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Effect of PME and JME B10 Biodiesel-Blends on Fuel Properties and Diesel Engine Performance

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ABSTRACT

The research is to investigate the effect of B10 biodiesel-blends from Palm Oil Methyl Ester (PME) and Jatropha Oil Methyl Ester (JME) on the fuel properties and diesel engine performance. Tests have been carried out to measure the fuel properties of the blended fuels (J10D90, P10D90, and J5P5D90) such as density, kinematic viscosity and calorific value compared with D100 pure diesel as base fuel. The experiments were performed with single cylinder four-stroke diesel engine at constant engine load of 3 Nm and variation engine speeds from 1000 to 3000 rpm at 500 rpm interval, thus to obtain the brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE). The results of fuel properties show that blend J10D90 have the highest density and kinematic viscosity which were 3% and 4% higher than base fuel respectively. The result shows that BSFC is increased with the increase of density and kinematic viscosity. The BSFC increased 16% when engine fuelled with J10D90 as compared with base fuel at 3000 rpm and constant engine load of 3Nm. In contrast, BTE is decreased 20% as compared with base fuel at same engine test condition. This is due to high viscosity which led to poor fuel atomization and mixing process. In conclusion, the blending of fossil fuel with PME and JME led to changes in several fuel properties which significantly improved the engine performance.

Keywords: B10; PME; JME; fuel properties; diesel engine

INTRODUCTION

The depletion of fossil fuel sources and a corresponding increase in its price together with the escalating demand of the fuels have inspired the pursuit for renewable sources of energy such as alternative fuels and even developing new energy storage for electromotive to achieved zero carbon emission (Ansari et al. 2022). Thus, alternative biofuels must be developed in order to overcome the escalating worldwide fossil fuel consumption. Biodiesel continues to play an important role in the transition toward more sustainable energy systems, especially when compared to other options. Biodiesel such as Palm Oil Methyl Ester (PME) and Jatropha Oil Methyl Ester (JME) is acknowledged as great potential to replace fossil fuel since biodiesel is biodegradable, oxygenated and renewable. In fact, biodiesel is economically feasible and environment friendly (Hanamesha 2023; Tatieli et al. 2023). Furthermore, biodiesel has a great potential to reduce the dependency on non-renewable sources that will drain in near future (Eman & Adzhim 2015).

According to ASTM D6751 and EN 14214, biodiesel is defined as a locally manufactured alternative fuel for diesel engines made from the edible and non-edible oils of rapeseed, soybean, palm, and jatropha that meet these standards (Yasin et al. 2017). In general, biodiesel comprises alteration of the oil which is long and branched chain triglyceride molecules in methyl ester (Fok et at. 2012). Biodiesel is actually a biodegradable fuel consist of fatty acid methyl ester and produced from the vegetable oil or animal fats transesterification (Ali et al. 2015). Biodiesel receiving attention most of the researchers due to its similar fuel properties as compared to base fuel and compatibility with diesel fuelled engines (Senthilkumar et al. 2015). The performance of differences in fuel blends, especially in the context of biodiesel blends can be quite complex. These differences are influenced by a variety of factors, ranging from fuel composition to engine characteristics.

The characteristics and properties of biodiesel fuel influenced by various plants feed stock, type of soil, health and maturity of plant (Ali et al. 2015). Source of biodiesel affected the physical and chemical properties of the biodiesel fuel. These properties of fuel have direct relation with the performance of the engine. Kinematic viscosity, density and calorific value are among parameters that can affect the performance and emissions of the diesel engine. Most of recent studies have reported that blended fuel exhibits better fuel properties as compared to base fuel (Ali et al. 2014; Abdullah et al. 2015). The performance of biodiesel fuel blends can vary significantly depending on factors such as the percentage of biodiesel in the blend, the engine type, the type of feedstocks, and the specific operational conditions such as ambient and engine temperature, and load. While higher biodiesel blends like B50 and B100 may offer substantial environmental and engine health benefits (such as reduced particulate emissions and improved lubricity), they can also lead to slightly reduced power output, lower fuel economy, and increased NOx emissions.

Biodiesel is not as effective as fossil fuel because it reduces the diesel engine performance. Furthermore, the real properties of biodiesel that can lead to diesel engine performance reduction remain unclear as a research on JME fuel highlighting its potential to improve performance and reduce emissions compared to traditional diesel, particularly when combined with internal air jet piston technology (Jaichandar et al. 2019). Kumar et al. (2024) unveiled the pros and cons of biodiesel in shaping the future of engine fuels explores the benefits and drawbacks of biodiesel while considering future developments for engine fuels. The study covers unregulated emissions, including Polycyclic Aromatic Hydrocarbons (PAHs) and Volatile Organic Compounds (VOCs), and aims to provide a general overview of how biodiesel applications affect engine performance and emissions. While biodiesel presents a promising alternative to diesel with environmental benefits, it also faces challenges that need to be addressed through further research and development. The careful selection of feedstock and improvements in production techniques are essential for maximizing its potential in the automotive sector.

The use of biodiesel presents a number of difficulties, such as its compatibility with current infrastructure and engine technology and production costs, which might differ according on location, climate, and competing feedstock usage. Since there are less studies that attempt to thoroughly evaluate the effects of biodiesel on engine power, performance, and emissions, Nguyen et al. (2023) offer a thorough understanding of the physicochemical characteristics of biodiesel that influence engine performance and emission characteristics. This turns into a significant obstacle to the spread of this promising energy source. A study by Stănescu et al. (2025) evaluated the performance and emissions of a compression ignition engine fueled with biodiesel blends from used cooking oil and sunflower oil, finding that up to 20% biodiesel concentration can balance engine performance and reduced emissions without engine modifications. The study indicates that biodiesel blends from used cooking oil and sunflower oil reduce brake power and torque, with a maximum reduction of 3.18% for SF50 compared to diesel, while increasing brake specific fuel consumption at higher concentrations.

Therefore, the objective of this research is to investigate the effect of B10 biodiesel-blends from different feedstock such as Palm Oil Methyl Ester (PME) and Jatropha Methyl Ester (JME) to be compared with base fuel D100 on the fuel properties and diesel engine performance. The scope of this research covered on several parameters which are fuel properties and engine performance. The fuel properties studied on this research are kinematic viscosity, density and calorific value. The engine performance parameters measured are brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE).

METHODOLOGIES

This section discusses on the preparation of sample, equipment and apparatus that are used for the fuel properties test, experimental work and uncertainty analysis. Standard reference atmospheric conditions must be used for engine performance testing. However, it is difficult to consistently sustain this condition. Observing the net power and torque to ascertain the difference between the reference fuel conditions, standard reference atmospheric conditions, and those observed during testing requires the application of a correction factor in order to provide a consistent level of evaluation. The SAE J1349 Surface Vehicle Standard Engine Power Test Code supplied this common foundation for comparison. Uncertainty was assessed for the instrumentation and physical quantity error analysis in the current experimental investigation.

TABLE 1. Engine Specifications

No	Items	Specifications
1	Type of Engine	Air-cooled 4-stroke OHV
2	Model of Engine	Robin Diesel Engine DY-23-2D
3	Displacement of the Piston	230 cm^3
4	Bore × Stroke	70 mm × 60 mm
5	Maximum Output	4.8 HP (3.5 kW)@3600 rpm
6	Continuous Output	4.2 HP (3.1 kW)@3600 rpm
7	Maximum Torque	10.5 Nm @ 2200 rpm
8	Combustion System	Compression Ignition with Direct Injection
9	Fuel	Diesel Light Oil
10	Fuel Tank Capacity	3.2 litres
11	Starting system	Recoil starter
12	Compression Ratio	21:1
13	Injection Nozzle	ZEXELDLLA150PN052
14	No. of Injection Hole(s)	4 (0.22 mm in diameter)
15	Injection Opening Pressure	195 kg/cm^3
16	Injection Timing	23^o before TDC
17	Lubrication Oil Capacity	0.9 litre

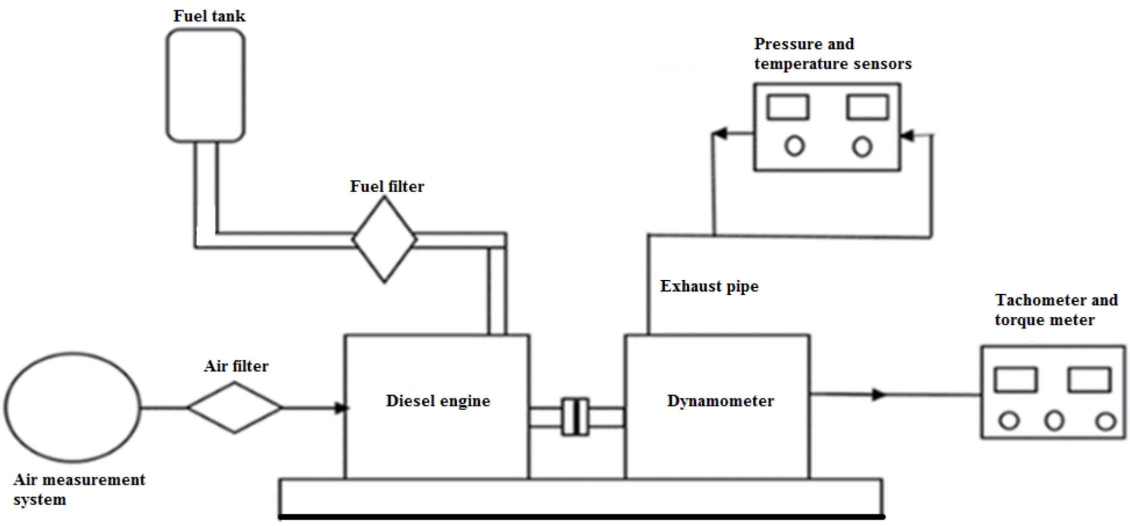

FIGURE 1. Schematic Diagram of Single Cylinder Four-Stroke Diesel Engine

(a) (b)

FIGURE 2. Preparation of Samples and Properties Tests, (a) Magnetic Stirring, and (b) Viscometer

(a) (b)

FIGURE 3. Properties Tests, (a) Bomb calorimeter, and (b) Digital Density Meter

SAMPLES PREPARATION

All the activities in this research were carried out at the Universiti Teknologi MARA. The blends of PME B10 and JME B10 were done by splash blending process. The samples of blended fuel were prepared by using an electrical magnetic stirrer as shown in Figure 2(a). The PME and JME were mixed together with the D100 pure petroleum diesel by using the stirrer.

The blending process is done at low rate of stirring and constantly for about 20 minutes. The blended fuels are left for another 30 minutes at room temperature after the stirring process is done in order to allow the mixture to reach an equilibrium state. There are three types of B10 blended fuel that has been prepared which are J10D90 (10% JME + 90% D100), P10D90 (10% PME + 90% D100) and J5P5D90 (5% JME + 5% PME + 90% D100).

FUEL PROPERTIES TESTS

The fuel property measurements were done in a laboratory under controlled temperatures and humidity in order to ensure accuracy. Three types of test were carried out which are kinematic viscosity, calorific value, and density. All samples were tested three times to obtain the average value. The kinematic viscosity was determined by using a kinematic viscosity bath viscometer based on the ASTM D6751 as shown in Figure 2(b). The Viscometer tube used is 75-K970 and the tube constant is 0.00728 mm2/s. The Viscometer is stabilized and calibrated to ensure the temperature is constant at 40ºC.

Meanwhile, the calorific values of blended fuels were measured by an oxygen bomb calorimeter according to minimum value of 35 MJ/kg in EN 14214 as in Figure 3. The density tests were conducted by using portable density meter at 15℃ according to the standard ASTM D6751. The digital density meter works based on fundamentals of the oscillating U-tube method. The blended fuel is filled into the U-tube and the mass from the fuel resulted in oscillation of the tube. The change in frequency of the oscillations caused by the mass is used to measure the relative density of the fuel. The low frequency of the oscillation indicates the high density of the sample.

ENGINE TESTING PROCEDURE

Table 1 and Figure 1 displays engine specifications and a schematic diagram of a small single cylinder four-stroke diesel engine which is Robin Diesel Engine model (DY-23-2D), respectively, equipped with 5kW S-DEC-1 model electric dynamometer. The experiment is carried out three times for all samples at constant 3 Nm engine load with engine speeds ranging from 1000-3000 rpm at 500 rpm interval. The low constant load is setup as to replicate low load of vehicle. Research in low-torque conditions helps optimize urban fuel consumption and reduce emissions during stop-and-go driving, which is common in cities (Fan et al. 2022; Dmytrychenko & Artemchuk 2024).

Due to measurement error which associated with various investigational measurements and variable derivation, each result might differ from the actual value. Testing strategy, selection, condition, instrument calibration, environment, observation, and reading can all be sources of investigation errors and uncertainties. The accuracy of the experiment must be validated using uncertainty analysis.a robustness stability analysis to the model parameter uncertainties is performed for the mass air flow and the manifold absolute pressure of an experimental Diesel engine (Mone et al. 2021).

RESULTS AND DISCUSSION

FLUID PROPERTIES

Kinematic viscosity is one of important properties that can affect engine performance and exhaust emissions. The use of fuel that has high kinematic viscosity may lead to poor atomisation and wear in the fuel system elements (Fok et at. 2012, Lv et al. 2024). Poor atomisation will result in inefficient combustion which lead to higher BSFC, and lower BTE.

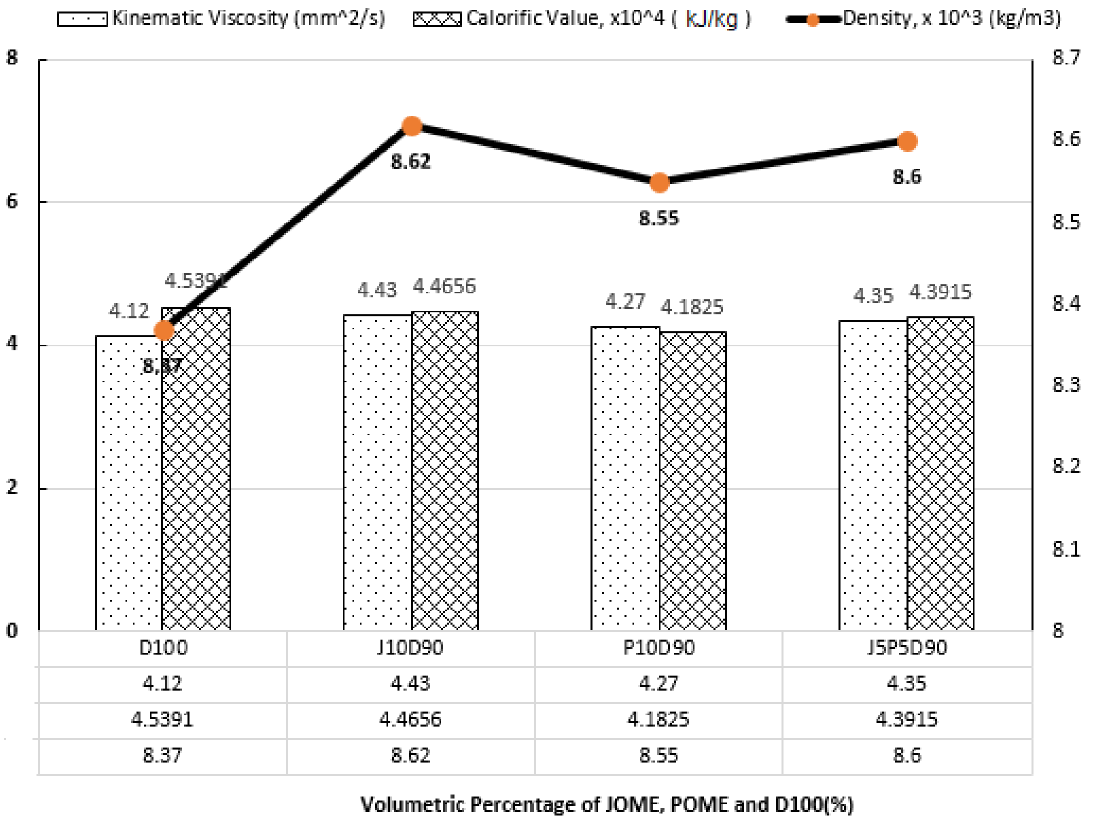

FIGURE 4. Variation of Blended Fuel Properties Compared to D100

Figure 4 shows that D100 has the lowest kinematic viscosity compared with blended fuels which is 4.12 mm²/s. Meanwhile, J10D90 has the highest kinematic viscosity with 7.5% as compared to D100. For P10D90 and J5P5D90, the increase of kinematic viscosity values are about 3.6% and 5.6% respectively as compared to D100. However, kinematic viscosity values for all fuel samples satisfied the requirements of ASTM D6751 standard (max. 6.0 mm²/s). In overall, the addition of PME and JME into the D100 resulted to the increase in kinematic viscosity of the mixture.

Calorific value is defined as the value of heating energy discharged by combustion of a unit value of fuels (Ali et al. 2015). Lower calorific value can lead to higher amount of fuel required to be introduced to the cylinder which will result in higher BSFC. The base fuel D100 has the highest calorific value with 45.391 MJ/kg. The blend that has the lowest calorific value is P10D90 which is 7.9% as compared to base fuel. Meanwhile, blend J10D90 and J5P5D90 also displayed small reduction in calorific value which is 1.6% and 3.3% respectively as compared to base fuel. Calorific value is not specified in the ASTM D6751.

However, the standard requirement of EN 14213 stated that the minimum value for calorific value is 35MJ/kg. Therefore, the results of calorific values met the standard requirement since all values were above the minimum standard. In overall, the addition of PME and JME in the D100 has resulted in reduction of calorific value of the mixture.

Density is one of important properties of fuel that can affect overall engine performance. Higher density will result in poor evaporation rate which lead to poor mixing process resulting in poor combustion. This may increase the engine BSFC. The base fuel has the lowest density which is 837 kg/m^3 as shown in Figure 4. Meanwhile, J10D90 has the highest density which is 3% as compared to base fuel. Similarly, both J5P5D90 and P10D90 also had slight increase in density which is 2.7% and 2.3% respectively. The density of all samples is quite similar with small percentage difference and the values were in the range of 837 to 862 kg/m^3. In fact, the values satisfied the standard requirement of ASTM D6751 (max. 880 kg/m^3). In overall, the addition of PME and JME in the base fuel has resulted in slight increment in density of the fuel.

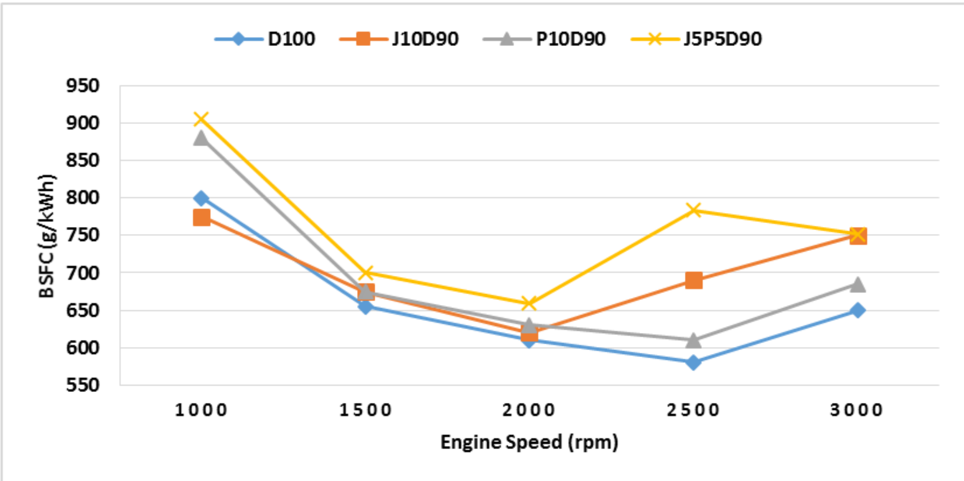

FIGURE 5. BSFC against variation of engine speeds at constant engine load of 3Nm

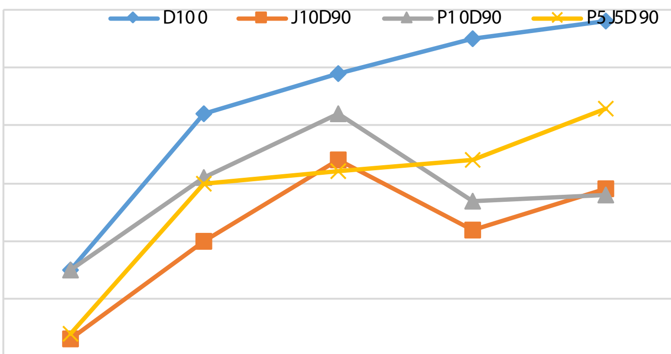

FIGURE 6. BTE against variation of engine speeds at constant engine load of 3Nm

TABLE 2. Uncertainty Parameters (Sapee, 2022)

Name of Instrument and Sensor Type	Variable Measured	Range of Instrument	Accuracy	Uncertainty (%)	
				Min	Max
Load Cell (S-Type)	Load (kg)	0-500	±1.0	-0.5	0.5
Weighing Scale	Fuel Weight (kg)	0.04 - 6.0	±0.02	-0.1	0.1
Thermocouple (Type-K)	Temperature (°C)			-0.3	0.3
Calculated Parameters					
BSFC				-0.1	0.1
BTE				-0.1	0.1

BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

The variation of BSFC for all fuel samples with respect to the engine speed is shown in Figure 5. The BSFC decreased with the increase in engine speed from 1000 to 2000 rpm. Meanwhile, BSFC increased when the engine speed increased from 2000 to 3000 rpm. Based on the graph, all biodiesel-blended fuels have resulted in higher BSFC compared to pure diesel. J5P5D90 has the highest BSFC compared to other blends as well as D100 at all engine speeds. Meanwhile, base fuel resulted in lowest BSFC for low and high engine speed condition. For J5P5D90, the BSFC increased 13.2% and 35.17% at speed of 1000 rpm and 2500 rpm respectively as compared to D100. For J10D90 and P10D90, the BSFC at low engine speed are comparable to the D100.

However, at high engine speed, the BSFC of J10D90 is increased to 16% as compared to the D100. BSFC of blended fuel is higher than D100 due to higher kinematic viscosity, density and lower calorific value of biodiesel. Higher kinematic viscosity results in poorer fuel atomisation and mixing process which lead to poor combustion process. The increase in BSFC is also due to high density which caused fuel injector to introduce the fuel with higher flow rate (Mawaa et al. 2014, Łagowski, 2020). Furthermore, lower calorific value leads to higher amount of fuel to be introduced to the cylinder in order to attain similar maximum brake torque (Jalaludin et al. 2015). In overall, blended fuel resulted in higher BSFC than D100 due to several fuel properties such as kinematic viscosity, density and lower calorific value.

Biodiesel has a lower calorific value and higher viscosity than diesel, resulting in higher brake specific energy consumption as stated in a recent literature by Ashfaque et al. (2023). They also acknowledge the challenges associated with biodiesel which need more exploration through further research and development. As for example, alcohol such as ethanol may be used to blend with biodiesel as to improve performance and lower emission in a small high compression ratio engine with low efficiency (Rashid et al. 2016).

BRAKE THERMAL EFFICIENCY (BTE)

The brake thermal efficiency (BTE) can be defined as the ratio of thermal energy available in the fuel to the power that engine supplies the crankshafts (Ganesan, 2014). The BTE exhibited an increment when the engine speed rose from 1000 rpm to 3000 rpm as shown in Figure 6. At all engine speeds, the D100 has the highest BTE. Meanwhile, J10D90 has the lowest BTE at both high and low engine speed conditions. It shows BTE decreased by 11.4% and 20% at speed of 1000 rpm and 3000 rpm respectively as compared to D100. The reduction of BTE was primarily due to higher kinematic viscosity of the blended fuel as compared to D100. When fuel at higher kinematic viscosity, it may lead to poor fuel atomisation and mixing process resulting in poorer combustion and caused reduction in BTE (Mawaa et al. 2014).

Besides, higher density and lower cetane number of the fuel resulted to higher ignition delay and greater fuel consumption, and decreased the BTE of the engine. The other reason that caused reduction of BTE is deficient of air which resulted by incomplete combustion. In overall, blended fuel resulted in lower BTE as compared to D100 is due to several fuel properties such as kinematic viscosity, density and cetane number (Mawaa et al. 2014).

The results emphasize the importance of feedstock selection for biodiesel production. Different feedstocks can significantly affect the properties of the biodiesel produced, which in turn influences the engine performance. This provides insights into various feedstocks and their characteristics, indicating that careful selection is crucial for optimizing biodiesel quality and performance (Ashfaque et al. 2023). As a future research directions, it can be concluded with a call for further research to address the challenges associated with biodiesel, such as its lower energy content and performance issues. It suggests that advancements in production methods and feedstock selection could enhance the viability of biodiesel as a mainstream fuel alternative in the automotive sector. Despite its reported reduction in engine performance, offers several advantages that make it a compelling alternative to conventional diesel fuels. As a renewable and cleaner fuel, biodiesel significantly reduces emissions of harmful pollutants, contributing to environmental sustainability.

UNCERTAINTY ANALYSIS

In the experimental work, uncertainty was evaluated for the error analysis of instrumentation and physical quantities. The accuracy and uncertainty of instruments and calculated parameters are shown in Table 2. The evaluation included the values and uncertainty of the engine parameters in subsequent operating cycles of a diesel-fuelled compression ignition engine. According to Bąkowski & Radziszewski (2015), analysis of combustion chamber pressure deviations from the mean values helped identify disturbance that affected the given signal. The impact of this disturbance can be checked for the parameter uncertainty and the coefficient of variation. Probst et al. (2016) employed a sequential design of experiments (DOE) to optimize diesel engine operating points, revealing significant variations in fuel consumption and emissions due to parameter uncertainties. Their findings highlight the importance of sensitivity analysis in understanding the impact of design parameters.

CONCLUSION

From the experiment, it can be concluded that the addition of the PME and JME to the D100 has resulted in increased of kinematic viscosity, lower calorific value and higher density as compared to D100. Blended fuel resulted in higher BSFC is due to fuel properties characteristic. High kinematic viscosity resulted in a poorer fuel atomisation and high density caused fuel injector to introduce the fuel with higher flow rate, hence increases the BSFC. Besides, lower calorific value of biodiesel led to higher amount of fuel to be introduced to the cylinder and resulted in higher BSFC.

Blended fuel resulted in lower BTE due to high kinematic viscosity which lead to poor fuel atomisation resulting in inefficient combustion. Moreover, higher density of blended fuels may lead in higher ignition delay and greater fuel consumption, and therefore decreases the BTE of the engine. The overall results show that the blended fuel resulted in higher BSFC and lower BTE due to change of kinematic viscosity, density and calorific value.

In a nutshell, the blending of PME and JME to the D100 resulted in changes in fuel properties which significantly influences the engine performance. While biodiesel may offer significant environmental benefits through reduce emissions, it also presents challenges in terms of engine performance that need to be considered via further research and development.

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DECLARATION OF COMPETING INTEREST

None.

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