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Effect of B30 Palm Oil Methyl Ester Biodiesel with Isobutanol Fuel Additive on Engine Performance of a Diesel Engine

N.H. Badrulhisam[1,2,3]*, N. E. Frere[1], I. M. Yusri[2,3]*, A. Adam[2,3], W Sawangsri[4]

[1] *Centre for Advances Engineering Design, Faculty of Engineering, Build Environment, and Information Technology, SEGi University, 47810 Petaling Jaya, Selangor, MALAYSIA*
[2] *Centre for Automotive Engineering, University Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, MALAYSIA*
[3] *Faculty of Mechanical and Automotive Engineering Technology, University Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, MALAYSIA*
[4] *Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University, Chatuchak, Bangkok 10900, THAILAND*

*Corresponding Author: yusri890@yahoo.com/yusriismail@umpsa.edu.my
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Abstract

Modern society is concerned about pollution and fossil fuel depletion. Many studies examined biodiesel substitution. Renewable diesel fuel, known as "biofuel", is derived from vegetable oils, animal fats, and grease. Based on the ASTM D7567, the highest ratio of biodiesel that can be used without modification is up to B20. The problem arises if the biodiesel ratio is higher than B20. More than B20, the engine performance will degrade. However, biodiesel's ability to run on diesel engines without modification makes it appealing, but it may affect engine performance and emissions because of its higher cetane number and lower volatility. These qualities can affect diesel combustion and fuel injections, producing less power and higher nitrogen oxides (NOx). Thus, this research uses palm oil and isobutanol fuel additives to boost engine performance and exhaust emissions. This experiment uses fuel samples of 5%, 10%, 15%, and 20% isobutanol and POME (B30). The diesel fuel sample acted as the baseline fuel of the experiment. The engine performance parameters including brake power, brake specific fuel consumption, and torque. Isobutanol can enhance the performance of biodiesel fuel, particularly at higher speeds. B30ISO20 consistently exhibited the highest brake power with an increment of 8% and the lowest brake-specific fuel consumption with an improvement of 26.55% compared to diesel, respectively. The torque of the fuel sample improved as much as 8% with the addition of isobutanol, especially at higher concentrations of B30ISO20.

1. Introduction

In 1900, an inventor fueled his engine with peanut oil, one of the first examples of biodiesel. Biodiesel is now generally recognised as a renewable fuel with strategic, environmental, and technological benefits over biomass, bioethanol, and biogas [1], [2]. Biofuels derived from vegetable oil have the benefit of being a sustainable, yearly renewable source of automotive fuel. As compared to diesel gas oil, using vegetable oil fuels is troublesome owing to combustion performance, molar ratio point, bio-fuel mix, antioxidants on deterioration, and high oxygen concentration. To meet the strict emission standards of the future, it is essential to reduce emissions of diesel vehicles running on palm oil-based biodiesel [3]. Biodiesel is a mono-alkyl ester produced by transesterification of vegetable oils or animal fats (including oil palm, soybean, sunflower, olive oil, or rapeseed oil) [4], [5]. The limitation of oil reserves, the worldwide increase in fuel costs, as well as a growing understanding of the possible pollution associated with the usage of petroleum fuels, have strategies for implementing biodiesel blends as sustainable, ecological, and alternative fuels in recent decades [6], [7]. As seen in Fig 1, shows the contributing factors that lead to the utilisation of biofuel as alternative energy to solve the dependency on petroleum diesel resources as diesel fuel for the compression ignition (CI) engine [8].

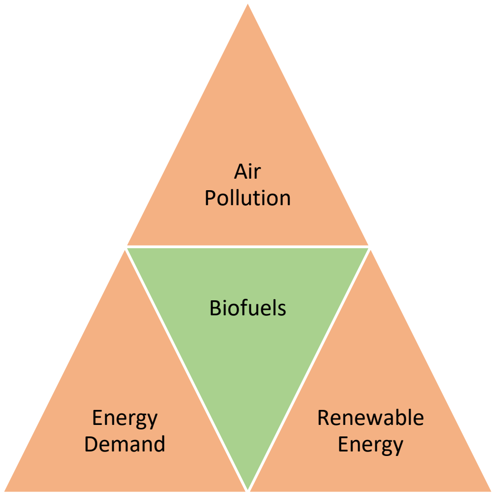

Fig. 1 *Global problems that contribute to the use of biofuel as an alternative energy [9]*

The primary concern with biodiesel is its poor performance in cold temperatures. Viscosity impacts the fluid frequency of petroleum, resulting in inadequate oil alienation throughout the burning procedure. The industrial sector is a major contributor to environmental air pollution. One of the reasons for the rising usage of biodiesel in heavy trucks is the fuel's source. Generally, biodiesel is produced through chemically decomposing palms and vegetables and fritter away frying oil lipids along a fatty acid ester to produce alcohol [10]. They are known as biodiesel, which is comprised of mono-alkyl esters produced from the oils or fats of animals. Biodiesel is widely used nowadays since it provides several assets, such as sustainable power and decreased carbon monoxide, hydrocarbon, and particle substance emission levels. Diesel engines are used in several ways, such as vehicles, ship propulsion, electrical generation, and agriculture, owing to their reduced gas use, greater thermal efficiency, and reduced exhaust fumes compared to diesel engines. Combined with growing petroleum costs, the fast depletion of crude oil supplies has spurred studies focused on non - conventional fuels. More recently, plant oils and their esters have gained appeal. Biodiesel is gaining popularity owing to its environmental advantages and promise as a non-modifiable alternative fuel for diesel engines [11].

Biodiesel is sustainable, biodegradable, and oxygenated, and studies have demonstrated that it may help reduce emissions of greenhouse gases to preserve rural growth and enhance wealth equality, emphasising its need to employ those oils. Many investigations on the mechanical and biochemical characteristics of biodiesel have been conducted, and the ability, efficiency, and exhaust emissions of engines have been conducted [12]. Fatty acid esters are often generated by the chemical interaction of palms, using ethanol, vegetable, and waste frying oil, as well as beef fats [13], [14]. Biodiesel is gaining appeal as a sustainable alternative fossil because of its oxygenation; pure fuel created from lard or oil is emulsified so that it may be used as a cooking medium. It has been recognised as an oil that helps to create eco-friendly energy that may be consumed either in its unadulterated or diluted form or in combination with regular diesel in CI engines. It is less harmful to the environment and non-toxic than normal Diesel, and because of the high lube content characteristics, it boosts engine efficiency [15].

Biodiesel fuels have been considered among the most promising petroleum derivatives in liquid replacement alternatives. Vegetable fuel conversion (including pome, sunflower or flax fuel, synthetic oils) Trans fats with alcohol yield biodiesel fuel [16]. Sustainable, clean, and ecological biofuels are becoming more important as a result of dwindling mineral reserves, climate change, and environmental concerns. Malaysia now employs (B10-B20-B30) palm oil biofuel blends successfully, whereas Southeast Asia plans to use 60% (b40) biodiesel blends by 2022. Malaysia should have used B30 (30% biodiesel and 70% diesel) by 2025 [17], [18]. Some countries can use more than 30 percent biofuel in diesel without modifying the engine one of the best things about diesel engines may run on biofuels as well. That is already in use without hurting their performance. Biodiesel has been the only renewable source for heavy vehicles that doesn't need any special changes to the way it is injected or stored. Biodiesel is a vegetable-based diesel engine fuel for automobiles, with FAME commercial goods originating from generation 1 biodiesel (Fatty Acids Methyl Ester). The refinery sector processes crude palm oil (CPO) derivatives to produce oil palm biodiesel. Methyl ester and gasification of oil are frequently used in the commercial production of biodiesel. Transesterification of alcohol (methanol) with a catalyst produces biofuel (fats methyl ether) as a primary item and glycerin as a byproduct. Fresh components such as refined palm oil (RPO), the Palm Fatty Acid Naphtha, stearic acid, and olein may be utilised in the palm oil refinery process to create biofuel. Next, esterification with palm fatty acid distillate (PFAD) glycerol may be utilised to generate biodiesel as a byproduct of RPO. As a byproduct of the oil palm refining process, PFAD was created. Stearin and Olein are byproducts CPO processing generated by oil palm through mordanting, whitening, and distillation [19]. Petroleum energy sources decreasing availability and increased carbon dioxide emissions make them less viable [20].

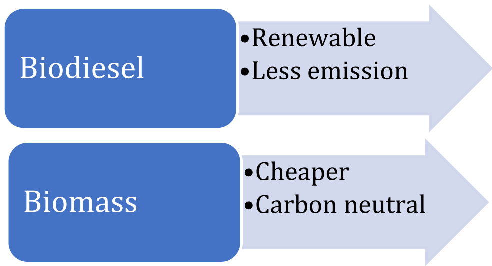

Fig. 2 *Petroleum diesel promising substitutes*

It is common knowledge that fossil fuel reserves are diminishing, and carbon dioxide emissions are soaring. However, because of their volatility, lubricity, density, and molecular weight, switching vegetable oils for diesel fuel in diesel engines creates several issues [21] alleviate their operating issues, the transesterification process was employed to make biodiesel fuel [22], [23] higher flash point of palm biofuel compared to diesel makes it safer to use. The spray characteristics may be altered, however, because compared to diesel fuel, the kinematics rheological properties are both higher [24]. Biodiesel is derived from sustainable Plants grown for their vegetable oil content.

Rising power use and the fast breakdown of fossil fuels motivate scientists to create advanced alternatives for later generations. An emulsion of biodiesel and water is one possible solution for slowing the rate. Since oil reserves are being depleted so quickly, the worldwide atmosphere's vulnerability to shift, numerous Scientists are looking for alternative energy sources. In addition, since the beginning of the revolution in industry, world energy consumption has been on the rise since the early nineteenth century. Figure 1 shows the main energy used worldwide from 1800 to 2017, in terawatt-hours (TWh) per year [25]. Scientists anticipate that petroleum-based fuels will run out by 2052 at the present pace. Rudolf Diesel discovered in 1897 that a motor could be started without a spark plug [26].

Biodiesel has gained prominence as an important energy source in the last few decades for partly replacing fossil fuels. An extensive study has been conducted to guarantee that biodiesel may be utilised in an engine that uses direct injection and compressed combustion without modification. Based on the ASTM D471 standard, the limitation to use biodiesel blended fuel up to 20 percent is to protect the elastomer parts of the fuel line system [27]. Notice how most of the studies found biofuels at a lower blend ratio are preferred. This is because of better performance for lower content of biodiesel. Higher content of biodiesel does have a higher cetane rank and more lubricity, it works better than regular diesel. However, higher lubricity of high biodiesel content will wear out less over time [28]. Global energy demand and the exhaustion of fossil fuels have also prompted serious exploration of biofuel as a replacement for diesel vehicles. The use of vegetable oils in diesel engines creates a variety of challenges with atomisation and injection of fuel nozzles due to their lower volatility and higher viscosity, molar mass, and density [29]. To enhance these qualities, biodiesel fuel was produced through transesterification of vegetable oil. Biodiesel may be used in diesel engines with modest changes to meet biodiesel engine specifications [30].

Most of the researchers used diesel and biodiesel fuels mixed with butanol fuel [31]. But the isobutanol in DFC was only used in a few studies [32]. Iso-butanol, a biofuel from the second generation, has the potential to lessen our reliance on fossil fuels and cut down on harmful emissions from vehicles that run back and forth [33]. There have not been many studies on how iso-butanol can be used in diesel engines.

Al-Hasan et al. [34] looked at how well 10%, 20%, 30%, and 40% iso-butanol/diesel blends worked in a single-cylinder diesel engine at different speeds. When compared to diesel fuel, their results showed that adding isobutanol made BTE go down and brake specific fuel consumption (BSFC) go up. [35], Karabektas et al. looked at how four iso-butanol/diesel blends (5%, 10%, 15%, and 20%) affected the performance and emissions of a naturally- aspirated, single-cylinder diesel engine at different speeds.

They found that the brake power decreased and the BSFC increased. They found that as the amount of isobutanol went up, NOx and CO emissions went down, while HC emissions went up. This study did not talk about soot emissions at all [36]. Ozsezan et al. looked at the effects of three isobutanol/diesel blends (5%, 10%, and 15%) in a turbocharged six- cylinder diesel engine and got the same results as Karabektas and Hosoz for NOx, HC, and CO emissions. They also said that as the amount of isobutanol in the blends went up, smoke emissions went down [37]. Recently, Zheng et al. looked at how blending 20% and 40% butanol isomers with diesel affected performance and emissions in a single- cylinder diesel engine with EGR rates up to 65%. They found that compared to other isomers, iso-butanol has the longest time before it starts to burn and makes the least amount of smoke. The study found that adding butanol isomers doesn't have a big effect on the regulated emissions.

Biodiesel improves engine performance and longevity by reducing wear and deposits, thanks to its higher lubricity compared to diesel fuel. It also ignites more easily and efficiently, leading to smoother engine performance, due to its higher cetane number. But the available standards only permitted the usage up to 20% biodiesel in the biodiesel blends (B20). This is because the kinematic viscosity and density will be higher as the ratio of biodiesel is more than B30. Biodiesel engine performance will be decreased due to the higher ratio of biodiesel in the biodiesel – diesel blends. Therefore, this research was done to study the effect of addition of isobutanol ranging 5 to 20 percentage volume to the B30 Palm Oil Methyl Ester (POME) biodiesel fuel blends towards the engine performance of diesel engine.

2. Research Methodology

2.1 Engine Test Setup

The experimental work was done using a YANMAR L48N engine. It is a vertical four-stroke single-cylinder naturally aspirated diesel engine. Table 1 shows the specifications of the engine used in this experiment and Fig 3 shows the schematic diagram of the engine test bed setup.

Table 1 *Specification for YANMAR L48N diesel engine*

Engine Specification	Details
Type	Air-cooled, 4-cycle, vertical single-cylinder
Bore	70 mm
Stroke	57 mm
Total displacement	219 cc
Maximum output	3.1 kW @ 3,000 rpm
Compression ratio	10:1

The YANMAR L48N engine was mounted to the 10kW eddy current dynamometer. The eddy current dynamometer is connected to the Powerlink CGK Dynamometer Controller. The speed range during the testing was 1600 to 2600 rpm with an interval of 200 rpm. The experiment was conducted at a constant full load for all engine speeds. The data of torque and fuel consumption was collected at each of speed intervals. Then the brake power and brake specific fuel consumption was calculated using the formula as in Equation (1) and (2).

$$Brake\ Power = \frac{2\pi NT}{60000} \tag{1}$$

$$BSFC = \frac{Fuel\ Flow\ Rate}{Brake\ power} \tag{2}$$

Where N is the engine speed in rpm and T is the torque in Nm.

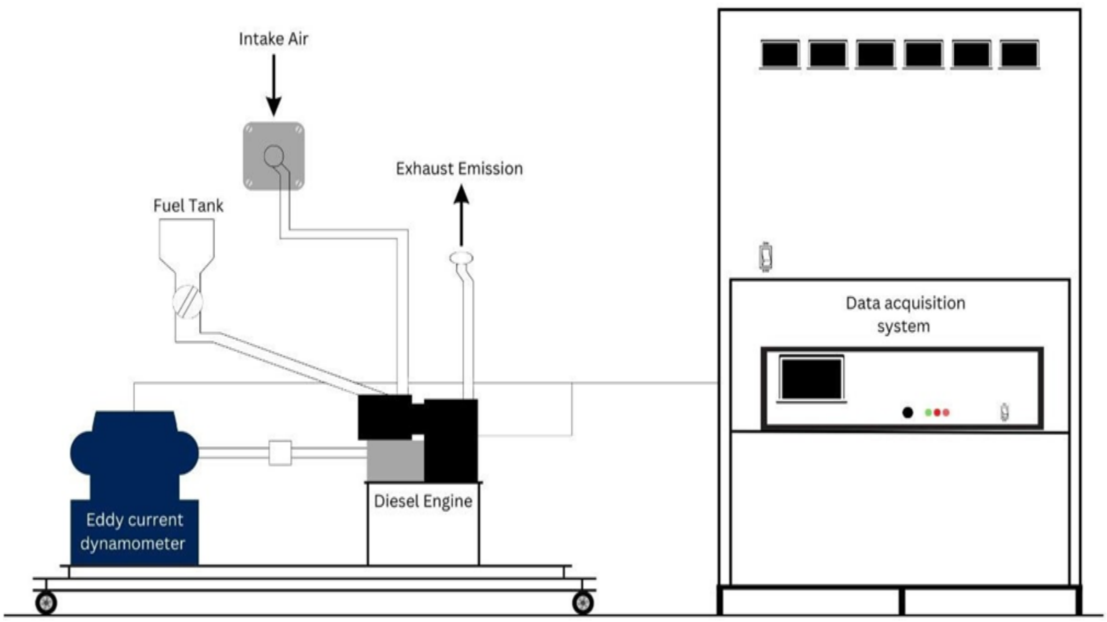

Fig. 3 *Schematic diagram of the engine test bed*

2.2 Test Fuels

Five fuel samples were used in this research. The diesel fuel was purchased from a local petroleum station, and the POME biodiesel was acquired from a local supplier, KLK-Oleo. The isobutanol, with a purity of 99.5%, was purchased from Zhong Ma Chemicals, a regional distributor in Malaysia. The B30 POME biodiesel blends were set as a baseline fuel. The B30 POME biodiesel blends were added with 5, 10, 15, and 20 volume percentages for each fuel sample. Initially, the B30 POME biodiesel was prepared for all five fuel samples. Then, each fuel sample with isobutanol was added with 5%, 10%, 15%, and 20% in volume percentage. The B30 POME biodiesel blended fuel samples with 5, 10, 15, and 20 volume percentages are categorised as B30ISO5, B30ISO10, B30ISO15, and B30ISO20, respectively. Before usage, diesel fuel will be blended by mixing palm oil methyl ester and isobutanol while stirring at a slower rate for twenty minutes, as recommended by Ali et al. [38]. Palm oil methyl ester will be added with Isobutanol to the diesel fuel with a constant 70% (B30) using the mechanical stirrer. The ratio and the composition can be seen in Table 2.

Table 2 *Content for each of the fuel samples*

Fuel samples	Content
B30	Diesel (70%) + POME Biodiesel (30%)
B30ISO5	Diesel (70%) + POME Biodiesel (30%) + Isobutanol (5%)
B30ISO10	Diesel (70%) + POME Biodiesel (30%) + Isobutanol (10%)
B30ISO15	Diesel (70%) + POME Biodiesel (30%) + Isobutanol (15%)
B30ISO20	Diesel (70%) + POME Biodiesel (30%) + Isobutanol (20%)

3. Results and Discussions

The graph in this section shows the BP (kW), BSFC (g/kWhr) and Torque (NM) on the y-axis and the engine speed rpm (in rotations per minute) on the x-axis. Each sample of fuel is represented by a different colored line, with the following key: diesel (blue), B30 (orange), B30ISO5 (green), B30ISO10 (red), B30ISO15 (purple), and B30ISO20 (brown). The graph shows the performance of each fuel sample at five different speeds (1600, 1800, 2000, 2200, and 2400 rpm).

The demand for sustainable and renewable energy sources has increased significantly in recent years, leading to a surge in the use of biodiesel as an alternative fuel for diesel engines. However, biodiesel has some limitations, such as low cetane numbers, lower energy content, and increased viscosity, which can negatively impact engine performance. To address these limitations, researchers have been exploring the potential of adding isobutanol to biodiesel fuel to improve its properties. A study evaluated the performance of six different biodiesel fuel samples with isobutanol additive at various speeds.

3.1 Brake Power (BP)

The engine brake power (BP) can be calculated based on torque obtained at all engine speed variations. The variation of brake power at full load was presented in Fig 4. Generally, the brake power increases as the engine speed increases for all fuel samples and the highest brake power was achieved at 2400 rpm.

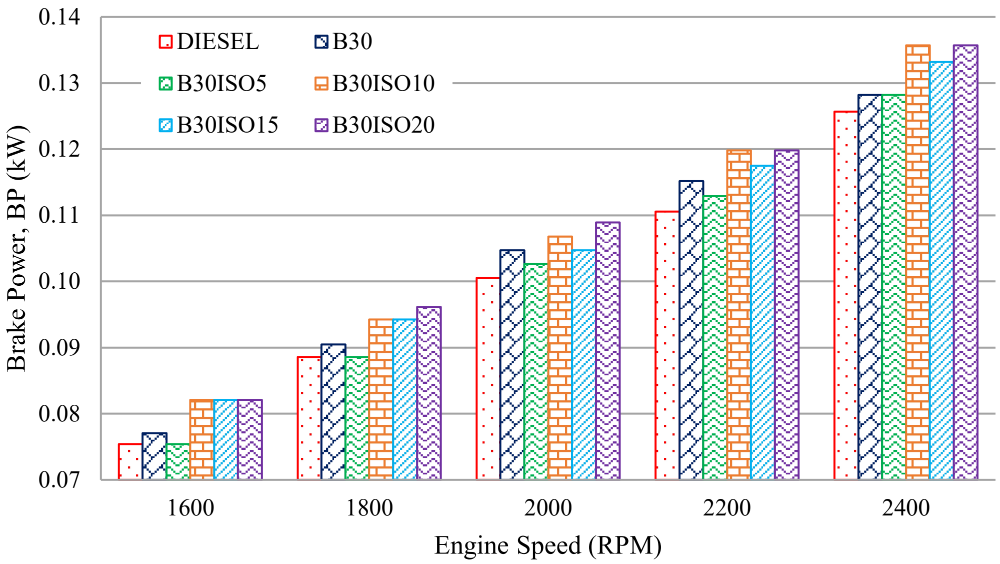

Fig. 4 *Variation of brake power at a different speed with a constant full load*

At 1600 rpm, the brake power of B30 was slightly higher by approximately 2.25% than diesel and B30ISO5, but B30ISO10, B30ISO15, and B30ISO20 had higher brake power by 8.89% than diesel and B30ISO5 but for B30 was by 6.49%, B30ISO10 showing the highest brake power. As the speed increased, all samples had higher brake power, but B30ISO20 showed the highest brake power at 2400 rpm with the increment of 8% compared to diesel.

The study's findings have significant implications for using biodiesel fuel with isobutanol additive in high-performance vehicles, where brake power is critical. Adding isobutanol to biodiesel fuel can increase its brake power, improving engine performance, especially at higher speeds. This is because the isobutanol content in biodiesel increases power output and engine performance due to higher energy content, better combustion characteristics, and improved fuel atomisation through lower viscosity, resulting in efficient combustion and utilisation of fuel energy, thus increasing the brake power [39]. However, Syahmi A et al. [40] found that increasing biodiesel in the blended fuel caused a drop in engine brake power. The author concludes that the drop in brake power might be due to the lower calorific value and higher cetane number of B30 compared to B7.

3.2 Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption is one of the most important engine performance characteristics. The BSFC was measured using a fuel tank hung on the digital weight balance. The weight before and after was calculated for each of the fuel samples. Comparing the six samples, we can observe that B30ISO20 consistently had the lowest BSFC values across all speeds, while B30 had the highest BSFC values. In contrast, at high speeds, B30ISO10 was the highest BSFC with an increment of 49.46% compared to diesel, and B30ISO20 decreased by 26.55% than the diesel. At lower speeds, diesel got the lowest BSFC like at B30ISO5 increased by 36.68% and B30 by 30.44%. in general, The BSFC values for B30ISO5, B30ISO10, and B30ISO15 were like each other and lower than B30 but higher than diesel and B30ISO20. At low speeds (1600 and 1800 rpm), B30ISO20 had the lowest BSFC values, followed by B30ISO10, B30ISO15, and B30ISO5.

The data in Fig 5 indicate that the addition of isobutanol to biodiesel fuel can significantly reduce BSFC, leading to more efficient fuel consumption, especially at higher speeds. This was due to the high volatility, low viscosity, and oxygen content. The results suggest that B30ISO20 is the most efficient biodiesel sample with isobutanol additive, followed by B30ISO10 and B30ISO15. From Fig 5, the BSFC decreases as the engine rpm increases. At lower engine rpm, the highest BSFC among the fuel samples with isobutanol is B30ISO5 and the lowest BSFC is obtained by B30ISO20. While at a high engine rpm of 2400 rpm, the highest BSFC obtained by the B30ISO10 and the lowest BSFC among the fuel samples with isobutanol is the B30ISO20. Generally, the Diesel shows the approximately lowest BSFC at all engine rpm compared to the

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The Fig 5 shows that isobutanol additives can improve biodiesel fuel consumption efficiency, with B30ISO20 showing the lowest BSFC values across all speeds. The data highlights the potential benefits of using biodiesel with isobutanol additives, especially in high-performance vehicles where fuel efficiency is a critical factor. However, more research is needed to fully understand the impact of isobutanol additives on biodiesel performance and to determine the optimal amount of isobutanol for maximum efficiency.

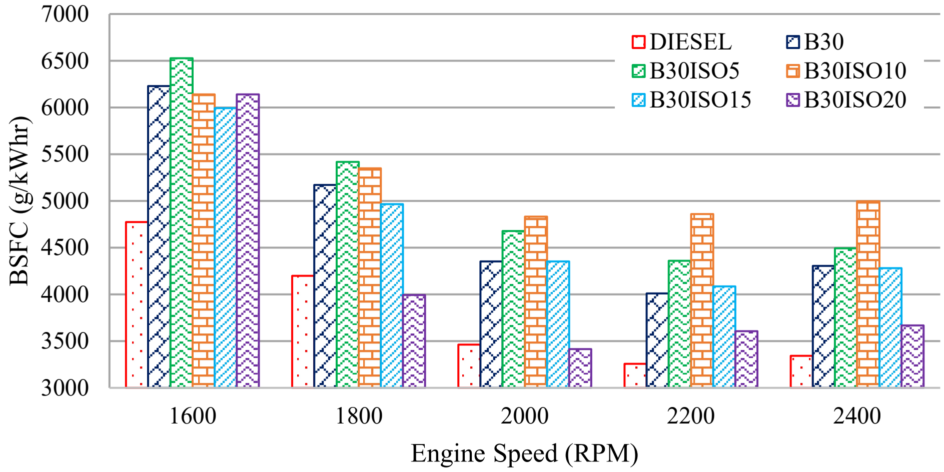

Fig. 5 *Variation of brake specific fuel consumption at a different speed with a constant full load*

3.3 Torque

It is observed that B30ISO10, B30ISO15, and B30ISO20 show a consistent improvement in torque at all speeds compared to other samples. However, the B30ISO5 and B30 show a similar trend, and diesel has the lowest torque at all speeds. At low-speed, B30ISO10, B30ISO15, and B30ISO20 increased by 8.89% compared to diesel. At high speed, B30ISO10 and B30ISO20 increased by 8% compared to diesel and by 5.88% compared to B30. Isobutanol addition to the fuel samples improves torque due to higher energy content, better combustion, and enhanced fuel-air mixture, Isobutanol has lower viscosity than diesel.

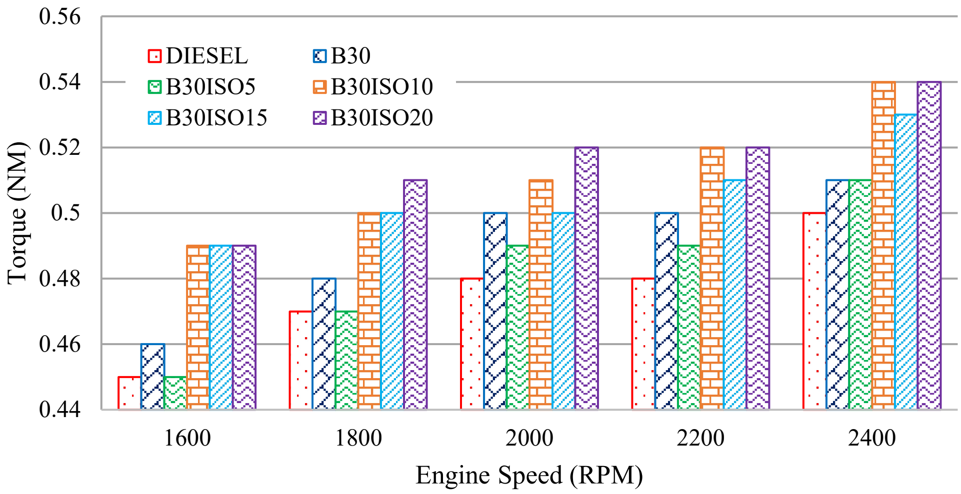

Fig. 6 *Variation of torque at a different speed with a constant full load*

Secondly, interpreting the data, the graph proves that adding isobutanol to B30 fuel increases the torque at all speeds. Isobutanol acts as an oxygenate that improves combustion efficiency, resulting in better performance. Additionally, increasing the concentration of isobutanol in B30 fuel significantly improves torque. However, beyond a certain concentration (15%), the increase in torque is not very significant because higher concentrations of isobutanol in the fuel blend can result in a more diluted fuel mixture, which may affect the overall combustion process. Excessive dilution can lead to reduced fuel-air mixture reactivity and lower combustion efficiency, limiting the increase in torque.

4. Summary and Conclusion

In conclusion, the analysis of engine performance for B30 biodiesel blends with isobutanol fuel additive has provided valuable insights into the potential benefits of this fuel combination. The study has demonstrated that adding isobutanol to biodiesel can enhance engine performance of brake power, brake-specific fuel consumption (BSFC), and torque.

The findings indicate that using isobutanol additive in biodiesel fuel can increase brake power, especially at higher speeds. B30ISO20 consistently exhibited the highest brake power across all speeds, indicating its potential for improving the performance of high-performance vehicles. The highest brake power achieved was by fuel samples at 20% in volume percentage with the increment of 8% at 2400 rpm compared to the diesel fuel. Isobutanol enhances power output and engine performance by increasing energy content, improving combustion characteristics, and facilitating better fuel atomisation through lower viscosity, resulting in efficient combustion and fuel energy utilisation.

Furthermore, the analysis revealed that isobutanol additive reduces BSFC, leading to more efficient fuel consumption. B30ISO20 consistently exhibited the lowest BSFC values across all speeds, highlighting its potential as an efficient biodiesel sample. The lowest BSFC was achieved by B20ISO20 fuel sample at 2400 with 26.55% compared to the diesel fuel sample. The volatility, low viscosity, and oxygen content contributed to the improved fuel consumption efficiency.

Regarding torque, adding isobutanol to biodiesel fuel led to consistent improvements at all speeds. B30ISO10, B30ISO15, and B30ISO20 consistently exhibited higher torque values than other samples. However, beyond a certain concentration of isobutanol (15%), the increase in torque becomes less significant. The highest torque achieved was by B20ISO20 at 2400 rpm with the increment of 8% compared to the diesel fuel. This suggests an optimal range of isobutanol concentration for maximising torque improvement.

The experimental study suggested that adding 10% Isobutanol by volume to a biodiesel blend is the best alternative fuel for improving a conventional diesel engine's performance and emission characteristics without requiring any modifications. These conclusions were drawn from tests conducted on a constant-speed diesel engine running on B30 with a 10% isobutanol additive. However, it is important to note that better results may be achieved by optimising the operating engine parameters specific to each biodiesel blend to enhance engine characteristics. Additionally, further observations of the combustion process and modifications of diesel engines when using biodiesel blends will be carried out to gain a comprehensive understanding of engine operation. Furthermore, exploring different engine speeds and concentrations of isobutanol and diesel/biodiesel blends may lead to even more favourable outcomes.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *N.H. Badrulhisam;* ***data collection:*** *N.H. Badrulhisam, N. E. Frere;* ***analysis and interpretation of results:*** *N.H. Badrulhisam, I. M. Yusri, N. E. Frere;* ***draft manuscript preparation:*** *N.H. Badrulhisam, I. M. Yusri, A. Adam and W Sawangsri. All authors reviewed the results and approved the final version of the manuscript.*

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