# Influence of Palm Oil Blending Ratio on Fuel Characteristics and Diesel Engine Performance under Different Operating Loads

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## ABSTRACT

The increasing demand for sustainable energy has accelerated research on renewable fuels for compression ignition (CI) engines. This study experimentally evaluated the performance of a small CI diesel engine fueled with palm oil–diesel blends (PO20, PO40, PO60, PO80, and PO100) under electrical loads of 300, 600, and 900 W. Engine performance was assessed using torque, brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE), with conventional diesel as the reference fuel. Performance improved with increasing load for all fuels. Diesel produced the highest overall performance, while several palm oil blends achieved comparable results at higher loads. Among the blends, PO80 exhibited the best balance of torque, fuel consumption, and thermal efficiency. In contrast, PO100 showed lower efficiency because of its higher viscosity and poorer atomization characteristics. These findings demonstrate that palm oil–diesel blends, particularly PO80, are promising renewable alternatives for small CI engines without requiring significant engine modifications.

**Keywords:** Palm oil–diesel blends, Engine performance analysis, Renewable biofuel, Alternative fuels for diesel engines, Compression ignition engine

## INTRODUCTION

The growing demand for energy and the environmental impacts of fossil fuel consumption have accelerated the search for sustainable alternative fuels. Diesel remains the primary fuel for compression ignition (CI) engines used in agriculture, transportation, and small-scale power generation. In Malaysia, diesel-powered machinery, generators, and irrigation systems play a vital role in agricultural activities. However, diesel combustion emits harmful pollutants, including nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (HC), contributing to air pollution and environmental degradation [1], [4].

Biodiesel has emerged as a promising renewable alternative because of its biodegradability, low toxicity, and potential to reduce greenhouse gas emissions [1], [2]. Among available feedstocks, palm oil is particularly attractive in Malaysia due to its abundant production, renewable supply, and compatibility with conventional diesel engines with minimal modification [3], [6]. To promote renewable energy, the Malaysian government has introduced biodiesel blending policies such as B7, B10, and B20.

Despite its environmental benefits, biodiesel alters engine performance because its physicochemical properties differ from those of diesel fuel. Variations in viscosity, density, heating value, and combustion characteristics influence key performance parameters, including torque, brake power, brake specific fuel consumption (BSFC),

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and brake thermal efficiency (BTE) [1], [4]. Although biodiesel generally reduces exhaust emissions, higher blend ratios may slightly decrease engine performance [2], [5]. Therefore, evaluating biodiesel–diesel blends is essential to balance engine efficiency with environmental sustainability.

Small CI engines are widely used in portable generators and agricultural equipment because of their reliability and fuel efficiency. Assessing their performance with palm oil–diesel blends under different operating conditions is necessary to determine their practical suitability. Experimental studies involving various blend ratios and engine loads provide valuable insights into fuel consumption, power output, and overall engine performance [2], [6].

This study experimentally evaluates the performance of a single-cylinder Depro CI diesel engine fueled with palm oil–diesel blends containing 20%, 40%, 60%, 80%, and 100% palm oil under electrical loads of 300, 600, and 900 W. Engine performance was assessed using brake power (BP), brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and torque. The results provide insights into the feasibility of palm oil biodiesel as a sustainable alternative fuel for small diesel engines used in agricultural and small-scale power generation applications.

## LITERATURE REVIEW

### Global Dependence on Fossil Fuels and Alternative Fuels

The growing demand for transportation, electricity generation, and industrial activities has increased global reliance on fossil fuels, particularly diesel. Although diesel remains a major energy source for compression ignition (CI) engines, its continued use contributes to greenhouse gas emissions, environmental pollution, and the depletion of non-renewable resources. These concerns have intensified research into renewable and sustainable alternative fuels.

Among the available options, biodiesel derived from vegetable oils has attracted considerable attention because of its renewability, biodegradability, and lower exhaust emissions. Biodiesel can be produced from various feedstocks, including soybean, palm, rapeseed, and waste cooking oils, and can be blended with conventional diesel for use in CI engines without significant engine modifications. Previous studies have shown that biodiesel blends reduce emissions of carbon monoxide (CO), particulate matter (PM), and unburned hydrocarbons (HC) compared with petroleum diesel [7], [8].

Malaysia is one of the world's leading palm oil producers, making palm oil a strategically important feedstock for biodiesel production. Its high oil yield, continuous availability, and compatibility with diesel engines make palm oil–based biodiesel a promising renewable fuel for diesel blending applications.

### Palm Oil Biodiesel as an Alternative Fuel

Palm oil biodiesel is derived from the oil palm (Elaeis guineensis), which is widely cultivated in tropical regions, particularly in Malaysia and Indonesia. The oil extracted from palm fruits can be processed into biodiesel through transesterification or directly blended with diesel fuel. Palm oil possesses several characteristics that make it suitable for diesel engines. These include high cetane number, good lubricity, and relatively stable combustion characteristics. Additionally, palm oil biodiesel is biodegradable and less toxic compared with fossil diesel fuels. Previous studies have reported that palm oil biodiesel blends can be used in compression ignition (CI) engines with minimal or no engine modifications while producing lower exhaust emissions compared with petroleum diesel [9], [10], [11]. However, palm oil also presents some technical challenges. Compared with conventional diesel fuel, palm oil exhibits higher viscosity and density. These properties may lead to poor atomization during fuel injection, incomplete combustion, and potential injector clogging if used in high concentrations. Therefore, blending palm oil with diesel fuel is commonly used to improve its fuel properties and maintain engine performance. Blending ratios such as B10, B20, and B30 (10%, 20%, and 30% biodiesel respectively) are frequently investigated in experimental studies to evaluate their suitability in diesel engines.

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### Engine Performance of Palm Oil–Diesel Blends

Numerous studies have investigated the impact of palm oil biodiesel blends on diesel engine performance. Key performance indicators commonly evaluated include brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), torque, and brake power. Experimental studies have shown that biodiesel blends generally produce slightly lower brake thermal efficiency (BTE) compared with pure diesel fuel due to their lower calorific value. Biodiesel blends such as B20 have been reported to result in a small reduction in BTE when compared with conventional diesel fuel [13]. In addition, palm oil biodiesel blends have demonstrated engine performance comparable to diesel fuel, although they typically require slightly higher fuel consumption to produce the same power output [14]. Despite these differences, biodiesel blends often exhibit improved combustion characteristics due to their oxygen content, which enhances fuel oxidation during combustion. This improvement can partially compensate for the lower heating value of biodiesel fuels.

### Brake Thermal Efficiency

Brake thermal efficiency (BTE) represents the ability of an engine to convert the chemical energy contained in fuel into useful mechanical power. Several experimental investigations have reported a slight reduction in BTE when biodiesel blends are used in compression ignition engines. For instance, biodiesel blends have been shown to reduce BTE by approximately 2–5% compared with pure diesel fuel [15]. This reduction is mainly attributed to the lower energy density and higher viscosity of biodiesel fuels. Higher viscosity can influence the fuel atomization process during injection, which may result in less efficient fuel–air mixing and incomplete combustion, thereby reducing engine efficiency. However, moderate biodiesel blends such as B10 and B20 often demonstrate brake thermal efficiency values comparable to conventional diesel fuel, particularly at higher engine loads. This indicates that palm oil biodiesel blends are capable of maintaining acceptable engine performance under suitable operating conditions.

### Brake Specific Fuel Consumption

Brake specific fuel consumption (BSFC) is another important parameter used to evaluate engine performance, as it represents the amount of fuel required to produce a unit of engine power. Due to the lower calorific value of biodiesel fuels, a higher amount of fuel is generally required to achieve the same engine output compared with conventional diesel fuel. Previous studies have reported that biodiesel blends typically increase BSFC by approximately 5–15% relative to diesel fuel [12], [16]. The increase in BSFC is mainly associated with the lower energy density of biodiesel fuels. However, the presence of oxygen in biodiesel molecules can enhance combustion efficiency, which may partially compensate for the higher fuel consumption observed during engine operation.

### Influence of Engine Load on Performance

Engine load significantly influences the combustion characteristics and performance of biodiesel blends. At low engine loads, combustion temperatures are relatively low, which may lead to incomplete combustion and reduced engine efficiency. Previous studies have reported that biodiesel blends tend to perform less efficiently under low-load conditions due to their higher viscosity and poorer atomization characteristics [17], [18]. These factors may result in incomplete combustion and increased fuel consumption during engine operation. Conversely, at higher engine loads, combustion temperatures and cylinder pressures increase, which enhances fuel atomization and improves combustion efficiency. Under these conditions, biodiesel blends often demonstrate performance characteristics comparable to conventional diesel fuel. This indicates that biodiesel fuels can maintain acceptable engine performance when operating under moderate to high load conditions.

### Experimental Engine Load Measurement

In laboratory experiments involving small diesel engines, dynamometers are commonly used to measure engine performance parameters. A dynamometer converts the mechanical energy produced by the engine into electrical energy, enabling researchers to apply controlled loads to the engine during testing. Load cells are frequently

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integrated with dynamometers to measure torque and brake power accurately. Accurate force measurements provided by load cells enable precise calculation of engine power and efficiency [19]. In small-scale experimental setups, electrical resistive loads such as incandescent light bulbs are sometimes used to simulate engine load conditions. By connecting different combinations of bulbs, for example 300 W, 600 W, and 900 W, researchers can create varying load levels to evaluate engine performance under different operating conditions.

### Challenges of Palm Oil Biodiesel

Despite its advantages, palm oil biodiesel also faces several technical and environmental challenges. One of the primary concerns is its relatively high viscosity compared with conventional diesel fuel, which may affect fuel injection characteristics and spray atomization. Poor atomization can lead to incomplete combustion and reduced engine performance. Another challenge is engine durability when operating with high biodiesel concentrations over extended periods. Prolonged use of high biodiesel blends may lead to fuel system deposits, injector fouling, and increased engine wear [20]. Furthermore, the cold flow properties of palm oil biodiesel can limit its application in colder climates, as the fuel may solidify or form crystals at low temperatures, potentially causing fuel flow problems in the engine fuel system.

### Research Gap

Although many studies have investigated palm oil biodiesel blends, further research is required to optimize engine performance under different loading conditions. In particular, limited research has focused on small CI diesel engines using electrical loading systems to simulate practical operating conditions. Therefore, this study aims to evaluate the performance characteristics of palm oil–diesel blends under varying electrical loads using a dynamometer setup. The investigation focuses on key performance parameters such as brake thermal efficiency and brake specific fuel consumption to determine the feasibility of palm oil biodiesel as an alternative fuel for diesel engines.

## MATERIALS AND METHODS

### Fuel Preparation

In this study, palm oil–diesel blends were prepared by mixing refined palm oil with conventional diesel fuel at different volumetric ratios. The blends used were PO20, PO40, PO60, PO80, and PO100, representing 20%, 40%, 60%, 80%, and 100% palm oil respectively. Each blend was thoroughly mixed to ensure homogeneity before being used in the engine tests. Conventional diesel fuel was also tested as the reference fuel for performance comparison. Figure 1 shows the samples of the palm oil–diesel blends.

**Figure 1: Samples Palm Oil–Diesel Blends**

**Figure 2: Deepro Diesel Engine**

### Experimental Setup

The experiments used a single-cylinder compression ignition (CI) diesel engine coupled to an electrical generator, as shown in Figure 2. The generator was connected to a resistive load bank to simulate various operating conditions. Engine performance was evaluated using instruments for speed, torque, and fuel

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consumption measurements under controlled conditions with different fuel blends. The engine specifications are summarized in Table 1.

**Table 1: Engine Specifications**

| | |
|---|---|
| Model Name | Deepro Air Cooled Diesel Engine DP186 |
| Type | Single cylinder, vertical, 4 stroke, air-cooled, direct injection |
| Bore x Stroke | 7.8 cm X 6.2cm |
| Displacement | 296 cubic centimetres |
| Compression Ratio (CR) | 20:1 |
| Rate power over speed | 6kW at full max rpm 3600 |
| Nozzle pressure | 200 kg. /cm2 |
| Fuel tank capacity | 3.5L |

### Experimental Procedure

The engine was initially operated with conventional diesel fuel to establish baseline performance. Palm oil–diesel blends were then tested under identical conditions at a constant speed with electrical loads of 300 W, 600 W, and 900 W. After stabilization, torque, brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE) were measured and calculated using standard engine performance equations.

### Data Analysis

The collected data were analyzed to compare the performance of the palm oil–diesel blends with conventional diesel fuel. Performance trends were evaluated with respect to varying load conditions and blend ratios. The results were presented in graphical form to illustrate the relationships between engine performance parameters and fuel blends.

## RESULTS AND DISCUSSION

This study investigated the performance of a compression ignition (CI) diesel engine fueled with palm oil–diesel blends containing 20%, 40%, 60%, 80%, and 100% palm oil (PO). Engine performance was evaluated at 300 W, 600 W, and 900 W loads. Fuel consumption, torque, brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE) were analyzed and compared with pure diesel to assess the feasibility of palm oil as a renewable alternative fuel. The experimental results and their implications for engine performance are discussed in the following sections.

### Fuel Consumption

Fuel consumption was evaluated by measuring the time required for the engine to consume 20 ml of fuel under different load conditions. Table 2 and Figure 3 show the time taken 20ml fuel run vs type of fuel at different loads.

**Table 2: The Result of Time Consumption of Fuel at Different Loads**

| Type of Fuel | Time Taken For 20ml run (Minutes) | | |
|---|---|---|---|
| | **Load, 300W** | **Load, 600W** | **Load, 900W** |
| Diesel | 2:10 | 2:06 | 1:50 |
| 20 % palm oil | 2:16 | 2:08 | 1:57 |
| 40% palm oil | 2:20 | 2:09 | 1:58 |

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| | | | |
|---|---|---|---|
| 60% palm oil | 2:22 | 2:10 | 2:01 |
| 80% palm oil | 2:08 | 2:02 | 1:41 |
| 100% palm oil | 2:25 | 2:04 | 2:02 |

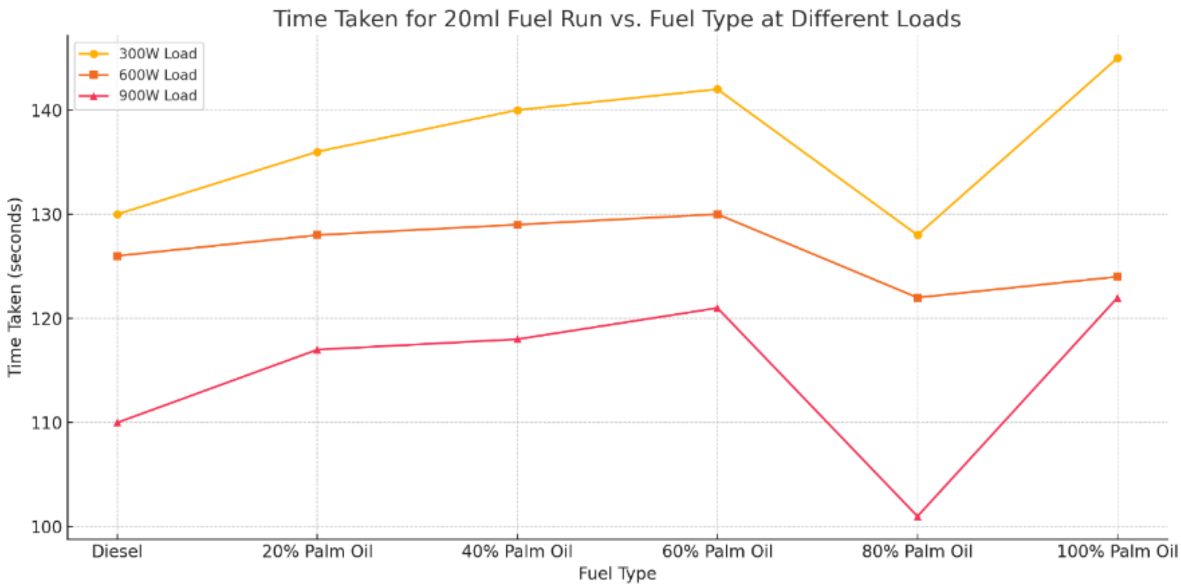


**Figure 3: Time Taken 20ml Fuel Run vs Type of Fuel**

### Fuel Consumption at 300 W Load

At a load of 300 W, pure diesel consumed 20 ml of fuel in 2 minutes 10 seconds, indicating relatively stable combustion performance. As the percentage of palm oil increased, the time required generally increased, suggesting slower fuel consumption due to the higher viscosity and lower volatility of palm oil. However, the 80% palm oil blend showed the shortest time of 2 minutes 8 seconds, indicating faster fuel consumption compared to diesel and other blends. This behaviour may be attributed to improved combustion characteristics resulting from the interaction between diesel and palm oil properties. In contrast, 100% palm oil required the longest time (2 minutes 25 seconds) to consume the same fuel volume, suggesting reduced combustion efficiency when palm oil is used alone without diesel blending.

### Fuel Consumption at 600 W Load

At a load of 600 W, a similar trend was observed. Diesel consumed 20 ml of fuel in 2 minutes 6 seconds, while the time gradually increased for blends with higher palm oil content. Interestingly, the 80% palm oil blend again recorded the shortest time of 2 minutes 2 seconds, indicating the highest fuel consumption rate. This suggests that under moderate load conditions, higher palm oil concentration may increase fuel consumption due to its lower calorific value. The 100% palm oil fuel consumed 20 ml in 2 minutes 4 seconds, which is still less efficient than diesel fuel. Overall, these results indicate that high palm oil content may lead to increased fuel consumption compared to diesel.

### Fuel Consumption at 900 W Load

Under the highest load condition of 900 W, the fuel consumption rate increased for all fuels due to greater power demand. Diesel consumed 20 ml in 1 minute 50 seconds, while palm oil blends required slightly longer times. Once again, the 80% palm oil blend showed the fastest consumption time of 1 minute 41 seconds, indicating the highest fuel consumption rate among all tested fuels. This behaviour may be linked to the balance between diesel's ignition quality and palm oil's energy contribution, resulting in efficient combustion at higher engine loads. However, 100% palm oil showed the longest consumption time of 2 minutes 2 seconds, confirming that

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pure palm oil is less efficient as a fuel without engine modification. This can be ascribed to a balance of high energy content of palm oil and partly availability of diesel that probably lowered the overall viscosity to just the right amounts to increase atomization and burn-up. The similar tendencies are registered in existing studies in this sphere, which indicates that on some occasions high percentage biodiesel blends may show even better results in case of certain thermal and engine conditions [16], [18].

**Torque**

Torque is a critical parameter for evaluating engine performance, especially in applications requiring high mechanical output such as transportation and industrial machinery. Test results data of Torque values for each variation of fuel can be seen in Table 3. The experimental results as shown in Figure 4 indicated that pure diesel produced the highest torque values at all load conditions. At 300 W, diesel produced 3.8 Nm, compared with 2.44 Nm for 100% palm oil. This reduction in torque can be attributed to the lower calorific value and higher viscosity of palm oil, which negatively affect fuel atomization and combustion efficiency. As the engine load increased to 600 W and 900 W, torque increased for all fuel types. Diesel again achieved the highest torque values of 6.01 Nm and 8.82 Nm, respectively. Among the palm oil blends, the 80% PO blend demonstrated the best performance, producing 3.2 Nm at 300 W, 5.72 Nm at 600 W, and 8.17 Nm at 900 W. These values are relatively close to diesel performance, indicating that the 80% blend provides improved combustion compared to other palm oil mixtures. The results indicate that a higher proportion of palm oil biodiesel combined with a small amount of diesel may provide an optimal balance between renewable fuel utilization and engine performance. A similar trend was reported by [21], where biodiesel–diesel blends were found to maintain satisfactory engine performance while enhancing the contribution of renewable fuel.

**Table 3: Data of Torque**

| Load (W) | Torque(Nm) | | | | | |
|---|---|---|---|---|---|---|
| | Diesel | 20% PO | 40% PO | 60% PO | 80% PO | 100%PO |
| 300 | 3.8 | 2.72 | 2.56 | 2.48 | 3.2 | 2.44 |
| 600 | 6.01 | 5.24 | 4.71 | 4.52 | 5.72 | 4.38 |
| 900 | 8.82 | 7.40 | 7.25 | 7.1 | 8.17 | 6.4 |

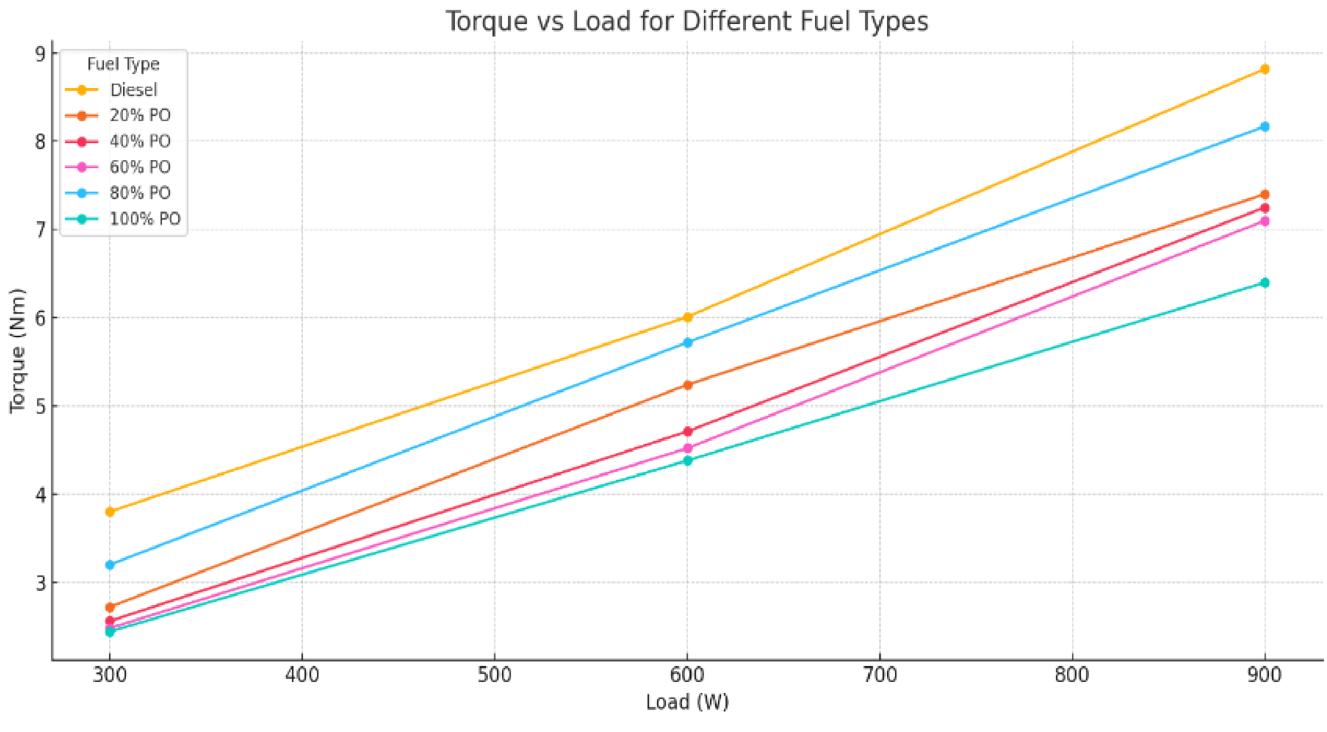


**Figure 4: Torque vs load for different type of fuels**

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### Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption measures the amount of fuel required to produce a unit of power. Lower BSFC values indicate better fuel efficiency. The results as shown in Table 4 and Figure 5 indicated that BSFC decreases as engine load increases for all fuels. This trend occurs because engines operate more efficiently at higher loads where a larger portion of fuel energy is converted into useful mechanical work. Diesel consistently recorded the lowest BSFC values, ranging from 806 g/kWh at 300 W to 421 g/kWh at 900 W, indicating the highest fuel efficiency. Palm oil blends showed higher BSFC values, reflecting their lower calorific value and poorer combustion characteristics. The 100% palm oil fuel showed the highest BSFC, confirming that more fuel is required to produce the same power output. However, the 80% PO blend demonstrated improved performance compared to other palm oil mixtures, particularly at higher loads, indicating better combustion stability.

**Table 4. The Result of BSFC of Variant Fuel at Different Loads**

| Load (W) | Diesel (g/kWh) | 20% PO (g/kWh) | 40% PO (g/kWh) | 60% PO (g/kWh) | 80% PO (g/kWh) | 100% PO (g/kWh) |
|---|---|---|---|---|---|---|
| 300 | 806 | 1220 | 1261 | 1280 | 1104 | 1104 |
| 600 | 540 | 673 | 743 | 769 | 648 | 648 |
| 900 | 421 | 466 | 528 | 526 | 547 | 547 |

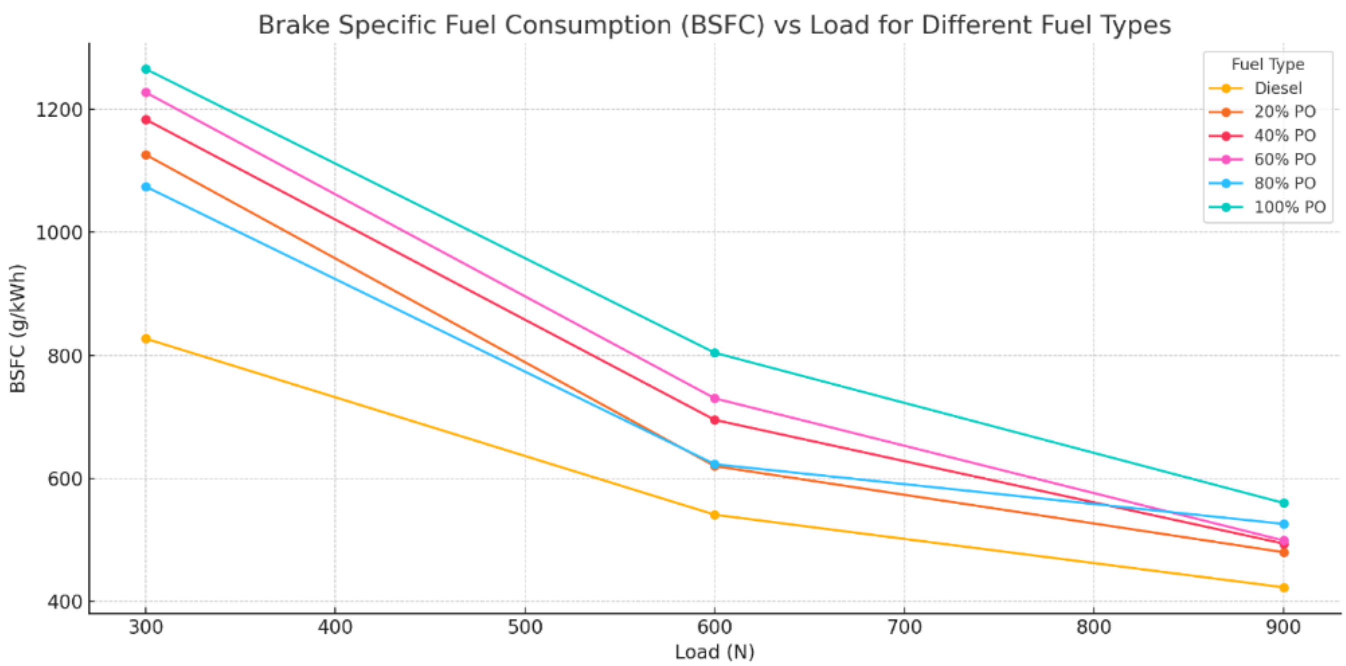


**Figure 5: Brake Specific Fuel Consumption (BSFC) vs Load Different Fuel Types**

### Thermal Efficiency (BTE)

Brake thermal efficiency (BTE) represents the effectiveness of converting the chemical energy of fuel into useful mechanical power at the engine crankshaft. The experimental results indicate that diesel achieved the highest BTE values at all load conditions, reaching 18.79% at 900 W, as shown in Figure 6. The calculated BTE values for each fuel blend are presented in Table 5. This result can be attributed to the higher calorific value and better combustion characteristics of diesel fuel, which promote more efficient energy conversion compared to biodiesel blends. As the proportion of palm oil increased, BTE generally decreased due to the higher viscosity and lower energy content of palm oil. However, the 80% PO blend showed relatively high BTE values, particularly at higher loads, achieving 16.62% at 900 W. This indicates that the blend provides improved combustion efficiency compared to other palm oil mixtures. The 100% palm oil fuel recorded the lowest BTE values, demonstrating that pure palm oil is less efficient without engine modifications.

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**Table 5: The Results of Brake Thermal Efficiency (BTE)**

| Load (W) | Diesel (%) | 20% PO (%) | 40% PO (%) | 60% PO (%) | 80% PO (%) | 100%PO (%) |
|---|---|---|---|---|---|---|
| 300 | 9.81 | 7.24 | 7.07 | 7.02 | 8.23 | 7.19 |
| 600 | 14.66 | 13.12 | 12.00 | 11.71 | 14.04 | 11.02 |
| 900 | 18.79 | 16.94 | 16.89 | 17.11 | 16.62 | 15.85 |

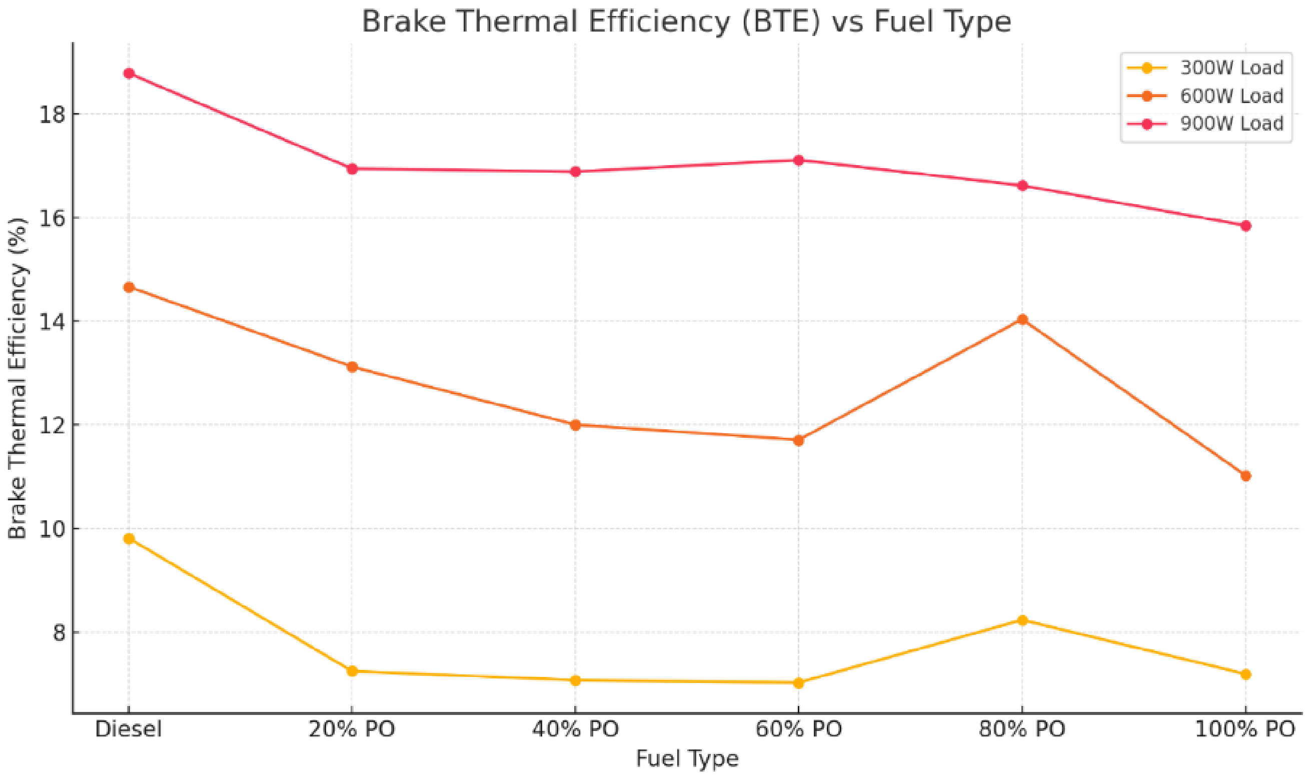


**Figure 6: BTE vs Fuel Type**

## Overall Discussion

Overall, the experimental results show that diesel fuel delivers the best engine performance in terms of torque, fuel efficiency and thermal efficiency. However, among the palm oil–diesel blends tested, the blend containing 80% palm oil consistently exhibited performance closest to that of pure diesel. This blend achieved relatively high torque and thermal efficiency while maintaining acceptable fuel consumption. The superior performance of the 80% palm oil blend may be attributed to the combined effects of diesel's favourable ignition and atomization characteristics with palm oil's renewable energy contribution. Diesel enhances combustion quality, whereas palm oil supports sustainable fuel use. These findings indicate that palm oil–diesel blends, particularly those with around 80% palm oil content, have strong potential as alternative fuels for compression ignition engines. This potential is especially relevant for palm oil–producing nations such as Malaysia.

## CONCLUSIONS

In conclusion, pure diesel fuel exhibited the best overall engine performance due to its superior fuel properties. Among the palm oil–diesel blends, PO80 showed the closest performance to diesel, delivering stable torque, acceptable fuel consumption, and competitive thermal efficiency, particularly at higher loads. In contrast, PO100 resulted in the poorest performance due to its high viscosity and poor combustion characteristics, indicating the need for engine modifications for its effective use. Overall, palm oil–diesel blends, especially PO80, demonstrate

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strong potential as alternative fuels for compression ignition engines, offering a practical balance between performance and renewable energy utilization especially in palm oil–producing countries such as Malaysia.

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