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Performance and Emission Analysis of Gasoline Engines Using Pertalite and Bioethanol Blends: A Comparative Study

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Abstract
The increasing number of motor vehicles in Indonesia has resulted in higher fuel consumption and significant environmental concerns, particularly due to exhaust emissions such as carbon monoxide (CO) and hydrocarbons (HC). This study explores the effects of blending Pertalite, a widely used gasoline variant, with bioethanol as an alternative fuel to improve engine performance and reduce harmful emissions. A 4-stroke gasoline engine (TecQuipment TD201) was used to test four fuel mixtures: pure Pertalite (E0) and three bioethanol-Pertalite blends with 5% (E5), 10% (E10), and 15% (E15) bioethanol concentrations. Performance parameters such as torque, power, and specific fuel consumption (BSFC) were evaluated at different engine speeds (1500, 2000, 2500, and 3000 RPM), while exhaust emissions were analyzed at 2500 RPM. The results indicated that the E15 blend produced the best improvements in engine performance, with a 9.52% increase in torque and a 10.4% increase in power output at 2500 RPM. Moreover, the E15 blend demonstrated the most significant reduction in specific fuel consumption (12.99%). In terms of emissions, the E15 mixture led to a reduction of 48.46% in CO and 47.71% in HC, demonstrating its potential to mitigate air pollution. This research confirms that bioethanol-blended fuels not only enhance engine efficiency but also provide an effective solution for reducing vehicular emissions, contributing to environmental sustainability. These findings support the continued exploration and adoption of bioethanol-based fuel mixtures as a cleaner alternative for Indonesia's transportation sector.

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INTRODUCTION

The increasing number of motor vehicles in Indonesia has significantly contributed to the rise in fuel consumption and the release of harmful exhaust emissions. According to data from the Indonesian Central Bureau of Statistics (BPS), in 2016, the number of motor vehicles reached over 128 million, reflecting a 5.86% increase from the previous year (Hasudungan, n.d.; Yakin & Yudha, 2024). This surge in vehicle numbers has resulted in a parallel increase in the consumption of gasoline, with 48.6 billion liters of fuel consumed in 2016 alone, as reported by BPH Migas (Jacobsen & van Benthem, 2015; Moshiri & Aliyev, 2017). Such a rise in fuel consumption has intensified the demand for fossil fuels, leading to environmental concerns, particularly with respect to air pollution and greenhouse gas emissions. Among the most concerning pollutants are carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), which are primarily emitted from motor vehicles (Aydın & İlkılıç, 2017; Huang et al., 2016; Winkler et al., 2018).

In response to these challenges, the search for sustainable and environmentally friendly fuel alternatives has become essential. One promising alternative is bioethanol, a renewable energy source derived from plant materials such as cassava, corn, and sugarcane (Adewuyi, 2020; Niphadkar et al., 2018). Bioethanol is an oxygenated fuel with a high octane rating, which makes it capable of improving combustion efficiency and reducing harmful emissions in internal combustion engines (Barua et al., 2023; Paluri & Patel, 2022; Yusuf & Inambao, 2021). Its incorporation into gasoline as a blend has been shown to enhance engine performance, increase thermal efficiency, and reduce emissions of CO and HC (Iodice & Cardone, 2021; Mohammed et al., 2021; Putrasari & Lim, 2019).

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Bioethanol's ability to oxygenate the combustion process is particularly advantageous in optimizing engine efficiency, improving fuel combustion, and ultimately contributing to reduced emissions (A perspective on bioethanol production from biomass as alternative fuel for spark ignition engine, 2016; García et al., 2020).

Despite the widespread adoption of bioethanol in many countries as a gasoline additive, there is limited research on the use of bioethanol mixed with Pertalite, a popular fuel variant in Indonesia. Pertalite, introduced in 2015, has an octane number (RON) of 90, which is higher than that of regular gasoline (RON 88) (Julianto et al., 2020). However, the effects of mixing bioethanol with Pertalite have not been extensively explored, particularly in terms of engine performance and exhaust emissions. Given that Pertalite is increasingly used in Indonesia, evaluating its potential as a base fuel for bioethanol blends is critical to understanding its environmental and performance benefits (Budianto et al., 2024; Ihtifazhuddin et al., 2024).

Additionally, the use of bioethanol as an additive to Pertalite may offer solutions to the growing concerns surrounding energy sustainability and air quality. Previous studies have demonstrated that bioethanol blends can improve engine performance and reduce harmful emissions, but these studies primarily focus on other gasoline variants or ethanol sources. Therefore, there is a clear need for research focusing on the effects of bioethanol-Pertalite blends in the context of Indonesian fuel standards, specifically targeting 4-stroke gasoline engines. This study aims to fill this gap by evaluating the impact of different bioethanol concentrations (5%, 10%, and 15%) when mixed with Pertalite on engine performance, fuel consumption, and exhaust emissions.

By examining these fuel blends in the context of Indonesian engines and fuel systems, this research will contribute valuable insights for optimizing fuel use, enhancing engine performance, and reducing emissions in the Indonesian transportation sector. This research will also provide essential data for policymakers and industry stakeholders working to develop more sustainable and environmentally friendly fuel options for Indonesia's rapidly growing automotive sector [need citation].

METHOD

Materials and Equipment

This study was conducted using a 4-stroke gasoline engine, the TecQuipment TD201, a standard educational engine designed for engine performance and emission testing. The engine was connected to a water brake dynamometer, which was used to measure the engine's performance under various operating conditions. This setup allowed precise control of engine load and rotational speed. The fuel used in the study included Pertalite (E0) and three bioethanol-Pertalite blends, namely E5, E10, and E15, corresponding to 5%, 10%, and 15% bioethanol concentrations, respectively. The Pertalite fuel used had an octane rating (RON) of 90, which is a common fuel type in Indonesia. The bioethanol used was sourced from PT. BRATACO, with a purity of 99.39%.

Fuel Preparation

The fuel mixtures were prepared by accurately measuring the required volumes of Pertalite and bioethanol using calibrated graduated cylinders. The specific blends were prepared as follows:

- E5: 95% Pertalite and 5% bioethanol
- E10: 90% Pertalite and 10% bioethanol
- E15: 85% Pertalite and 15% bioethanol

These fuel mixtures were thoroughly mixed and stored overnight to ensure uniform blending before being used in engine testing. Each mixture was used immediately after preparation to prevent any phase separation.

Experimental Procedure

The engine was tested under controlled conditions at four different operating speeds: 1500 rpm, 2000 rpm, 2500 rpm, and 3000 rpm, chosen to represent typical operating speeds of gasoline engines in vehicles. Prior to conducting any measurements, the engine was allowed to run for a sufficient amount of time to reach its optimal operating temperature. This ensured that all performance data collected was representative of the engine's performance under normal operating conditions. At each of the specified engine speeds, engine performance parameters such as torque, power output, and specific fuel consumption (BSFC) were measured. These parameters were assessed by the dynamometer, which recorded the engine's output under different loads. Torque and power output were directly measured by the dynamometer at each RPM setting. BSFC was calculated by measuring the rate of fuel consumption and correlating it with the engine power output at each RPM setting.

Emission Testing

Emission testing was carried out at a constant engine speed of 2500 rpm, as this speed is commonly encountered in typical driving conditions and reflects mid-range engine loads. The emissions of carbon monoxide (CO) and hydrocarbons (HC) were measured using a Stargas 898 exhaust gas analyzer, which was calibrated according to the manufacturer's instructions before testing began. The analyzer provided real-time measurements of the exhaust gases emitted by the engine during operation, and data was recorded for each of the four fuel blends. CO and HC emissions were the primary focus of the testing, as these are the major pollutants emitted by gasoline engines.

Data Analysis

Data obtained from the performance and emission testing was carefully analyzed to assess the effects of bioethanol on engine performance and exhaust emissions. The key performance indicators (torque, power output, and BSFC) were compared across the four different fuel blends and engine speeds to determine the most effective bioethanol concentration in Pertalite. Emission reductions for CO and HC were also evaluated, comparing the results for each fuel blend at 2500 rpm. For each engine speed, the reduction in specific fuel consumption (BSFC) was calculated to assess the fuel efficiency of the bioethanol blends. Similarly, the emission reductions were calculated as a percentage decrease in CO and HC emissions compared to the baseline (E0 - Pertalite only). Statistical analysis was performed to determine the significance of the results using standard deviation and analysis of variance (ANOVA), with a significance level set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Results

Engine Performance

The engine performance tests revealed significant improvements in both torque and power output when using bioethanol-Pertalite blends compared to pure Pertalite (E0). The torque and power output were measured at four engine speeds: 1500 rpm, 2000 rpm, 2500 rpm, and 3000 rpm. The performance results are summarized in Table 1, which provides the percentage change in torque and power at each engine speed for the different fuel blends. As shown, the E15 blend (15% bioethanol) consistently resulted in the highest increases in torque and power output.

At 2500 rpm, the E15 blend produced the highest increase in torque (9.52%) and power (10.4%) compared to E0 (pure Pertalite). E10 and E5 blends showed moderate improvements in torque and power, with E10 yielding a 5.3% increase in torque and a 7.2% increase in power, while E5 showed a 3.2% increase in torque and a 5.1% increase in power. These findings align with previous research that suggests bioethanol's higher octane number and oxygen content improve combustion efficiency, leading to better engine performance.

Table 1. Engine Performance at Different Fuel Blends and RPMs

Fuel Blend	Torque Increase (%)	Power Increase (%)
E0 (Pertalite)	-	-
E5 (5% Bioethanol)	3.2%	5.1%
E10 (10% Bioethanol)	5.3%	7.2%
E15 (15% Bioethanol)	9.52%	10.4%

Specific Fuel Consumption (BSFC)

Specific Fuel Consumption (BSFC) is a key indicator of fuel efficiency. The results showed that the E15 blend achieved the lowest BSFC, with a 12.99% reduction compared to pure Pertalite (E0). This indicates that the higher bioethanol content led to more efficient fuel use. The E10 blend also showed a decrease in BSFC (8.7%), while the E5 blend showed the smallest reduction (4.3%). The reduction in BSFC is primarily attributed to the oxygen content in bioethanol, which facilitates more complete combustion, improving the overall fuel efficiency. Figure 2 presents the correlation between fuel blends and BSFC at 2500 rpm, showing the fuel efficiency improvements with increasing bioethanol concentrations.

Emissions

Emission testing at 2500 rpm focused on carbon monoxide (CO) and hydrocarbons (HC), which are two major pollutants from gasoline engines. The emission results are shown in Table 2. The E15 blend resulted in the most significant reductions in both CO and HC emissions, with a 48.46% reduction in CO and a 47.71% reduction in HC compared to the baseline fuel (E0). The E10 blend also led to significant reductions in emissions, with a 34.21% reduction in CO and a 38.55% reduction in HC. The E5 blend showed the smallest reductions in both CO (21.14%) and HC (24.76%), indicating that lower concentrations of bioethanol in the fuel blend have a more limited effect on emission reduction. These reductions in emissions can be attributed to the improved combustion efficiency facilitated by bioethanol's oxygen content, which enables a more complete oxidation process, reducing the formation of CO and HC during combustion. These results align with previous studies (Yoon et al., 2009; Kim et al., 2010), which also demonstrated that bioethanol blends reduce harmful exhaust emissions by promoting more efficient combustion.

Table 2. Emission Reductions for CO and HC at 2500 rpm

Fuel Blend	CO Reduction (%)	HC Reduction (%)
E0 (Pertalite)	-	-
E5 (5% Bioethanol)	21.14%	24.76%
E10 (10% Bioethanol)	34.21%	38.55%
E15 (15% Bioethanol)	48.46%	47.71%

Comparative Analysis of Bioethanol Concentration

The comparison of different bioethanol concentrations in Pertalite-based fuel blends demonstrated that increasing bioethanol content led to both higher engine performance and greater reductions in emissions. The E15 blend provided the best overall performance, achieving the highest torque, power, and the lowest BSFC. Furthermore, it resulted in the most significant emission reductions, making it the most optimal blend for both performance and environmental sustainability. The E10 blend, while slightly less effective than E15 in terms of performance and emission reduction, still showed considerable improvements over E0, particularly in emission reductions. The E5 blend, on the other hand, had only modest benefits in terms of both performance and emission reductions, suggesting that a higher concentration of bioethanol is necessary to achieve meaningful improvements in both areas.

Implications for Fuel Policy and Future Research

This study demonstrates that bioethanol-Pertalite blends—particularly the E15 blend—offer a promising solution for enhancing engine performance and reducing emissions in the context of Indonesia's automotive sector. The reduction in fuel consumption and harmful emissions aligns with Indonesia's goals for reducing environmental pollution and improving fuel efficiency. The results suggest that the adoption of bioethanol as a blending agent in Pertalite can significantly contribute to a more sustainable transportation sector. However, further research is needed to evaluate the long-term effects of bioethanol blends on engine durability and fuel system compatibility. Studies examining a broader range of engine types, vehicle conditions, and different ethanol sources will provide a more comprehensive understanding of the potential benefits and challenges associated with bioethanol as a fuel additive.

Discussion

The results of this study demonstrate that bioethanol-Pertalite fuel blends, particularly with higher bioethanol concentrations, offer significant improvements in engine performance and a substantial reduction in harmful emissions, supporting their potential as an environmentally sustainable alternative fuel. The E15 blend (15% bioethanol) outperformed both E5 and E10 in all measured parameters, showing the highest increase in torque (9.52%) and power output (10.4%) at 2500 rpm, which can be attributed to the higher octane rating of bioethanol that allows the engine to operate at a higher compression ratio, enhancing combustion efficiency. Additionally, the E15 blend resulted in a 12.99% reduction in specific fuel consumption (BSFC), indicating that the higher ethanol content contributes to more efficient fuel utilization. Furthermore, the E15 blend led to the most significant reductions in carbon monoxide (CO) and hydrocarbons (HC) emissions—48.46% and

47.71%, respectively—due to the improved combustion process facilitated by the oxygen content in bioethanol, which promotes more complete oxidation of the fuel. These findings are consistent with previous studies that show bioethanol blends can lower harmful emissions by enhancing the combustion process, which reduces the formation of CO and HC. While the E10 blend showed moderate improvements in performance and emission reductions, the E5 blend had relatively modest benefits, particularly in emission reduction, suggesting that higher ethanol concentrations are necessary to achieve meaningful gains. The results of this study underscore the potential of bioethanol-Pertalite blends in contributing to fuel efficiency and environmental sustainability, offering a viable solution to the growing concern of vehicular emissions in Indonesia. However, further research is needed to explore the long-term impacts of bioethanol on engine durability and fuel system compatibility to ensure the broader adoption of these fuel blends. Additionally, studies focusing on different engine types and operational conditions are crucial for providing a more comprehensive understanding of the full potential of bioethanol as an alternative fuel.

Implication

The implications of this study are significant for both the automotive industry and environmental policy, particularly in Indonesia, where the transportation sector is a major contributor to air pollution and carbon emissions. The findings highlight that bioethanol-Pertalite blends, especially those with higher concentrations of bioethanol, offer a viable pathway to improving fuel efficiency and reducing harmful emissions, making them an essential component in the transition toward more sustainable energy sources. The substantial emission reductions observed with the E15 blend, in particular, suggest that bioethanol can play a key role in helping Indonesia meet its environmental goals, such as reducing greenhouse gas emissions and improving air quality in urban areas. The performance improvements associated with higher bioethanol concentrations also suggest that bioethanol can enhance the energy security of the country by reducing dependency on fossil fuels. Furthermore, these findings could influence fuel policy decisions, supporting the adoption of bioethanol-blended fuels in national fuel standards and potentially spurring the growth of the bioethanol industry in Indonesia. However, to fully capitalize on the potential of bioethanol as an alternative fuel, additional research is needed to assess the long-term effects on engine durability, fuel system compatibility, and the economic feasibility of large-scale bioethanol production. Such studies will be crucial in ensuring that bioethanol-Pertalite blends can be effectively implemented across various engine types and operational conditions, providing a sustainable and practical solution for Indonesia's growing transportation sector.

Limitation and Suggestion for Further Research

While the results of this study provide valuable insights into the performance and emission benefits of bioethanol-Pertalite blends, there are several limitations that should be addressed in future research. First, this study focused on a single type of engine, the TecQuipment TD201, which may not fully represent the diverse range of gasoline engines used in vehicles across Indonesia. Therefore, it is essential to conduct further studies using different engine types, including multi-cylinder and larger capacity engines, to assess the generalizability of the findings. Additionally, the study was conducted under controlled laboratory conditions, which may not fully replicate real-world driving scenarios. Future research should explore the effects of bioethanol-Pertalite blends under various operational conditions, such as varying load factors, driving cycles, and long-term use, to better understand how these blends perform in everyday vehicle operation. Another limitation is the relatively short duration of the emission and performance tests, which do not account for the long-term impact of bioethanol on engine durability and fuel system components, such as fuel injectors and seals, which may degrade over time with higher ethanol concentrations. Therefore, future research should include durability testing to determine the long-term effects of bioethanol on engine components. Furthermore, while the study focused on the environmental benefits of bioethanol blends, additional research is needed to evaluate the economic feasibility of large-scale bioethanol production in Indonesia, considering factors such as production costs, supply chain logistics, and its potential impact on fuel prices. Addressing these limitations will provide a more comprehensive understanding of the benefits and challenges associated with the widespread adoption of bioethanol-blended fuels in Indonesia's transportation sector.

CONCLUSION

In conclusion, the findings of this study demonstrate that bioethanol-Pertalite blends, particularly those with higher concentrations of bioethanol (such as the E15 blend), offer substantial improvements in both engine performance and emission reductions, making them a promising alternative fuel option for Indonesia's transportation sector. The E15 blend resulted in the highest increases in torque and power, as well as the most significant reductions in specific fuel consumption (BSFC) and carbon monoxide (CO) and hydrocarbon (HC) emissions, underscoring the potential of bioethanol to enhance fuel efficiency and contribute to environmental sustainability. These results highlight the ability of bioethanol to improve combustion efficiency and reduce pollutant emissions, aligning with global efforts to transition to cleaner energy sources. However, while the study provides valuable insights, it also identifies several areas for future research, including the need for long-term testing on engine durability, fuel system compatibility, and the economic feasibility of large-scale bioethanol production. Overall, this research contributes to the growing body of evidence supporting the use of bioethanol as a viable, sustainable fuel alternative, offering a pathway to reduce Indonesia's reliance on fossil fuels and mitigate the environmental impact of motor vehicle emissions.

AUTHOR CONTRIBUTION STATEMENT

The corresponding author, Yuda Helmi, was primarily responsible for conceptualizing the research framework, developing the experimental design, conducting the engine performance tests, and performing data acquisition and analysis. He also led the manuscript preparation, drafting, and revision process to ensure scientific clarity and coherence. Herry Wardono contributed to the supervision of the experimental procedures, providing expert guidance on mechanical system modeling, performance evaluation, and validation of the experimental setup. He also reviewed and refined the analytical methods and contributed to the critical interpretation of the findings. Moh. Badaruddin assisted in the fabrication and assembly of the test rig, the calibration of measuring instruments, and the evaluation of fuel consumption and emission characteristics. He contributed to data verification, literature synthesis, and the refinement of technical discussions in the manuscript

CONFLICTS OF INTERES

The authors declare that there is no conflict of interest regarding the publication of this article. The research was conducted independently and objectively without any financial, institutional, or personal relationships that could be perceived as influencing the results or interpretation of the study. All analyses, findings, and conclusions were solely based on empirical data and academic integrity.

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