

RESEARCH ARTICLE

Influence of isobutanol fuel additive in B40 palm oil methyl ester on engine performance of a diesel engine

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ABSTRACT - Modern concerns of pollution and the depletion of fossil fuels have drawn much research to alternative energy sources, and biodiesel is a prime example. Biodiesel's special properties, such as a cetane number higher than that of other diesel fuels and lower volatility, can influence diesel combustion and fuel injection systems, potentially leading to power reduction and increased nitrogen oxide emissions. This study focuses on palm oil methyl ester (POME) biodiesel and uses isobutanol as an additive to investigate the potential for improving engine performance. This experiment was conducted precisely from 2000 to 3000 RPM with a data step of 200 RPM. The fuel blends of 5%, 10%, 15%, and 20% isobutanol with B40 (POME) on a diesel engine. The reference fuel will be standard diesel. Among the tested fuels, the B40ISO10 blend achieved the highest torque at 2200 RPM and delivered peak brake power at 3000 RPM, highlighting its efficiency at mid-to-high engine speeds. While diesel performed well at lower RPMs due to its high calorific value, biodiesel blends, particularly those with isobutanol, exhibited improved performance characteristics. Notably, B40ISO15 consistently showed lower brake-specific fuel consumption, indicating better fuel economy at higher RPM. Additionally, B40ISO20 displayed significant efficiency gains at increased speeds. These findings suggest that carefully formulated isobutanol-enriched biodiesel blends can provide an effective balance of engine performance and fuel efficiency.

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1. INTRODUCTION

Biodiesel is a viable alternative fuel that offers increased energy efficiency, environmental benefits, and ease of use in the pursuit of greener, more sustainable fuel sources [1–3]. Biodiesel is quite simple to utilize, in contrast to several alternative fuels that require significant alterations to the current infrastructure or automobile engines. Beyond its ease of use, biodiesel has shown noteworthy improvements in affordability, efficiency, and power generation. Due to its efficient generation of electricity, it can compete with more conventional petroleum-based options. Additionally, due to its improved combustion efficiency, it uses less gasoline, which benefits both the environment and the economy. The attractiveness of biodiesel is further underscored by its safety benefits. Biodiesel is a safer fuel choice than petroleum. It is safer in terms of volatility and toxicity, and it is simpler to handle and store [4]. However, various previous studies have found that biodiesel blended fuel with a biodiesel content of less than 20% does not require extensive engine modifications, and its performance remains comparable to that of diesel fuel [2, 5, 6]. When used in conjunction with biodiesel, alcohol and engine running can have several consequences on the engine's overall performance. Combining biodiesel with ethanol or methanol can change the fuel's characteristics, such as its octane rating and combustion mode. This mixture frequently raises the oxygen level of the fuel, which may improve combustion efficiency and result in smoother engine operation. However, the actual impact on engine performance, which encompasses factors such as torque, power output, fuel economy, and emissions, may vary depending on the blend ratios, engine type, and operating conditions. When alcohol is mixed with biodiesel, its impact on engine performance mainly depends on how effectively it mixes with engine parts and how it affects combustion behavior. The optimal blend ratios must be determined through extensive testing and analysis to meet performance goals while maintaining engine durability and reliability. Experts have recently conducted extensive studies on alternative fuels thanks to their experimental efforts. Researchers interested in renewable energy sources, such as alcohol and biodiesel, have increased due to the depletion of fossil fuels. The feasibility of adding alcohol to biodiesel and diesel fuel blends is not well-researched in the literature [7, 8].

A diesel engine replacement fuel with much potential is biodiesel. Nevertheless, biodiesel's high viscosity and poor low-temperature flow characteristics prevent it from being used in engines. Researchers, therefore, view alcohol as a potential ingredient for diesel–biodiesel (DB) blends [9, 10]. Several fuel combinations containing alcohol and biodiesel were investigated, and the engine's performance, ignition, and exit characteristics were evaluated using numerical

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modelling. The results showed that ethanol combustion, compared to biodiesel combustion, produced a lower chamber temperature and, consequently, reduced Nitrogen Oxides (NO_x) emissions. The injection timing has a significant impact on the amount of pilot injection used for emissions reduction and the heat release rate. Lastly, there was a discernible drop in emissions and engine performance when the injection start was altered from 695 to 700 [11]. Due to their reduced surface tension, boiling point, and kinematic viscosity, alcohol blends enhance atomization and vaporization rates, thereby increasing the atomization performance of biodiesel and diesel fuel [12]. Simikic et al. [13] demonstrated that, compared to the baseline diesel, the engine's braking thermal efficiency decreased as the methyl ester level in the fuel mix increased. The lower energy content and higher viscosity of biodiesel were the causes of the lower carbon content across the whole range of fuels containing methyl esters.

Recent studies have explored advanced methods to enhance the performance and stability of biodiesel, particularly through the incorporation of oxygenated alcohols and nanoparticle additives. These modifications have been shown to improve combustion characteristics, regulate fuel properties, and support more efficient engine operation, positioning biodiesel as a stronger candidate to replace conventional diesel. In the Indian context, biodiesel production primarily utilizes non-edible, second- and third-generation feedstocks such as jatropha, mahua, karanja, microalgae, and waste cooking oil. The National Biofuel Policy 2018 outlines a framework to encourage the adoption of biofuels, including a target of 10% biodiesel blending (B10) by 2030, aimed at reducing fossil fuel consumption and mitigating environmental impact. Despite this, poor cold flow behavior remains a significant technical barrier, particularly in colder climates where fuel solidification and filter plugging may occur, negatively impacting engine performance. To address these limitations, researchers have focused on fuel enhancement strategies using alcohol and nanoparticle-based additives, which have shown potential in improving cold flow properties, reducing operational issues, and ensuring compliance with international standards such as ASTM D6751 and EN 14214 [14,15]. According to study results, the blend B10D90 produced the most power and torque at 2600 and 1800 RPM, respectively. 1800 RPM is the B10D90 blend speed that exhibited the least exact fuel usage [16]. Engine power increased by 5.6% when fuel oil content (up to 10%) was added to the blended fuels [17]. Furthermore, as the amyl alcohol ratio in the mixture increases, the power and torque values decrease because the implicit heat of vaporization of amyl alcohol is more significant than that of diesel, which reduces combustion efficiency [18]. The low heating may limit the diesel engine's maximum brake power [19]. Alcohol and biodiesel have lower calorific values and lower energy densities, which cause a 7.58% decrease in brake power (BP) and a 3.2%–13.9% increase in brake-specific fuel consumption (BSFC) [20,21]. BTE and total hydrocarbon (THC) often decline in biodiesel-diesel blends, but BSFC and BP tend to increase as the proportion of biodiesel in the blend increases. Conversely, with blended biodiesel diesel mixes, BTE, engine torque (ET), and BP tend to be lower, while BSFC tends to be higher [22]. The effects of alcohol and biodiesel on braking power can be complex and variable. To understand how different blends affect engine performance and efficiency, scientists and engine manufacturers are studying these combinations. Optimizing engine designs and tuning for specific fuel blends can maximize the advantages of using biodiesel-alcohol mixes in terms of power output and emissions. Oxygenated fuels, such as high-alcohol (high-carbon) blends, including propanol (C3), n-butanol (C4), and 1-pentanol (C5), as well as biodiesel blends, are of interest to many scientists [23]. Relates to the conversation about fuel alternatives for diesel engines that are less harmful to the environment. When the fuel mix is compared to baseline diesel, there is a decrease in NO_x and particulate matter (including PAH-related emissions), which reduces the harmfulness of PAHs. Nonetheless, there is an increase in carbon monoxide (CO), BSFC, exhaust gas temperature (EGT), and hydrocarbons (HC) [24]. Based on engine performance and exhaust emissions data, the addition of C3, C4, and C5 to waste oil biodiesel (WB) raised exhaust gas temperatures (EGT) and BSFC while decreasing BTE [25].

Pentanol is favoured as a higher alcohol because it possesses superior inherent properties compared to other first-generation alcohols such as ethanol or methanol. The experiment's findings using Mahua Oil Biodiesel (MOBD) demonstrate that mixes of pentanol and biodiesel outperform pure biodiesel (MOBD100). A MOBD100 and MOBD90P10 (MOBD 90% + Pentanol 10%) show somewhat high brake specific fuel consumption (0.6 to 1.1%) and brake thermal efficiency (0.2–0.4%) at all engine loads. Numerous factors can impact the multifarious effects of biodiesel with alcohol on brake thermal efficiency. While addressing potential adverse impacts on BTE, research and engine optimization efforts continue to focus on maximizing the efficiency of these blends [26, 27]. Because it uses equivalent diesel fuel consumption, BTE is a more reflective metric of fuel economy [28]. Butanol blends reduce engine torque and power ratings compared to pentanol blends [29]. Biodiesel can be utilized directly in compression ignition (CI) engines without any modifications; nevertheless, the primary limiting factor is the loss of torque and power output due to its lower calorific value [30]. In another study, the authors noticed engine execution and emissions issues, including elevated BSFC, NO_x , and BP [31]. An extensive investigation was conducted to assess the impact of n-butanol on the efficiency, emissions, and combustion properties of biodiesel and diesel blends (B/D) in diesel engines. Butanol's physicochemical characteristics suggest that it could be a viable biofuel or additive to enhance the quality of biodiesel blends. For blends of butanol–biodiesel (Bu/B), butanol–biodiesel–diesel (Bu/B/D), and biodiesel–diesel (B/D) blends, it is deduced that somewhat increased BTE, BSFC, and BP are obtained as performance metrics. This is explained by a decrease in the calorific value (CV) of the blends due to butanol's lower CV. Because butanol-based blends have inherent oxygen content that promotes proper combustion while CO_2 increases, diesel engines running on these blends produce lower carbon monoxide (CO), NO_x , smoke, and unburned hydrocarbon (UHC) emissions [32]. Therefore, this study was conducted to investigate the correlation between the addition of isobutanol and the engine performance of a diesel engine. In varying amounts, adding isobutanol to diesel fuel blended with cottonseed oil has an effect similar to adding pure cottonseed oil,

reducing the temperature of exhaust gases and specific fuel consumption while increasing brake thermal efficiency [33]. BTE is reduced when high-calorific-value fuel concentration is substituted with low-calorific-value fuels due to the general increase in biodiesel and isobutanol content. In addition, a superior combustion process is detected due to the high oxygen ratio in *Calophyllum inophyllum* methyl ester (CIME), which results in increased BTE compared to blends with lower CIME concentration [34]. Due to its potential environmental and economic benefits, the use of B40 POME, a biodiesel alternative fuel for diesel engines, has garnered considerable attention. Optimizing its combustion qualities and resolving performance issues remain challenging, however. One suggestion for boosting the combustion efficiency of biodiesel blends is to use isobutanol as an additive. This has shown potential. The effects of the isobutanol addition on the performance of the B40 POME diesel engine remain mostly unknown, despite some preliminary research. Therefore, this study focuses on POME biodiesel and uses isobutanol as an additive to investigate the potential for improving engine performance.

2. MATERIALS AND METHODS

2.1 Engine Test Setup

An eddy current dynamometer was connected to a four-stroke, vertical, single-cylinder YANMAR L48N naturally aspirated diesel engine. The engine specifications are presented in Table 1. Figure 1 and the schematic diagram in Figure 2 show the setup of the engine test bed. The YANMAR L48N engine was mounted to the 10-kW eddy current dynamometer. The eddy current dynamometer is connected to the Powerlink CGK Dynamometer Controller. The speed range during the testing was 2000 to 3000 RPM with an interval of 200 RPM.

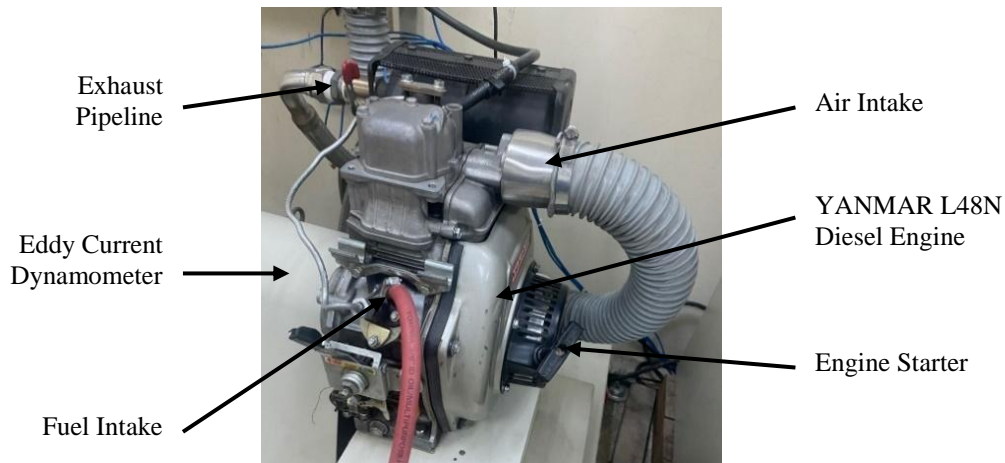


Figure 1. YANMAR L48N diesel engine mounted to the 10kW eddy current dynamometer

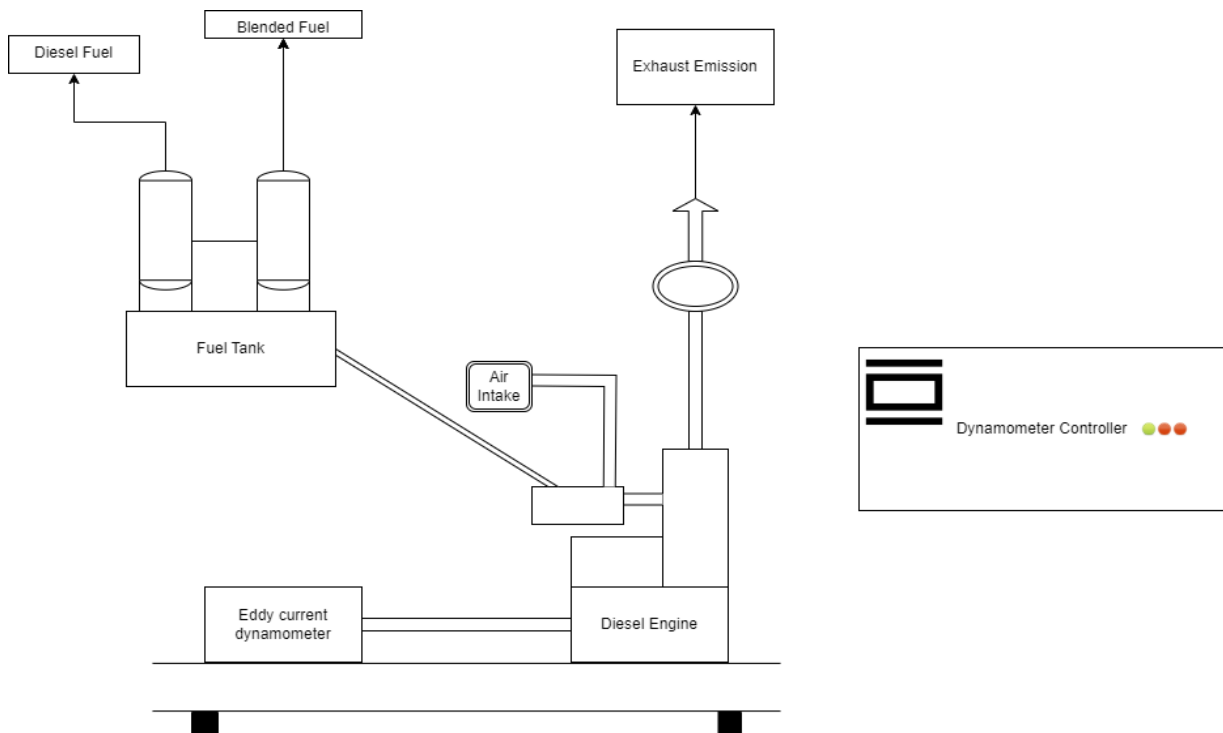


Figure 2. Schematic diagram of the engine test bed setup

Table 1. YANMAR L48N diesel engine specification used for the experimental engine testing

| 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 |

2.2 Experimental Engine Testing

The experiment was conducted at a steady state and constant full load for all engine speeds. The data on torque was recorded from the dynamometer controller. At each of the speed intervals of 200 RPM, fuel consumption was measured using a measuring cylinder connected to the fuel intake. Then, the brake power and brake-specific fuel consumption were calculated using the formula as in Eqs. (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.

2.3 Fuel Sample Preparation

A biodiesel blend containing 60% diesel oil, 40% POME, and various additives (5%, 10%, 15%, 20%) requires a careful approach. Begin by measuring the required amounts of diesel fuel and palm oil methyl ester, based on the desired ratio of 60:40. Next, calculate the amounts of each additive according to the specified percentages. Carefully mix the diesel and POME in a suitable container, ensuring thorough homogenization to obtain a uniform mixture. Gradually add each addition to the mixture, stirring constantly to ensure even distribution for 30 minutes, to maintain the homogeneity of the fuel samples [35]. The addition of additives at 5%, 10%, 15%, and 20% affects the final properties of the biodiesel mixture, including stability, lubricity, and combustion characteristics. Moreover, the selection of 5%, 10%, 15%, and 20% isobutanol blending ratios in B40 biodiesel is based on a balance of scientific relevance, fuel stability, and practical applicability. These incremental steps enable a clear assessment of the additive's influence on engine performance, facilitating the identification of any nonlinear trends or optimal concentration ranges. Blends above 20% may lead to phase separation, reduced fuel stability, and potential engine compatibility issues, especially in unmodified engines. Moreover, these selected ratios are commonly referenced in previous studies, ensuring comparability with existing literature while remaining within safe and practical limits for real-world application and regulatory compliance. Table 2 presents the content of each fuel sample.

Table 2. Content for each of the fuel samples

| Fuel samples | Content |
|----------------------|--|
| B40 | Diesel (60%) + POME (40%) |
| B40 + 5% Isobutanol | Diesel (60%) + POME (40%) + Isobutanol (5%) |
| B40+ 10% Isobutanol | Diesel (60%) + POME (40%) + Isobutanol (10%) |
| B40 + 15% Isobutanol | Diesel (60%) + POME (40%) + Isobutanol (15%) |
| B40 + 20% Isobutanol | Diesel (60%) + POME (40%) + Isobutanol (20%) |

3. RESULTS AND DISCUSSION

The graph displays the BP (kW), BSFC (g/kWh), and torque (Nm) on the y-axis, and the engine speed (RPM) on the x-axis. Each sample of fuel is represented by a different coloured line, with the following key: diesel (blue), B40 (orange), B40ISO5 (grey), B40ISO10 (yellow), B40ISO15 (light blue), and B40ISO20 (green). The graph illustrates the performance of each fuel sample at five different speeds (2,000, 2,200, 2,400, 2,600, 2,800, and 3,000 RPM).

3.1 Brake Power

Figure 3 displays the relationship between brake power (BP) and engine speed, measured in RPM, for a diesel engine using different fuel additives. The additives appear to be blends of biodiesel with conventional diesel at various percentages: pure diesel (DIESEL), B40 (40% biodiesel blend), and B40 with additional biodiesel at 5%, 10%, 15%, and 20% levels, respectively. At 2000 RPM, Diesel has a brake power value of 0.182 kW, which is the highest among other fuels at this engine speed. B40 fuel exhibits the second-highest brake power value, 0.175 kW, representing a 3.922% difference from Diesel. The B40ISO blends show a lower value than diesel and B40, with B40ISO5 exhibiting the highest

value among all the B40ISO blends at 0.159 kW. In comparison, B40ISO10 shows a decrease in brake power of 8.525% to reach a brake power value of 0.146 kW. B40ISO15 shows a slight increase in brake power value compared to B40ISO10, with a 4.027% increase. In other terms, it reached 0.152 kW. For B40ISO20, the brake power value is 0.142 kW; in percentage terms, it has decreased by 6.803% from B40ISO15. Moving towards 2200 RPM, Diesel has a brake power value of 0.204 kW, which is the lowest brake power value amongst all fuel samples at this engine speed. B40 shows the second-lowest value of brake power after diesel, with a value of B40 increasing by 2.421% to reach 0.209 kW. B40ISO5 exhibits a slight increase in brake power, reaching a value of 0.214 kW, representing a 2.364% increase over B40. As the isobutanol percentage increases in the following three fuel samples, the brake power in the engine increases, showing that B40ISO10 has the highest BP amongst all fuel samples, where it reached a value of 0.232 kW compared to B40ISO15, the BP value is 0.223 kW, and B40ISO20, 0.214 kW. B40ISO5 and B40ISO20 have the same brake power value of 0.214 kW.

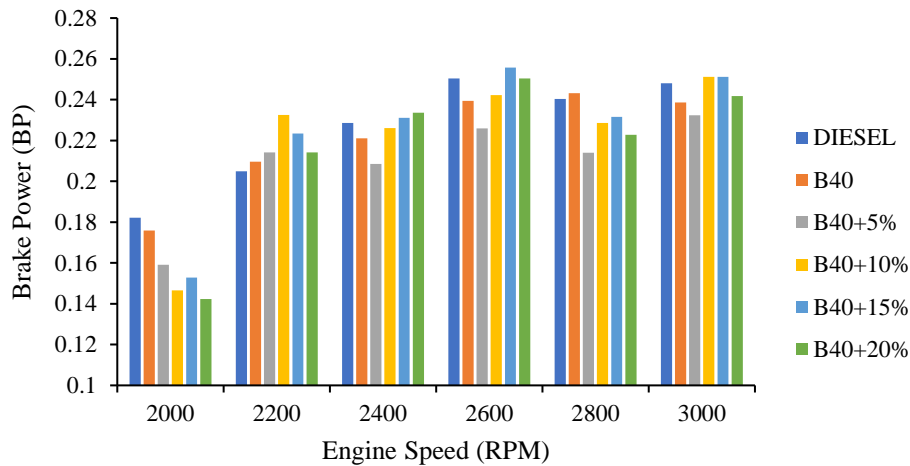


Figure 3. Brake power against engine speed

At an engine speed of 2600 RPM, B40ISO15 has demonstrated the best brake power value among other fuel samples at this speed. Diesel has shown the second-highest value of BP at 0.250 kW, which is 4.499% higher than B40 fuel, which stands at 0.239 kW. Moving to B40ISO's, B40ISO5 has a lower brake power value among the other three blended fuel samples, with a value of 0.225 kW. In contrast, B40ISO10 has an increased brake power value of 7.281%. B40ISO15 has shown an increase in brake power value of 5.231%. B40ISO20 has a brake power value of 0.250 kW. The values of B40ISO show the opposite results to those at 2400 RPM, where 2400 RPM showed a continuous increase in brake power. The last experiment for brake power was conducted at an engine speed of 3000 RPM, where diesel showed a value of 0.248 kW and B40 showed 0.238 kW. B40ISO5 exhibited a slight decrease in brake power compared to B40, with a value of 0.232 kW. B40ISO10 and B40ISO15 showed the exact value of brake power, 0.251 kW, which is the highest at 3000 RPM. B40ISO20 shows a 4.065% drop from B40ISO10 and B40ISO15.

The developed brake power values across the different fuel samples at different engine speeds can be interpreted in terms of the calorific value. Diesel can be defined as having an excellent calorific value and peak performance of fuel at lower engine speeds (2000 and 2800 RPM), which evidently reflects efficient energy conversion from fuel to mechanical power. Based on previous literature [36], B40, with 40% biodiesel, exhibits intrinsic properties of biodiesel, showing a slightly lower calorific value, which is almost equal to that of diesel at brake power. For B40ISO blends with isobutanol, the properties exhibited were more complex. The energy content of isobutanol would generally be low in comparison to diesel, which would suggest a decrease in overall calorific value. Isobutanol, however, could exert its effect by enhancing the combustion characteristics or increasing the oxygen content, resulting in improved performance under certain conditions, as observed in higher brake power at 2200, 2400, and 2600 RPMs. These variations in performance dictate that engine operational conditions and the engine's configuration guide the selection of an optimal fuel blend to maximize brake power. This points out the fact that, although isobutanol may reduce the calorific value compared to diesel, all other properties of it may be beneficial for fuel performance, especially at higher engine speeds.

3.2 Brake Specific Fuel Consumption

Figure 4 shows BSFC versus a range of engine speeds for various fuel types. BSFC is the amount of fuel required by an engine to produce a unit quantity of power in a unit time and is expressed in g/kWh. This is one of the important performance indicators in the design and testing of the engine, as it reflects the fuel economy of the engine under different operating conditions, with an increasing percentage of biodiesel (B40, B40ISO5, B40ISO10, B40ISO15, B40ISO20). Thus, a low BSFC value indicates that the engine requires a low amount of fuel to produce one unit of power, resulting in higher efficiency. For Diesel fuel, a decreasing BSFC with increasing engine speed has been observed. At 2200 RPM, the BSFC is approximately 1311.62 g/kWh, reducing further to about 974.006 g/kWh at 2400 RPM. Moving on to the B40 biodiesel blend, the BSFC increases to approximately 796.178 g/kWh at 2000 RPM, indicating lower fuel efficiency compared to Diesel at the same RPM. At 2200 RPM, the BSFC for B40 increases to an estimated 1296.919 g/kWh. The

trend of declining BSFC values continues, with values of 1641.846 g/kWh at 2,400 RPM, 1134.804 g/kWh at 2,600 RPM, and 1492.073 g/kWh at 2,800 RPM. At 3000 RPM, the B40 blend's BSFC is estimated at 1456.796 g/kWh. For the B40ISO5 blend, the BSFC starts at approximately 1090.743 g/kWh at 2000 RPM, indicating a slight improvement in fuel efficiency compared to the base B40 blend. This improvement carries on as the engine speed increases, with estimated values of 1250 g/kWh at 2200 RPM, 1512 g/kWh at 2400 RPM, 1255 g/kWh at 2600 RPM, and 1253 g/kWh at 2800 RPM. At the highest measured speed of 3000 RPM, B40ISO5 is estimated to have a BSFC of 1356 g/kWh. The B40ISO10 blend seems to continue this pattern of incremental efficiency gains. At 2000 RPM, its BSFC is around 1545 g/kWh. With the engine's speed increase to 2200 RPM, the BSFC decreases to 910 g/kWh and further to 1202 g/kWh at 2400 RPM. At 2600 RPM and 2800 RPM, the values are 995 g/kWh and 1253 g/kWh, respectively. Lastly, at 3000 RPM, B40ISO10 shows a BSFC of approximately 1203 g/kWh.

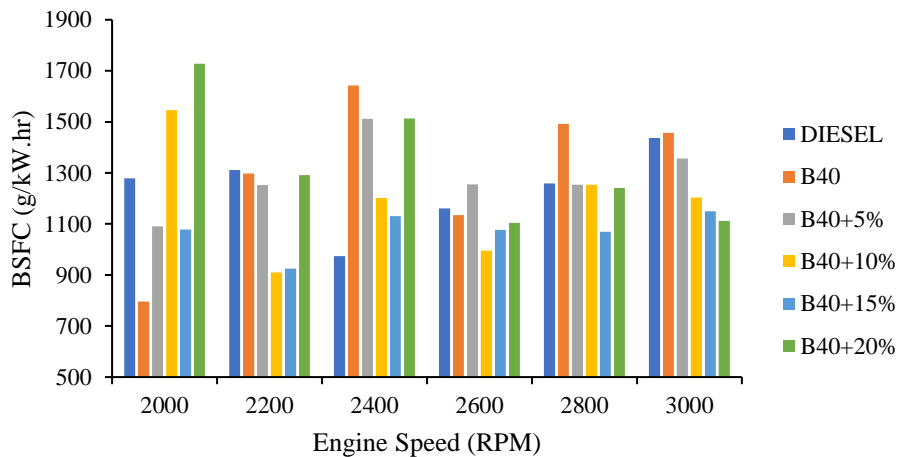


Figure 4. BSFC versus engine speed

As for the B40ISO15 blend, the pattern starts at 2000 RPM with a BSFC value of about 1077 g/kWh, indicating that this blend is even more fuel-efficient. The value decreases to 924 g/kWh at 2200 RPM, to around 1130 g/kWh at 2400 RPM, and down to 1076 g/kWh at 2600 RPM. At 2800 RPM, the BSFC is estimated at 1069 g/kWh, and it concludes with 1149 g/kWh at 3000 RPM. Finally, for the B40ISO20 blend, the BSFC at 2000 RPM is approximately 1727 g/kWh, which is considerably higher than the original B40 blend. The BSFC decreases to 1291 g/kWh at 2200 RPM, 1513 g/kWh at 2400 RPM, 1104 g/kWh at 2600 RPM, and 1241 g/kWh at 2800 RPM. At a speed of 3000 RPM, the B40ISO20 blend is estimated to have a BSFC of 1111 g/kWh. In each case, regarding the effect of BSFC on cetane number, kinematic viscosity, and calorific value, the picture becomes more complicated [37]. The cetane number characterizes how fast the diesel fuel burns. This can be affected not only at engine start but also during the whole engine cycle by burn completeness. Generally, the higher the cetane number, the better it will ignite and burn, reducing potential BSFC, as it will be burned more completely, making the engine work more efficiently. Kinematic viscosity shows the resistance of the fuel to flow. Kinematic viscosity affects the fuel injection process. Fuel with high viscosity may fail to atomize well, resulting in low combustion efficiency and higher BSFC. However, if viscosity is too low, it may be unable to provide proper lubrication to engine components, causing wear over time and, in some instances, increasing fuel consumption.

3.3 Torque

Figure 5 illustrates that significant differences contribute to the torque output of an engine, stemming from variations in calorific value, which affect the amount of energy a fuel can release during combustion. Diesel generally exhibits a torque output at specific RPMs, where torque increases before dropping as RPMs rise. On the other hand, based on previous research [17], biofuel blends, such as B40 and its variants with additives (ISO 5, ISO 10, ISO 15, ISO 20), usually start with lower torque values due to their low calorific values, but will show variable torque outputs at different RPMs. These fluctuations could be attributed to the fact that additives in the biofuels enhance combustion characteristics, thereby allowing for the effective utilization of available energy at certain speeds. For example, the graph shows that B40ISO10 exhibits the most significant increase in torque at 2200 RPM, indicating that this blend may produce the best energy from its calorific value at this engine speed. This relationship between fuel type, calorific value, and engine torque highlights the importance of matching an engine design with the appropriate fuel type for optimal energy utilization and performance. This view may also inform the development of new biofuel formulations that are both environmentally beneficial and offer equal or better performance than conventional diesel. Based on this visual assessment, the B40+10% blend exhibits the highest overall trend in torque across the engine speed range compared to the other fuel blends, including Diesel. It appears to have achieved a combination of high initial torque and good sustained performance across the entire RPM range, as indicated on the chart. Comparative studies on the performance of diesel fuels and different biodiesel blends have given mixed results in engine performance tests. B30 biodiesel exhibited less power with adequate torque at different levels of RPM, while PSO's biodiesel blends showed a decrease in brake power, torque, and thermal efficiency, with an increase in fuel consumption compared to diesel [38, 39]. Further blends of *Salvia macro siphon* biodiesel with diesel were reported to increase brake power and torque, while also reducing CO₂ and NO_x emissions and

decreasing specific fuel consumption, CO, and HC emissions [40]. It was observed that the B10D90 blend had an optimized power and torque of 2600 and 1800 RPM, respectively, with lesser specific fuel consumption at 1800 RPM [16]. A higher ratio of amyl alcohol would result in lower power and torque, since amyl alcohol has a much higher heat of vaporization, which affects combustion efficiency.

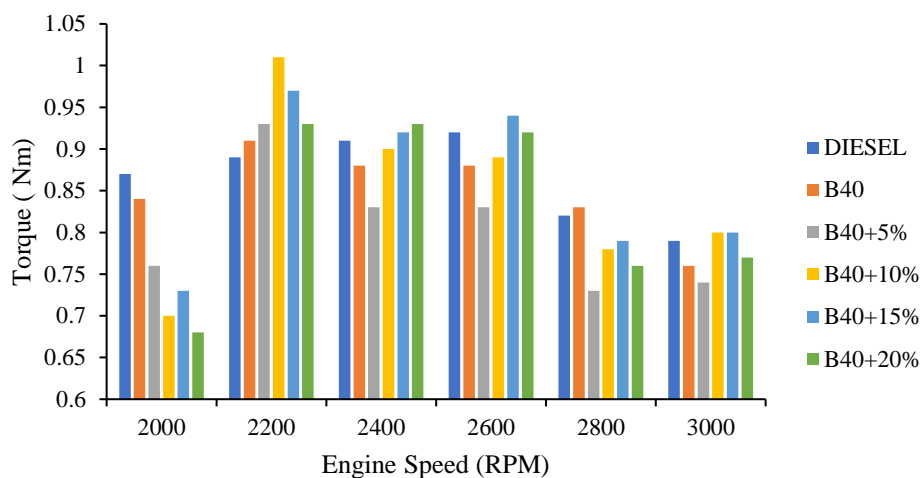


Figure 5. Torque versus engine speed graph

4. CONCLUSIONS

This study comprehensively examined the impact of isobutanol as an additive to B40 biodiesel on engine performance. The results confirm that isobutanol-blended B40 fuels significantly enhance brake power, torque, and brake-specific fuel consumption, demonstrating their potential as efficient and sustainable alternatives to conventional diesel. Torque analysis revealed that diesel, with its high calorific value, achieved peak torque at mid-range RPMs, whereas B40 blends exhibited varying torque characteristics. These differences suggest improved combustion behavior in certain isobutanol-enhanced blends, particularly at specific engine speeds. This is attributed to better volatility and oxygen content introduced by isobutanol. In terms of brake power, although diesel retained an advantage at lower speeds, some B40-isobutanol blends, especially B40ISO10, showed competitive performance at higher RPMs. This suggests that these blends have the potential to deliver sufficient power under high-load or high-speed conditions, likely due to enhanced atomization and improved combustion stability. BSFC patterns reinforced these findings. While biodiesel blends initially showed higher consumption at lower RPMs, some mixtures, notably B40ISO15, demonstrated improved fuel efficiency at higher speeds. B40ISO20 also demonstrated marked improvement in BSFC with increasing RPM, suggesting that higher isobutanol content may offer better thermal efficiency under certain operating conditions. In summary, isobutanol-blended B40 biodiesel fuels provide tangible performance advantages by improving combustion efficiency and reducing specific fuel consumption at higher engine speeds. These findings underscore the feasibility of adopting such blends in real-world applications and support their further development as part of the transition toward greener, more sustainable fuels.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHORS CONTRIBUTION

N. H. Badrulhisam (Conceptualization; Formal Analysis; Supervision; Resources; Writing - review & editing)

O. A. Malek (Methodology; Data curation; Formal analysis; Investigation; Project Administration; Writing-original draft)

I. M. Yusri (Resources; Software; Visualisation; Funding acquisition; Validation; Writing - review & editing)

A. Adam (Visualisation; Validation; Writing - review & editing)

ETHICAL STATEMENT

The authors have not employed an AI-based tool or AI technology to write this article.

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