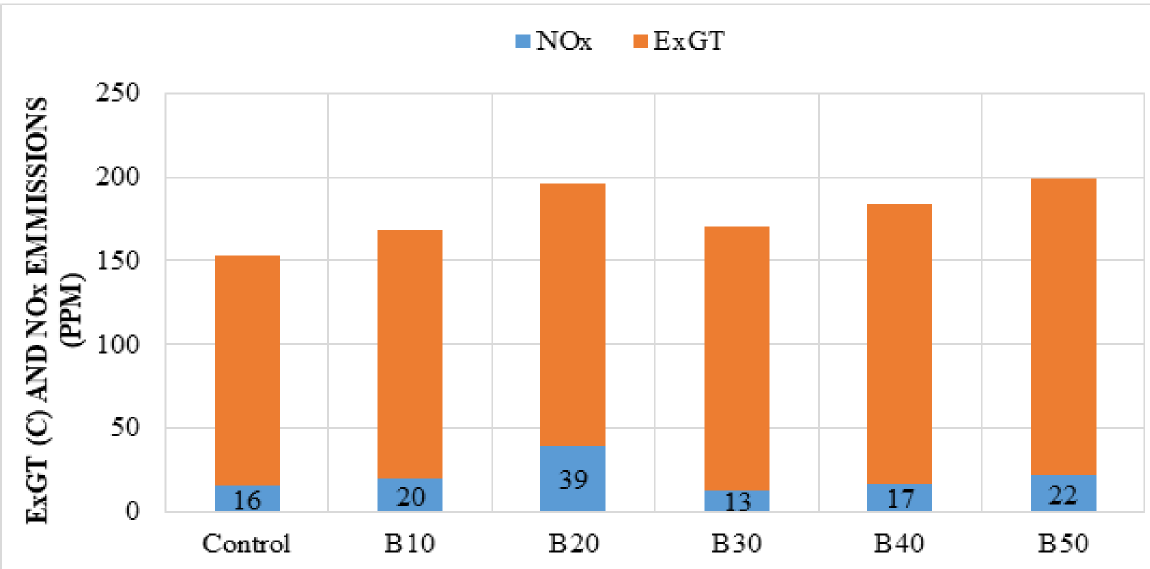

Fig 4: Variation of ExGT (C) and NOx emissions (PPM) against COME-Biodiesel blend at 1400 rpm

CONCLUSIONS

This study has provided valuable insights into the engine performance characteristics of biodiesel blends derived from castor seed oil, focusing on Castor Oil Methyl Ester (COME) as a key component. The findings presented herein contribute to understanding the intricate interactions between COME blend composition, engine speed, and critical performance parameters.

Although the calorific value of pure COME is lower than that of diesel by about 15%, the blend B20 exhibits a calorific value of about 45.50 MJ/kg that is only 2 % lower than that of diesel, Brake power of 1.5kW, fuel consumption rate of 37s, brake thermal efficiency of 96%, an exhaust gas temperature and NOx emission of 157 °C and 13 parts per million (ppm) respectively. In this study, B20 gives the best performance characteristics in CI engines.

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