International Journal of Technology and Education Research

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E-ISSN: 2986-0733

Comparative Performance Analysis of the Gunung Belah Diesel Power Plant Using B35 and B40 Biodiesel: Technical Assessment and Implications for National Energy Security

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Abstract

In response to rising global energy uncertainty and geopolitical fragmentation, Indonesia has accelerated its energy transition through the development of high-percentage biodiesel blends. This study analyzes diesel engine performance using B35 (2024) and B40 (2025) blends to assess their technical feasibility and impact on national energy resilience. Using a quantitative experimental method, daily energy production data from three diesel generator (PLTD) units were collected over four months under real operating conditions. The 2024 results show that B35 produced a consistent increase in monthly output, peaking at more than 1,025 MWh in April, indicating good combustion efficiency and operational stability. In contrast, 2025 data show that B40 exhibited more fluctuating performance, with peak output in March but a decline in April due to system load prioritization. Nevertheless, B40 demonstrated potential for better thermal efficiency and specific fuel consumption (SFC) if load management is optimized. These findings highlight the need for adaptive system management and infrastructure readiness to support the integration of high-percentage biodiesel, thereby strengthening Indonesia's energy transition and national energy independence.

Keyword: Biodiesel B40; Energy Security; SFC; Diesel Engine Performance; Renewable Transition

INTRODUCTION

The escalating global energy crisis, exacerbated by geopolitical tensions and the fragmentation of international cooperation, has intensified the need for countries to strengthen

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their energy resilience. As one of the world's largest consumers of diesel fuel and a major producer of palm oil, Indonesia has accelerated the implementation of biodiesel blending policies to reduce dependence on imported fossil fuels while supporting its long-term energy transition objectives. In this context, ensuring the operational reliability and efficiency of diesel power generation systems using higher biodiesel blends has become increasingly important, particularly for critical sectors such as electricity generation, transportation, agriculture, and national defense (Cahyadi 2020) .

Recent studies have extensively investigated biodiesel blends as a promising alternative fuel capable of reducing greenhouse gas emissions and improving fuel sustainability. Previous research has demonstrated that biodiesel blends, including B30 and B40, can reduce carbon emissions and improve fuel lubricity compared with conventional diesel fuel. However, these benefits are often accompanied by changes in combustion characteristics, fuel consumption, thermal efficiency, and exhaust gas temperature. Although numerous studies have evaluated biodiesel performance under various operating conditions, their findings remain inconsistent due to differences in engine specifications, testing procedures, and fuel properties (Fandi, 2024).

Furthermore, most existing studies primarily emphasize emission characteristics or fuel properties, while relatively few provide a comprehensive comparison of key engine performance indicators including brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature, and engine output between conventional diesel fuel and B40 biodiesel under standardized operating conditions (Indriyani, 2022). This limitation restricts a comprehensive understanding of the technical feasibility of large-scale B40 implementation, particularly for diesel power plants operating as critical energy infrastructure. In addition, the large-scale adoption of biodiesel continues to generate debate regarding its economic feasibility, feedstock sustainability, and its potential implications for food security, highlighting the need for more robust empirical evidence.

To address these research gaps, this study presents a comparative technical evaluation of diesel engine performance using conventional diesel fuel and B40 biodiesel under controlled laboratory conditions (Noval, 2024). Unlike previous studies that primarily focus on emissions or fuel characteristics, this research simultaneously evaluates multiple operational performance parameters and discusses their implications for Indonesia's national energy security. The findings are expected to provide scientific evidence supporting the technical viability of higher biodiesel blends while contributing to policy discussions on strengthening energy independence amid increasing global geopolitical uncertainty.

Therefore, the primary objective of this study is to compare the operational performance

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of a single-cylinder diesel engine fueled with conventional diesel and B40 biodiesel by analyzing brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature, and other relevant performance indicators. The results are subsequently interpreted within the broader framework of Indonesia's energy transition strategy and national energy security, providing technical insights that may support future biodiesel utilization in diesel-based power generation systems (Salsabila, 2023).

METHOD

This study employed a quantitative experimental approach to evaluate the performance of a diesel engine using two different fuels: conventional diesel fuel and B40 biodiesel. Performance testing was conducted using a diesel power plant (PLTD) operating under controlled field conditions over a four-month period, from January to April 2025.

Operational data were collected by monitoring the daily electricity generation output, expressed in kilowatt-hours (kWh), from three diesel generator units, namely MAK 2, MAK 3, and MAK 4, operating under actual field conditions. An identical testing configuration had previously been implemented in 2024 using B35 biodiesel, thereby enabling a direct comparison between the B35 and B40 biodiesel blends while minimizing variations attributable to operating conditions.

The collected performance data were subsequently analyzed to identify variations in power generation trends, engine responsiveness, and potential operational instability associated with each fuel type. The comparative analysis was conducted to assess the influence of B40 biodiesel on diesel engine operational performance and reliability. Furthermore, the findings were interpreted within the broader context of Indonesia's national energy security strategy, providing empirical evidence on the potential contribution of higher biodiesel blends to enhancing energy resilience amid increasing global geopolitical uncertainty.

RESULTS AND DISCUSSION

Energy Generation of the Diesel Power Plant (PLTD) Using B35 Biodiesel in 2024

Performance monitoring was conducted to evaluate the operational behavior of the diesel power plant (PLTD) while operating on B35 biodiesel, a fuel blend consisting of 35% biodiesel and 65% conventional diesel. The evaluation was carried out over a four-month period, from January to April 2024, during which the daily electrical energy output of each generator unit was systematically recorded.

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International Journal of Technology and Education Research

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E-ISSN: 2986-0733

Throughout the monitoring period, the three generator units (MAK 1, MAK 2, and MAK 3) exhibited a stable and consistent increase in electrical energy output. These results indicate that the B35 biodiesel blend effectively supported reliable engine operation while demonstrating the potential to maintain or gradually improve operational performance under actual field conditions. The findings further suggest that B35 biodiesel is technically compatible with diesel engine systems used in power generation applications, providing evidence of its suitability as an alternative fuel for enhancing the sustainability of diesel-based electricity generation.

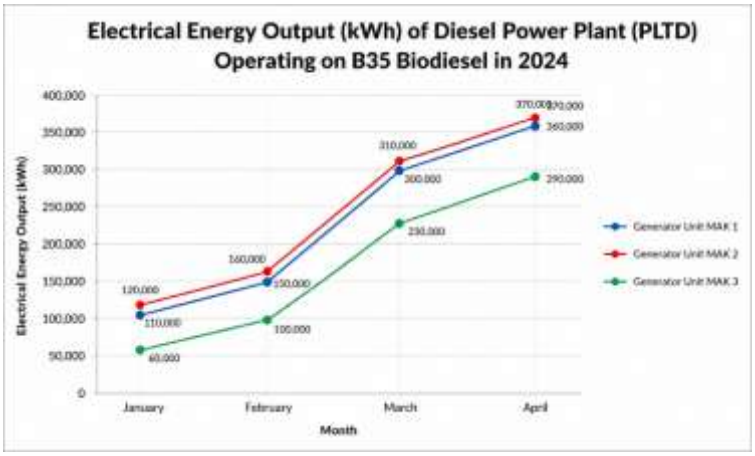


Figure 1. Electrical Energy Output (kWh) of the Diesel Power Plant (PLTD) Operating on B35 Biodiesel in 2024

In January 2024, Generator Unit MAK 1 produced 110,890 kWh of electrical energy, while Generator Unit MAK 2 and Generator Unit MAK 3 generated 124,670 kWh and 62,630 kWh, respectively. In February 2024, the electrical energy output increased to 134,710 kWh for Generator Unit MAK 1, 160,850 kWh for Generator Unit MAK 2, and 106,230 kWh for Generator Unit MAK 3. A substantial increase in electricity generation was observed in March 2024.

Generator Unit MAK 1 produced 293,010 kWh, Generator Unit MAK 2 generated 299,400 kWh, and Generator Unit MAK 3 recorded an output of 233,750 kWh. By April 2024, all three generator units reached their highest recorded electrical energy outputs during the observation period. Generator Unit MAK 1 produced 357,750 kWh, Generator Unit MAK 2 generated 365,110 kWh, and Generator Unit MAK 3 achieved 295,540 kWh. It should be noted that the generator units were operated on demand, meaning that each unit was started and dispatched only when electricity was required by consumers. Consequently, the recorded energy output reflects the

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actual operational demand during the observation period rather than continuous generator operation.

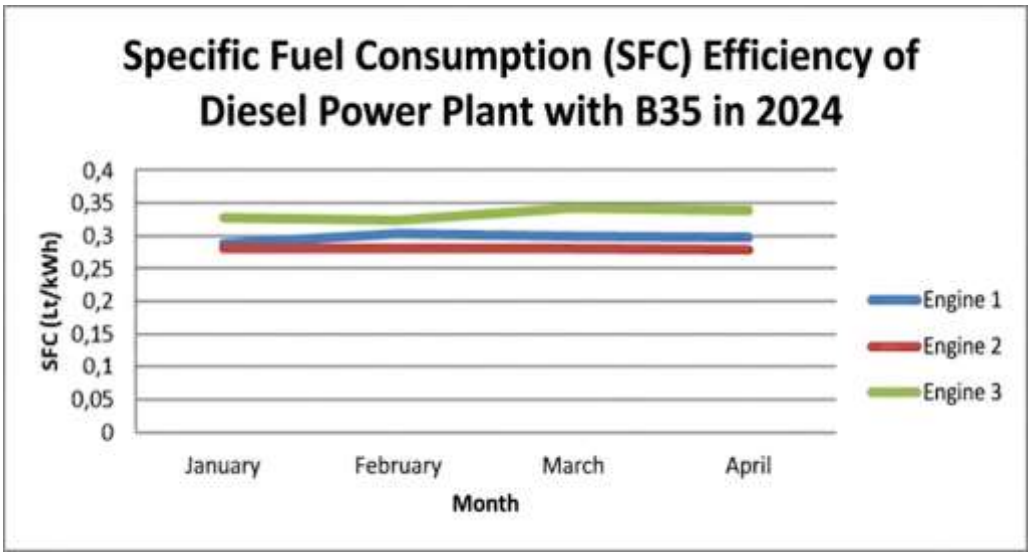


Figure 2. PLTD's Specific Fuel Consumption Efficiency (SFC) with B35 In 2024

In January engine 1 was efficient by 0.289 l/kWH, engine 2 : 0.280 l/kWH, engine 3 : 0.328 l/kWH.
In February engine 1 was efficient by 0.304 l/kWH, engine 2 : 0.280 l/kWH, engine 3 : 0.324 l/kWH.
In March engine 1 was efficient by 0.300 l/kWH, engine 2 : 0.281 l/kWH, engine 3 : 0.342 l/kWH.
In April engine 1 was efficient by 0.298 l/kWh, engine 2: 0.279 l/kWh, engine 3 : 0.339 l/kWH.

In addition to increased output, the efficiency of specific fuel consumption (SFC) has also improved. Initially the SFC was high due to non-routine operations, but improved in February, and reached peak efficiency in April when almost the entire unit was fully operational. These findings suggest that the sustainable use of B35 can improve energy conversion efficiency while strengthening the reliability of generator operations, particularly in remote or off-grid power systems.

Production of Diesel Power Generation (PLTD) Energy Generator (kWh) with B40 by 2025

In 2025, testing the use of B40 biodiesel will be carried out on three diesel generator units, namely MAK 2, MAK 3, and MAK 4 during the period from January to April. The data shows

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that MAK 2 consistently produces the highest energy output, particularly in March and April which reached more than 252 million and 278 million kWh respectively.

MAK 4 also made a major contribution in January with a production of more than 256 million kWh, but experienced a sharp decline in the following months. Meanwhile, MAK 3 showed very low activity, barely producing throughout the test period, except for a small output recorded in April.

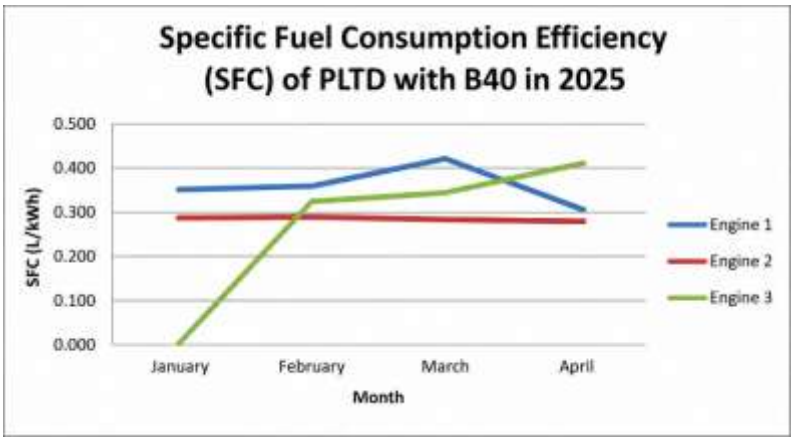


Figure 3. Production of PLTD Energy Generator (kWh) with B40 In 2025

In January the 1st engine produced 12,580 kWh, the 2nd engine: 2,220 kWh, the 3rd engine: 0 kWh, no need to operate.
In February engine 1 produced 20,290 kWh, engine 2 : 21,040 kWh, engine 3 : 35,460 kWh.
In March the 1st engine produced 94,220 kWh, the 2nd engine: 103,120 kWh, the 3rd engine: 59,740 kWh.
In April engine 1 produced 38,610Wh, engine 2: 40,870 kWh, engine 3: 13,230kWH.

Figure 4. PLTD's Specific Fuel Consumption Efficiency (SFC) with B40 by 2025

In January engine 1 was efficient by 0.353 l/kWH, engine 2 : 0.287 l/kWH, engine 3 : 0 l/kWH.
In February the 1st engine was efficient by 0.360 l/kWH, the 2nd engine : 0.287 l/kWH, the 3rd engine : 0.325 l/kWH.
In March engine 1 was efficient by 0.423 l/kWH, engine 2 : 0.283 l/kWH, engine 3 : 0.345 l/kWH.
In April engine 1 was efficient by 0.303 l/kWh, engine 2: 0.280 l/kWh, engine 3 : 0.410 l/kWH.

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In the first quarter of 2025, the transition to the use of B40 biodiesel provides opportunities as well as operational challenges for the MAK 2, MAK 3, and MAK 4 generator units. In January, total energy production was still low: MAK 2 produced 12,580 kWh, MAK 3 only 2,220 kWh, and MAK 4 was not in operation due to low load demand.

In terms of specific fuel consumption (SFC), energy conversion efficiency shows gradual improvement. January recorded high SFC due to non-routine operations and low load. In February, SFC started to stabilize, and reached peak efficiency in March when loads were high and stable. Although production declined in April, the overall trend suggests that the B40 is capable of being optimized through load planning, fuel injection arrangements, and proper operation management.

CONCLUSION

The results of the analysis show that both types of biodiesel mixtures are technically feasible for use in diesel engines. B35 has proven to provide operational stability and continuity of energy production, making it relevant for applications in decentralized generation systems in remote areas. Meanwhile, B40 shows good technical adaptability and has the potential to provide higher thermal efficiency, reflected in the lower specific fuel consumption (SFC) value of 0.278 liters/kWh on average compared to 0.303 liters/kWh in B35. This indicates that an increase in biodiesel content of up to 40% can improve energy conversion efficiency if supported by proper operation management. Thus, technically the B40 not only meets the performance standards of diesel engines, but is also able to surpass the B35 in terms of fuel utilization efficiency.

Tip: To support the sustainable implementation of B40, more adaptive load scheduling, improved plant infrastructure readiness, and real-time performance monitoring systems are needed. This step is important to ensure that the implementation of B40 can strengthen national energy security while encouraging the achievement of decarbonization targets.

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