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Experimental study of bioethanol addition to enhance power efficiency and torque in the C-series 100 engine

Asroful Abidin
Universitas Muhammadiyah Jember
Jember, Indonesia

Email of the corresponding author: asrofulabidin@unmuhjember.ac.id

Abstract

This study evaluates the effect of adding bioethanol to Pertamax fuel at concentrations of 10%, 15%, and 20% on the performance of a C-series 100 gasoline engine. Using a quasi-experimental design, tests were conducted with a dynamometer to measure changes in power (horsepower) and torque at various time intervals. The results showed that the addition of 20% bioethanol resulted in a significant improvement, with a peak power of 3.6 HP and a maximum torque of 36.2 N·m at 3.78 seconds, indicating more efficient combustion due to the higher-octane rating and oxygen content in bioethanol, which enhances the combustion process. The 15% blend also delivered positive results with a peak power of 3.3 HP and torque of 32.79 N·m at 4.54 seconds, while the 10% blend showed more moderate gains. Despite the performance improvements, attention should be paid to potential long-term side effects such as corrosion and changes in the engine's lubrication characteristics due to bioethanol's hygroscopic properties. These findings reinforce the role of bioethanol as an eco-friendly and efficient alternative fuel in improving vehicle performance while reducing carbon emissions. This research significantly contributes to the automotive industry and policymakers developing sustainable fuel technologies. It serves as a reference for optimizing bioethanol blends to achieve a balance between enhancing engine performance and component durability.

Keywords: alternative fuel, bioethanol, C-series 100, dynamometer, engine performance

1. Introduction

As awareness of climate change increases, many countries are adopting renewable energy policies to reduce the impact of fossil fuels, particularly in the transportation sector. Biofuels have emerged as a promising alternative with lower carbon emissions and can be produced from renewable biomass. Biofuels are classified into three generations based on biomass sources: first generation (food crops), second generation (lignocellulosic biomass), and third generation (algal biomass), with technology continuously evolving to enhance sustainability [1], [2], [3], [4], [5]. Global biofuel demand is projected to rise by 28% from 2021 to 2026 to support sustainable development goals and reduce greenhouse gas emissions [6], [7], [8]. Fossil fuel-powered vehicles, which accounted for 41% of CO2 emissions in the transportation sector or 7.3 billion metric tons in 2020, especially in the U.S., China, and Europe, highlight the need for alternatives such as bioethanol and biodiesel to reduce the carbon footprint [3], [9], [10], [11], [12]. However, energy policies are often short-term and face challenges, including the impact of the COVID-19 pandemic, which delayed renewable energy priorities [13], [14]. While biofuels from various generations show improved sustainability, their success depends on policies like carbon taxes and emission standards [9]. Although each country takes a different approach, biofuels remain crucial in the clean energy transition [2], [15].

Bioethanol can partially replace fossil fuels with lower greenhouse gas emissions as a renewable fuel. Produced from materials such as sugarcane, corn, and lignocellulosic biomass (agricultural residues and waste), second-generation bioethanol has significant potential without threatening food security. However, an effective pretreatment process is necessary to address the complexity of lignocellulose [16]. In Indonesia, approximately 104.47 million tons of lignocellulosic biomass waste are available annually, potentially producing 59.98 billion gallons (227.01 billion liters) of bioethanol. This production increases in line with the growth in crop production, livestock populations, and the number of animals slaughtered [17]. Although there have been advancements in bioethanol production from lignocellulosic biomass, its commercial-scale application still needs to be improved. The main challenges lie in developing more cost-effective and efficient pretreatment strategies and improving the efficiency of biocatalysts and enzymes [18].

Bioethanol blends, such as E60, have been shown to provide optimal torque and power output compared to other blends, while E50 exhibits the lowest specific fuel consumption [19]. Globally, efforts to develop biofuels continue to be supported by policies such as the Renewable Energy Directive (RED) in the European Union, which promotes the production of biofuels from non-food raw materials [20]. The development of bioethanol from lignocellulose supports the transition to clean energy. It contributes to the circular economy by utilizing waste residues, which aligns with sustainable economic growth objectives [21]. One application of bioethanol is blending it with gasoline, such as Pertamax, to reduce carbon dioxide emissions and increase the octane rating. With its high-octane number and evaporative cooling effect, bioethanol improves combustion efficiency and reduces soot formation in gasoline engines. Alcohol use in fuel blends has also been proven to reduce soot emissions, unburned hydrocarbons, and carbon monoxide while enhancing thermal efficiency [22].

Testing of blended fuels, such as BE50 (50% bioethanol, 50% isooctane), demonstrated the best performance at an ignition timing of 12° before top dead center (BTDC), with cleaner combustion and lower emissions of carbon monoxide and hydrocarbons [23]. Adding additives, such as cyclohexanol, to gasoline-bioethanol blends can improve combustion stability, although specific fuel consumption (SFC) remains higher than pure gasoline [24]. The use of E20 fuel (20% bioethanol, 80% gasoline) showed no significant differences in terms of power, torque, fuel consumption, and emissions (CO2, CO, NOx, hydrocarbons, and volatile organic compounds) compared to regular gasoline, even after 100,000 km of use [25]. However, thermal efficiency can increase by up to 25%, and fuel consumption can be reduced by up to 28% with optimized bioethanol blends, accompanied by a decrease in carbon monoxide emissions by 10% and hydrocarbons by up to 18% [26].

Gasoline engines like the C-series 100 can benefit from bioethanol blends, with improved combustion quality resulting in better power and torque output. For example, an E60 blend (60% bioethanol, 40% gasoline) provides optimal torque and power compared to E40 and E50, indicating that higher bioethanol content can enhance engine performance. E50 exhibits the lowest specific fuel consumption, while E40 and E60 show the lowest hydrocarbon emissions at low and high engine speeds, indicating increased combustion efficiency as bioethanol content rises [19]. Adding ethanol to gasoline effectively reduces hydrocarbon (H.C.) and carbon monoxide (C.O.) emissions, especially in spark-ignition engines operating cold with a 20% ethanol blend. This effect is due to the higher oxygen content in the fuel, which improves combustion efficiency [27]. Alcohol-gasoline blends reduce C.O., NOx, and unburned hydrocarbon (UHC) emissions compared to conventional gasoline due to more complete combustion [28]. Blends like bio-gasoline and ethanol can increase torque, power, and efficiency, with the best results obtained from mixtures combining both fuels [29]. However, increased fuel consumption and reduced thermal efficiency may occur, indicating a trade-off between performance and fuel efficiency [30].

Research indicates that an E10 blend (10% bioethanol, 90% gasoline) achieves the highest engine torque and best volumetric efficiency while reducing C.O. and hydrocarbon emissions compared to pure gasoline [31]. However, higher bioethanol concentrations, such as E20, can decrease engine power and torque by approximately 30% [32]. Adding 20% bioethanol to diesel-biodiesel blends also increases unburned hydrocarbon and C.O. emissions, although adding 10% can improve efficiency and reduce NOx emissions [33]. Including bioethanol in biodiesel-diesel blends has been shown to enhance engine performance and lower emissions compared to pure diesel, highlighting the potential benefits of bioethanol in various types of fuel mixtures [34]. While the E10 blend (10% bioethanol) demonstrates positive results in improving combustion efficiency and reducing carbon monoxide emissions, research on higher concentrations, such as E15 (15%) and E20 (20%), remains limited [35].

Further in-depth studies are needed to explore the benefits and limitations of using higher bioethanol concentrations, especially in engines like the C-series 100 [36]. Most current bioethanol studies focus on the impact on emissions and combustion without addressing specific changes in power output and engine torque as bioethanol concentration increases. For example, Zhang and Wang (2021) reported that adding ethanol to fuel can increase combustion temperature and exhaust emissions but did not evaluate detailed changes in engine power [37]. This highlights the need for more targeted research on the impact of varying bioethanol concentrations on engine performance [38].

The long-term effects of high bioethanol blends on engine components, such as the potential for corrosion and combustion stability in C-series 100 gasoline engines, have yet to be extensively discussed. Some studies suggest that bioethanol can significantly increase the risk of metal corrosion if its concentration exceeds 10% [39]. Therefore, further research is needed to explore these effects on engines like the C-series 100 [40]. While many studies focus on fuel efficiency, few investigate how bioethanol concentrations above 10% impact exhaust emissions and engine operating temperatures. For instance, using E15 bioethanol has been reported to increase engine temperature, potentially shortening component lifespan [41].

More empirical data is also required regarding the impact of emissions such as NOx and fine particulates [42]. Thus, clear, practical guidelines regarding the optimal bioethanol concentration used in C-series 100 engines to enhance performance without compromising stability are needed. Such guidelines are crucial for the automotive industry and consumers in balancing fuel efficiency with engine durability [43].

This research is necessary because bioethanol as a blended fuel can be a sustainable solution to reduce carbon emissions by up to 60% compared to conventional gasoline and support clean energy in the automotive sector [44]. With the growing demand for environmentally friendly fuels, understanding the impact of varying bioethanol concentrations is essential to achieving emission reduction targets in the transportation sector [45]. This study will test adding 10%, 15%, and 20% bioethanol to Pertamax on the power and torque of the C-series 100 engine, using a dynamometer for precise measurements. The empirical data generated will help fill the information gap regarding specific effects on engine performance and provide practical guidelines on the most optimal bioethanol blend [46]. The research is also relevant for energy policymakers and the automotive industry in developing more eco-friendly fuel technologies, reducing dependence on fossil fuels, and enhancing energy resilience [47], [48]. Additionally, the results are expected to assist the industry and users in determining efficient blends, supporting global efforts to reduce emissions and achieve environmental sustainability.

2. Methods

The study employs a quasi-experimental design to examine the effect of varying bioethanol concentrations in Pertamax fuel on the performance of a four-stroke gasoline engine, precisely the C-series 100 type. The tested bioethanol concentration variations are 10%, 20%, and 30%, with a bioethanol purity level of 90%. This experimental design allows for observing changes in dependent variables, such as horsepower (H.P.) and torque (T.Q.), in response to adding bioethanol concentration to the fuel. The testing is conducted under controlled laboratory conditions using a dyno test to ensure accurate and reliable results regarding the engine's performance. The data is then statistically analyzed to determine significant differences between bioethanol concentrations.

The population in this study consists of gasoline engines using Pertamax fuel, focusing on the C-series 100 type engine. The sample used includes one unit of the C-series 100 engine, tested with three different bioethanol blend variations, namely 10%, 20%, and 30%. Each blend variation is tested three times to obtain consistent and reliable data. The fuels used in the tests are Pertamax and bioethanol, with a purity level of 90%. The testing is conducted at the Energy Conversion Laboratory of Universitas Muhammadiyah Jember.

The main instrument used in this study is a chassis-type dynamometer from sportdevices.com, capable of measuring engine power output and torque with high precision. Additionally, a blower is used to direct air towards the engine during the testing process. The results from the dyno test are displayed and analyzed using the Sport Dyno software version 3.8.44. Each test is conducted under calibrated conditions to ensure accuracy.

The research was carried out through several stages, starting with the preparation phase, in which the C-series 100 engine was calibrated and set to standard conditions to measure the baseline performance using pure Pertamax, thus establishing the engine's initial performance before adding bioethanol. Next, bioethanol with a purity level of 90% was mixed with Pertamax in three different concentrations: 10%, 20%, and 30%, homogenized to ensure an even distribution of bioethanol. The scheme of the research process is presented in Figure 1 below.

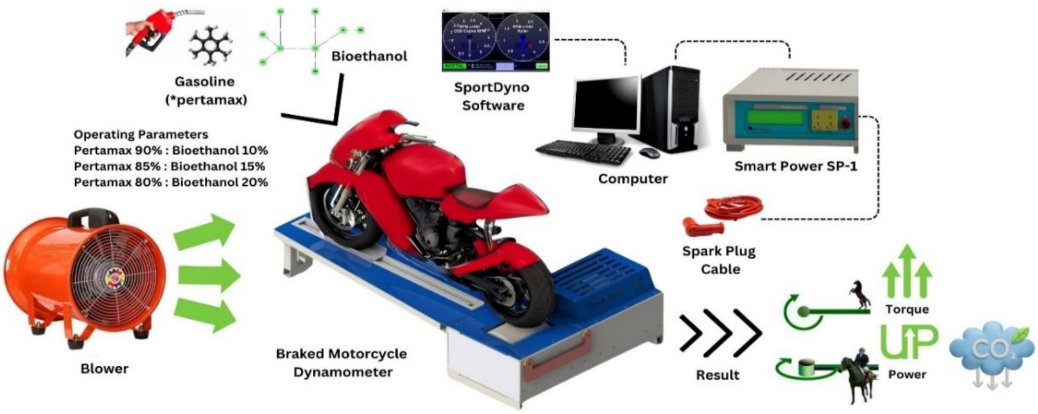

Figure 1. Research Process Scheme

The dyno test was conducted by operating the engine with each fuel mixture alternately, with power and torque measurements taken using a dynamometer at various time intervals. The testing was conducted at the Energy Conversion Laboratory of the Universitas Muhammadiyah Jember, with each mixture tested three times to ensure data accuracy and reduce variability. The data obtained was analyzed using statistical software to identify performance differences among the 10%, 15%, and 20% bioethanol mixtures and to determine which mixture provided the best increase in power and torque. The study employed a dyno test apparatus scheme shown in Figure 1, which illustrates the testing layout and the use of a blower to enhance air circulation to the engine during testing.

3. Results and Discussion

This research successfully fills a gap by providing empirical data on the impact of adding 15% and 20% bioethanol to Pertamax fuel on the performance of the C-series 100 engine. Increasing the bioethanol concentration in gasoline can enhance engine performance and reduce specific emissions, although it requires ignition timing adjustments and may lead to increased nitrogen oxide and hydrocarbon emissions [49]. The dyno test results indicate that the 20% bioethanol blend can boost maximum power by up to 3.6 HP and torque by 36.2 N·m at 3.78 seconds. Moreover, higher ethanol concentration and engine speed can improve volumetric efficiency and fuel consumption, though thermal efficiency decreases, and exhaust emissions are reduced compared to pure gasoline [50]. The horsepower (H.P.) test results are presented in Figure 2 below.

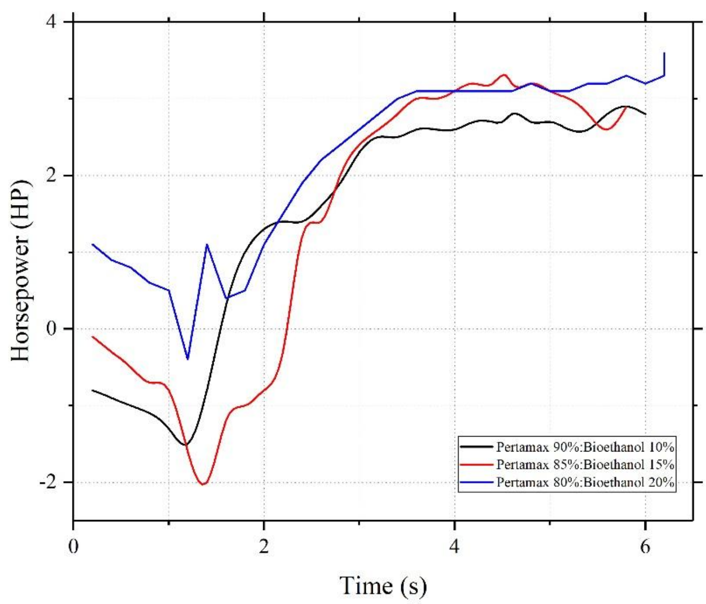

Figure 2. Test Results of Horsepower (HP) on the C-Series 100 Engine

This study provides a more in-depth focus on the changes in power and torque resulting from variations in bioethanol blends, where the addition of 15% bioethanol yields a peak power of 3.3 HP and torque of 32.79 N·m at 4.54 seconds. The molecular characteristics of isooctane and bioethanol, such as the number of non-rotatable bonds and bond angles, affect engine performance, with the more reactive and combustible nature of bioethanol leading to cleaner combustion and lower C.O. and H.C. emissions at an ignition timing of 12° BTDC [51]. On the other hand, the addition of 10% bioethanol in diesel/biodiesel mixtures has been shown to improve engine efficiency and reduce NOx emissions, but increasing the bioethanol concentration to 20% results in higher unburned hydrocarbons and C.O. emissions [52]. Although there is a slight reduction in torque and maximum power under partial load conditions, adding ethanol to these mixtures does not cause significant losses in overall engine performance or efficiency [53].

These differences indicate that increasing the bioethanol concentration directly affects the performance of the C-series 100 engine in terms of power and torque. The primary reason for the improved engine performance with the addition of bioethanol lies in the combustion characteristics of bioethanol itself. Bioethanol has a higher-octane rating than fossil fuels like Pertamax, making it more resistant to knocking or detonation. With a higher octane number, the bioethanol blend allows the engine to operate at a higher compression ratio and improve combustion efficiency, resulting in greater power and torque [54], [55]. Additionally, bioethanol contains a higher oxygen content, which supports a more complete and efficient combustion process [56], [57]. In this study, increasing the bioethanol concentration from 15% to 20% significantly impacted engine performance, as evidenced by increased maximum power and torque [58], [59]. This demonstrates that bioethanol serves as an alternative fuel and enhances engine performance in a measurable way, which is valuable for developing environmentally friendly vehicle technologies [60], [61], [62]. The torque test results (N·m) for the C-series 100 engine are presented in Figure 3 below.

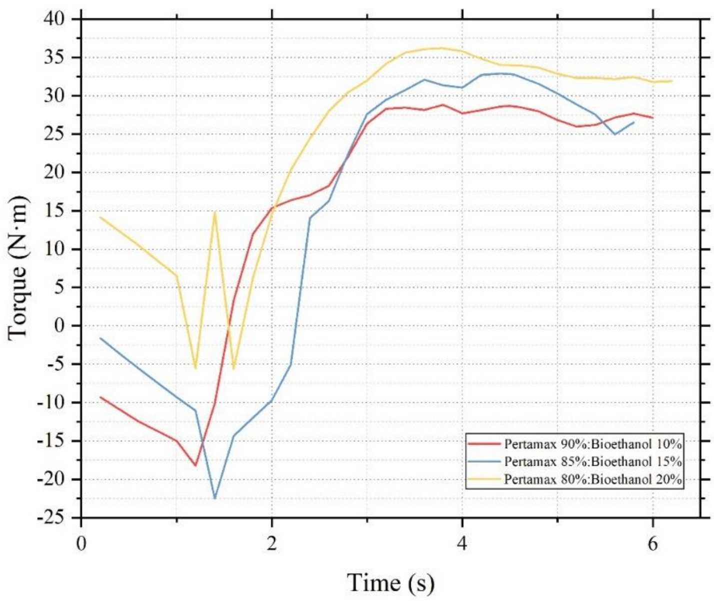

Figure 3. Torque Test Results (N·m) on the C-series 100 Engine

This study reveals that higher bioethanol concentrations can produce greater power output, but the longarm to evaluate engine components still needs to be evaluated. Several studies indicate that using bioethanol at high concentrations, such as 20%, improves engine performance in terms of power and torque, thanks to the higher octane number and oxygen content that supports more efficient combustion [63], [64]. The high octane rating allows the engine to operate at a more optimal compression ratio, reducing the risk of knocking or detonation and resulting in higher energy efficiency [65], [66]. However, there are concerns about potential adverse effects on engine components due to bioethanol's corrosive properties and its ability to absorb water, which can accelerate wear and material degradation in engine parts [38], [67]. Some research suggests that bioethanol may affect engine lubrication because of increased metal wear over the long term [67], [68]. This highlights the importance of long-term evaluation to determine the impact on engine lifespan when increasing bioethanol concentration in fuel [51], [69].

Additionally, some studies indicate that bioethanol can alter engine lubricants' properties and potentially affect lubrication performance at high temperatures [70]. The impact of bioethanol on lubrication may also increase the risk of engine damage over the long term if not accompanied by proper lubrication [71]. Other research highlights the importance of examining the effects of bioethanol blends on the fuel injection system and the formation of deposits in the combustion chamber, which can contribute to a decline in engine performance [68], [72].

Although bioethanol improves combustion efficiency and engine performance, further research is needed to ensure that these performance gains do not compromise engine lifespan in the long run. The results of this study suggest that blending 15% to 20% bioethanol with Pertamax significantly increases power and torque for the C-series 100 engine. These findings can serve as a practical reference for users in selecting the appropriate bioethanol concentration based on performance needs, as well as for manufacturers in developing more optimal fuel specifications for the engine.

4. Conclusion

This study evaluates the effect of adding bioethanol at 10%, 15%, and 20% to Pertamax fuel on the power and torque of a C-series 100 gasoline engine. The results indicate that adding bioethanol, particularly at a 20% concentration, improves engine performance, achieving a maximum power of 3.6 HP and torque of 36.2 N·m in 3.78 seconds, thanks to the higher-octane rating and more excellent oxygen content that supports more efficient combustion. These findings reinforce the role of bioethanol as an environmentally friendly alternative fuel that can also enhance vehicle performance, encouraging the use of higher bioethanol blends for fuel efficiency and carbon emission reduction. However, due to bioethanol's hygroscopic nature, attention must be given to potential long-term impacts, such as corrosion on engine components. Theoretically, these results highlight the importance of optimizing bioethanol blends to balance performance enhancement and engine durability and the need for further research on long-term effects to support sustainable fuel policies and automotive industry standards. Future strategies could combine higher bioethanol blends with advanced ignition and engine control technologies to achieve maximum performance without compromising component longevity.

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