International Journal of Automotive & Transportation Engineering
ISSN: 3083-9726

Performance Analysis of Ethanol and Fusel Oil Blends in RON95 Gasoline Engine

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This study investigates the performance of RON95 gasoline blended with ethanol (E10, E20, E30) and fusel oil (F10, F20, F30) in a spark-ignition engine at varying engine loads (10%–40%) and rotational speeds (1000, 2000, and 3000 RPM). The experiments were conducted using a single-cylinder, four-stroke engine under controlled conditions to evaluate Brake Power (BP) and Brake Mean Effective Pressure (BMEP). The results show that adding ethanol and fusel oil enhances engine performance compared to pure gasoline (G). At 1000 RPM and 40% load, the highest BP was recorded for E20 at 10.4 kW, while gasoline achieved only 9.4 kW. Similarly, at 2000 RPM and 40% load, F10 reached 27.1 kW compared to gasoline's 24.5 kW. The most significant improvement was observed at 3000 RPM and 40% load, where F30 achieved 55.2 kW, outperforming gasoline at 45.8 kW. BMEP values followed a similar trend, with the highest BMEP at 3000 RPM and 40% load for F30 at 7.6 bar, surpassing gasoline at 7.0 bar. These findings demonstrate that ethanol and fusel oil blends, particularly at higher concentrations and engine speeds, can substantially improve engine performance. This research contributes novelty by systematically comparing the effects of ethanol and fusel oil blends on gasoline engine performance, providing an alternative pathway to utilizing bio-based fuels for enhanced power output without engine modifications.

Received: 9 March 2025
Revised: 15 March 2025
Accepted: 25 March 2025
Available online: 25 May 2025

Spark-Ignition Engine
Ethanol Blend
Fusel Oil
Brake Power
Brake Mean Effective Pressure

1. Introduction

The increasing global energy demand has driven various efforts to develop alternative fuels that are more environmentally friendly and sustainable. Fossil fuels, such as gasoline, are still the primary energy source in the transportation sector. Still, their limited availability and negative environmental impact are the main reasons for looking for cleaner fuel substitutes. Bioethanol and fusel oil are two types of renewable fuels that are widely studied because they come from biomass, agricultural, and industrial waste, so they have great potential to reduce dependence on fossil fuels and exhaust emissions. Bioethanol is a biomass-based alcohol that has been shown to improve the performance of gasoline engines. Using an ethanol mixture of up to 20% (E20) can increase the octane number of the fuel and improve the combustion process so that engine efficiency increases and harmful emissions decrease [1–3]. In addition, the use of ethanol in gasoline engines can significantly reduce carbon monoxide (CO) and hydrocarbon (HC) levels [4–7]. This is because the oxygen content in ethanol helps combustion to be more perfect, which positively impacts engine performance and the environment.

In addition to bioethanol, fusel oil, as a by-product of the bioethanol fermentation process, has also received attention in developing alternative fuels. Fusel oil has a relatively high mixed alcohol content, so it can be used as a fuel additive [8–12]. Using 10% to 30% fusel oil in a gasoline mixture is known to increase combustion efficiency and reduce fuel consumption. In line with these findings, fusel oil can provide good combustion stability in gasoline engines. However, its physical characteristics differ from pure ethanol, especially water content and mixed alcohol compounds [13–17]. Another study also showed that using a mixture of bioethanol fuel and fusel oil can be an effective solution to improve engine performance without the need for significant modifications to the standard engine [18–21]. This mixture can maintain a balance between engine power and fuel consumption and reduce exhaust emissions. Meanwhile, a mix of ethanol and fusel oil positively impacts the combustion process because both contain high oxygen, accelerating the combustion chamber's fuel oxidation process [22–26].

Considering the potential of bioethanol and fusel oil as alternative fuels, further in-depth research is still needed regarding the effect of this mixture on the performance of gasoline engines under various operating conditions [16,27–29]. Several previous studies were still limited to testing under low load conditions or at certain engine speeds only, so more extensive testing is needed to determine the extent to which the mixture of bioethanol and fusel oil provides an optimal effect under various variations in load and engine speed [30–34]. This is important to ensure the reliability of the mixed fuel in everyday motor vehicle applications. Therefore, this study was conducted to enrich the study related to the use of bioethanol and fusel oil as an alternative fuel mixture in gasoline engines [35–39]. The main focus of this study is to observe the effect of variations in the mix of ethanol and fusel oil on engine performance, especially in terms of Brake Power (BP) and Brake Mean Effective Pressure (BMEP), under various engine speed and load conditions. With this approach, it is hoped that a more comprehensive picture can be obtained regarding the potential of renewable fuel mixtures in supporting efforts to reduce emissions and save energy in the transportation sector.

The specific objective of this study is to analyze the effect of using a mixture of ethanol fuel (E10, E20, E30) and fusel oil (F10, F20, F30) on the performance of a RON95 gasoline engine, especially in terms of Brake Power (BP) and Brake Mean Effective Pressure (BMEP), at various engine speed variations (1000 rpm, 2000 rpm, and 3000 rpm) and load levels (10%, 20%, 30%, and 40%). This study offers novelty in a systematic comparison between two types of alcohol-based biofuels, namely ethanol and fusel oil, in a high concentration range, with direct testing on the engine without special modifications. In addition, this study enriches the literature by providing experimental data on the effect of a combination of fuel variations, loads, and engine speeds, which were previously limited in previous studies. The results of this study are expected to be the basis for the development of more efficient and environmentally friendly alternative fuels for gasoline engine-based vehicle applications.

2. Methodology

Figure 1 shows a schematic diagram of a four-cylinder gasoline engine test system used to evaluate the performance of ethanol-based fuel blends (E10, E20, E30) and fusel oils (F10, F20, F30) under various operating conditions. The system starts from the main fuel tank, which supplies fuel through the fuel pump to the engine inlet. There are drain and fuel return valves to control the flow of unused fuel back to the tank. A fuel flow rate sensor measures the fuel flow rate before entering the combustion chamber. On the other side, the fuel blends from the external tank are conditioned by a heat exchanger to stabilize the temperature before being delivered to the engine. An in-cylinder pressure sensor monitors the combustion process, while the crank angle encoder records the crank angle, and all data is sent to a computer for analysis. In addition, this testing system is equipped with various temperature sensors

(T1–T12) installed at different strategic points to monitor the temperature of the fuel flow, exhaust gas, and engine area, such as T4 and T5 located in the exhaust duct to detect the temperature of the combustion gas. The exhaust gas analyzer is used to observe exhaust emissions resulting from the combustion process of each type of mixed fuel. An engine dynamometer measures the power generated by the engine, which is directly connected to the engine output shaft. With this system, engine performance testing can be carried out accurately to compare the effect of fuel variations on performance parameters such as Brake Power (BP), Brake Mean Effective Pressure (BMEP), and engine thermal efficiency under various load and engine speed conditions. This scheme ensures that the entire testing process runs safely and produces precise data.

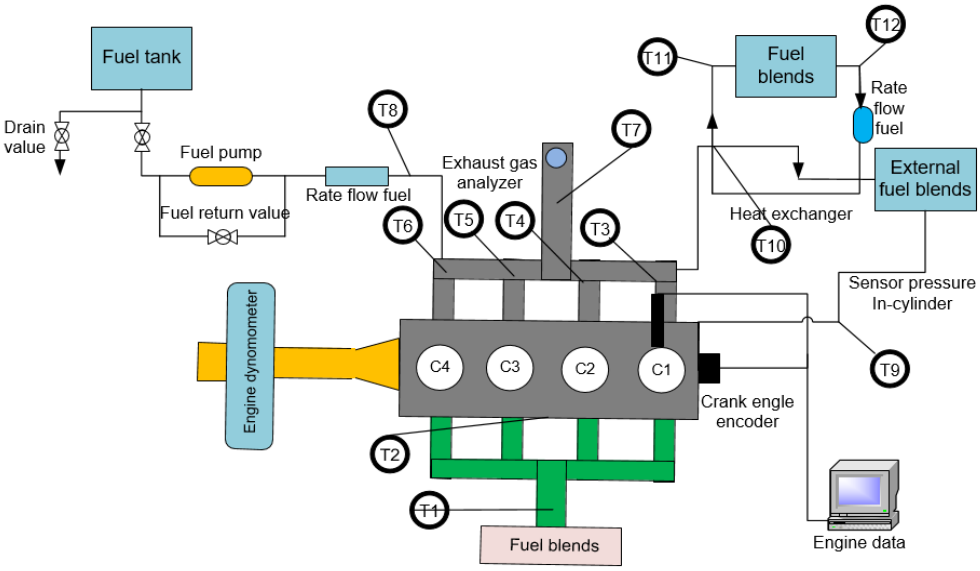

Figure 1: Schematic diagram

Figure 2 shows the test configuration of a four-cylinder gasoline engine equipped with various main components to support the performance and emission evaluation of ethanol and fusel oil blend fuels. The system consists of an engine connected to a dynamometer to measure output power in real-time and a throttle position controller that precisely controls the throttle valve opening during the test. In the air intake section, an intercooler and turbocharger are used to increase the density of air entering the combustion chamber, thereby helping combustion efficiency. On the other hand, an in-cylinder pressure sensor is installed to record the combustion pressure in the combustion chamber, the data of which is sent through an encoder for engine crank angle synchronization. A gas analyzer probe takes samples directly from the engine exhaust for exhaust emission monitoring. The entire engine cooling system and dynamometer are also available to maintain a stable operating temperature throughout the test. With this setup, experiments can be carried out accurately and safely to evaluate the effects of blended fuels on engine performance under various working conditions.

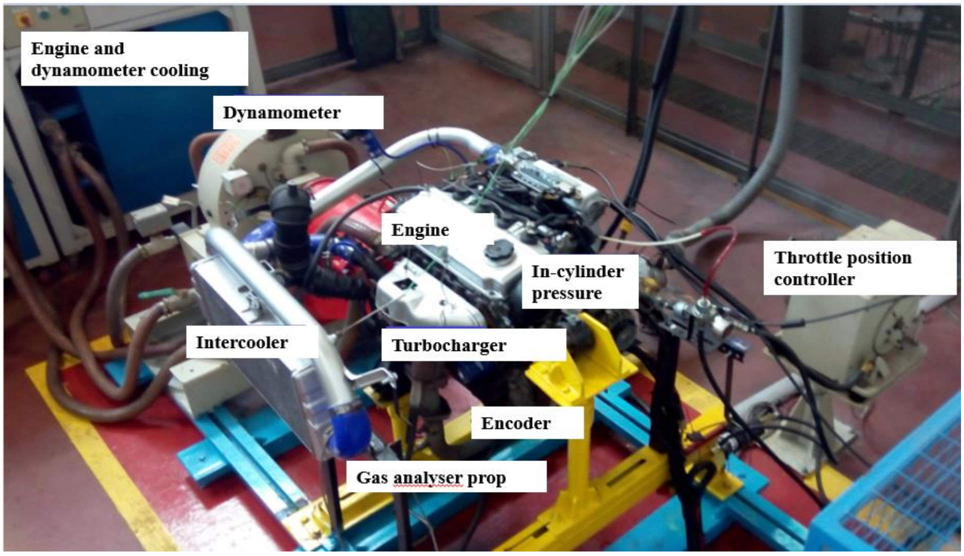

Figure 2: Engine setup [18]

3. Result & Discussion

Figure 3 shows the relationship between Brake Mean Effective Pressure (BMEP) and Engine Load at 1000 RPM for various fuel types. In general, the increase in engine load is directly proportional to the rise in BMEP for all kinds of fuel. At a load of 10%, the BMEP value ranges from 3.4 bar to 3.7 bar, with RON95 showing the highest figure of 3.7 bar while F20 shows the lowest figure of 3.4 bar. At a load of 20%, the BMEP value increases, where RON95 reaches around 4.3 bar, while other fuels such as E10, E20, and F10 are in the range of 4.1–4.2 bar. Meanwhile, F30 has a BMEP value of around 4.0 bar, which is still lower than RON95. At higher loads, namely 30% to 40%, the pattern of BMEP increase remains consistent. At 30% load, RON95 BMEP is around 4.5 bar, followed by E10 at 4.4 bar, while F20 and F30 show almost similar values at 4.2–4.3 bar. At a maximum load of 40%, RON95 BMEP is still the highest, with a value approaching 4.7 bar. Other fuels such as E10, E20, and F10 show quite competitive performance in the 4.4–4.5 bar range, while F20 and F30 are still slightly behind with BMEP values of around 4.3–4.4 bar. Overall, this graph shows that RON95 provides the highest average adequate pressure at low speeds of 1000 RPM, while the mixture of ethanol and fusel oil-based fuels is slightly lower but still in a stable performance range as engine load increases.

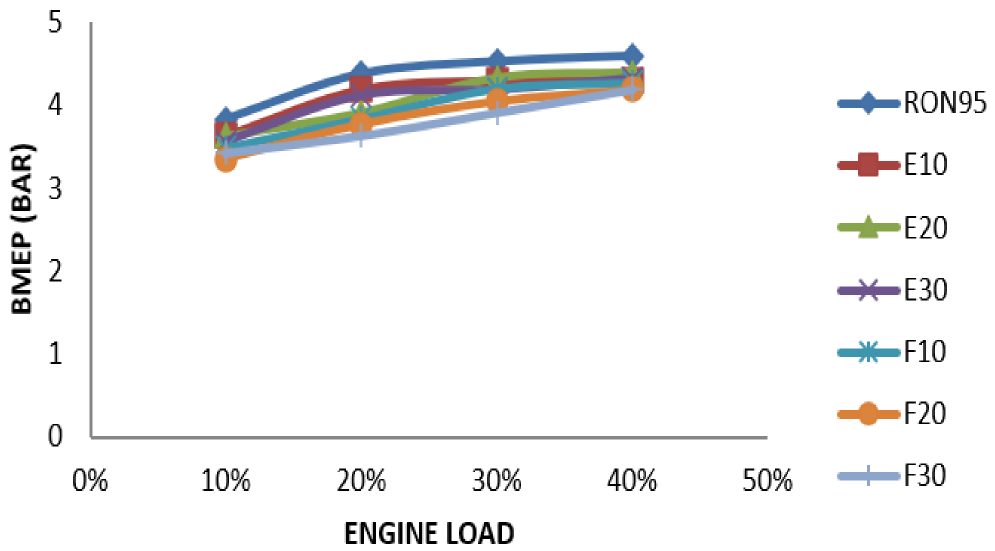

Figure 3: Brake Mean Effective Pressure (BMEP) vs. Engine Load at 1000 RPM for Various Fuels

Figure 4 shows the relationship between Brake Mean Effective Pressure (BMEP) and Engine Load at 2000 RPM for various fuel types. Overall, BMEP increases with increasing engine load for all fuels. At a load of 10%, BMEP is in the range of 2.2 bar to 2.7 bar, with RON95 recording a value of 2.5 bar, E10 at 2.7 bar, and F30 being the lowest at 2.2 bar. At an increase in load of up to 20%, all fuels show a significant spike, with RON95 reaching around 4.6 bar, E10 at 4.8 bar, and E30 at 4.3 bar. F20 performs exceptionally well with a BMEP value of 4.7 bar, while F30 increases to 4.1 bar. At higher loads of 30% to 40%, the BMEP value increases further and shows a relatively stable performance between fuels. At 30% load, RON95 BMEP reached around 5.3 bar, E10 and F10 recorded the highest figure at around 5.6 bar, while F30 and E30 were slightly lower at 5.2 bar. At 40% maximum load, the highest BMEP was achieved by F10 at 5.8 bar, followed by E10 and F20 with a value of around 5.7 bar. RON95 was at around 5.6 bar, while E30 and F30 were still stable at around 5.5 bar. Overall, at 2000 RPM engine speed, blended fuels such as F10, E10, and F20 began to show competitive performance and even surpassed RON95, especially at high loads, indicating the potential efficiency of alternative fuels at medium to heavy workloads.

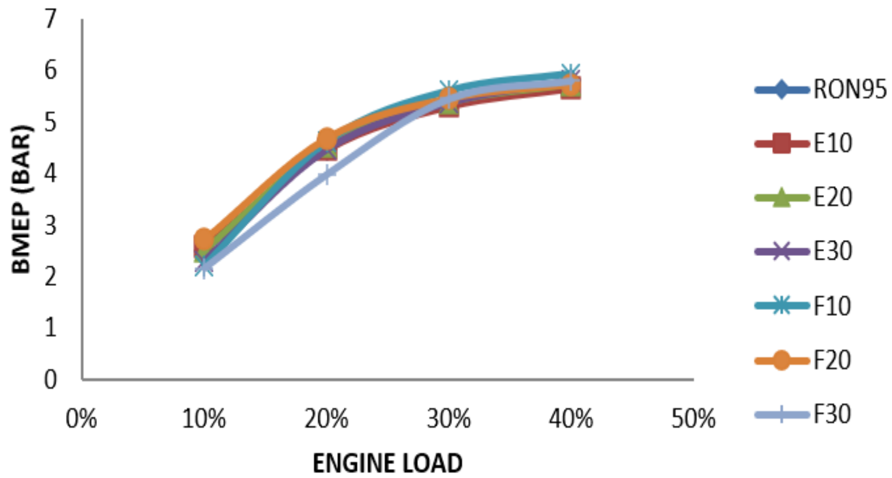

Figure 4: Brake Mean Effective Pressure (BMEP) vs. Engine Load at 2000 RPM for Various Fuels

Figure 5 shows a graph of the relationship between Brake Mean Effective Pressure (BMEP) and Engine Load at 3000 RPM for various fuel types. At the lowest load of 10%, the BMEP value is relatively uniform in the 1.8 bar to 2.0 bar range. RON95, E10, E20, and F20 have BMEP values of around 1.9 bar, while F30 is slightly higher at 2.0 bar. Increasing the load to 20% gives a significant jump in BMEP, where RON95 and E10 reach around 4.2 bar, E20 and F10 at 4.1 bar, while F30 also shows good performance with 4.3 bar. The difference between fuels is still relatively small at this stage, indicating consistent performance at high engine speeds. When the engine load increases from 30% to 40%, the BMEP value increases more evenly across all fuels. At 30% load, RON95, E10, and E20 range from 6.8 bar to 7.0 bar, while F30 and F20 also show similar performance at 7.0 bar. At a maximum load of 40%, the highest BMEP is achieved by F30 with 7.8 bar, followed by F20 and E30 at around 7.5 bar, while RON95 and E10 are stable at around 7.3 bar. From these results, at high speeds of 3000 RPM, alternative fuels such as F30 and F20 can match or even slightly exceed the performance of RON95, especially at high loads, thus indicating the potential for using blended fuels in high-speed engine operations.

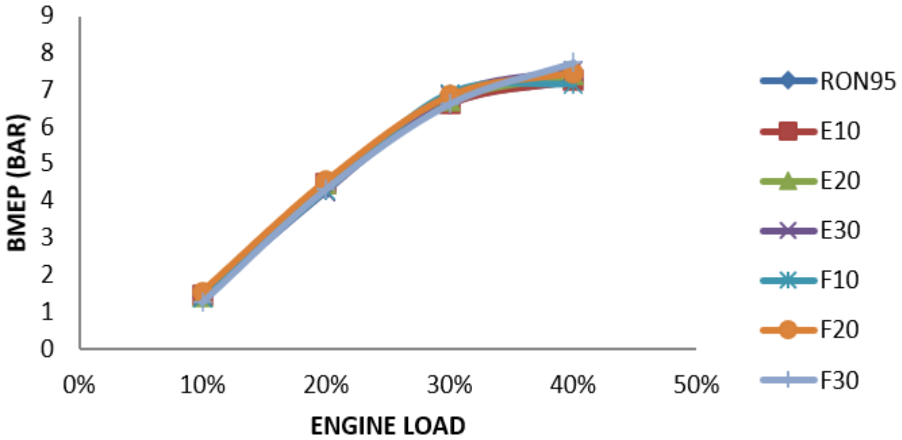

Figure 5: Brake Mean Effective Pressure (BMEP) vs. Engine Load at 3000 RPM for Various Fuels

Figure 6 shows the relationship between Brake Power (BP) and Engine Load at 1000 RPM engine speed for various fuel types. At the lowest load of 10%, Brake Power is in the range of 7.8 kW to 8.7 kW. The lowest value is shown by F30 fuel at 7.8 kW, while E10 achieves the highest value at 8.7 kW. At a load of 20%, the increase in Brake Power begins to be seen significantly, where E10 again shows the best performance with 10.1 kW, followed by E20 and E30 at around 9.5 kW, while F20 and F30 are at 9.1 kW and 9.0 kW. This shows that E10 provides more optimal brake power performance than other low-speed fuels. As the engine load increases to 30% and 40%, the trend of brake power increases but is not too sharp. At 30% load, E10 recorded a power of 10.4 kW, while E20 and E30 were in the range of 10.2 kW. F10, F20, and F30 showed similar performance in the range of 9.7 kW to 10.0 kW. At the maximum load of 40%, the highest Brake Power was maintained by E10 with 10.5 kW, while other fuels such as E20 and E30 reached around 10.3 kW, and F30 was slightly lower at 9.6 kW. Overall, it can be concluded that at 1000 RPM, E10 fuel showed the most stable and superior Brake Power performance, especially at all load levels, making it a compelling choice for low-speed engine operation.

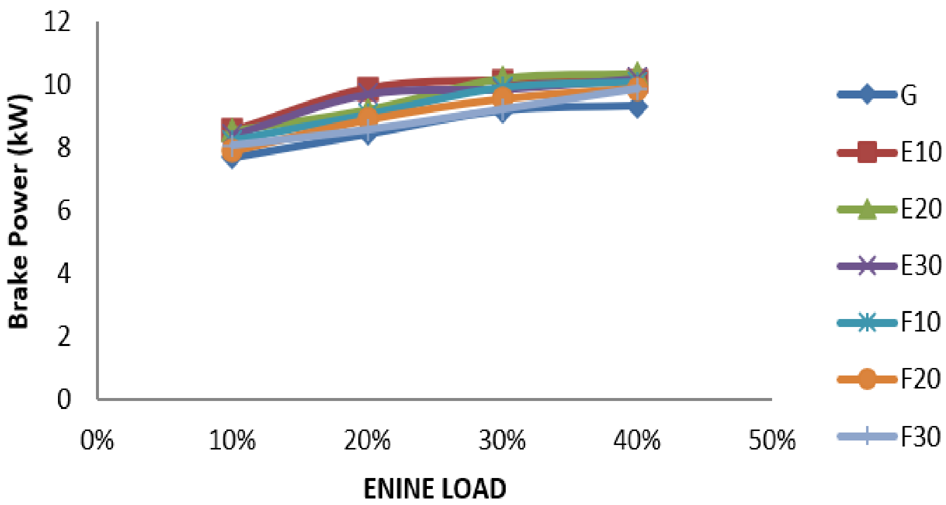

Figure 6: Brake Power vs. Engine Load at 1000 RPM for Various Fuels

Figure 7 shows the relationship between Brake Power (BP) and Engine Load at 2000 RPM engine speed with various fuel variations. At 10% load, Brake Power ranges from 10.7 kW to 12.5 kW. The lowest value is shown by F10 fuel with 10.7 kW, while F20 achieves the highest value at 12.5 kW. Furthermore, at 20% load, a significant increase occurs, with F20 again showing the highest performance at 22.1 kW. This is followed by E20 and E10, which each reach 21.7 kW and 21.5 kW, while G or RON95 fuel can only produce 19.6 kW, showing lower performance compared to a mixture of ethanol and fusel oil fuel at this load. At 30% to 40% engine load, the increasing trend in Brake Power remains stable. At 30% load, F30 showed quite good performance with a BP value of 26.0 kW, while F20 reached 25.6 kW and E10 25.2 kW. At a maximum load of 40%, F10 recorded the highest Brake Power with 28.3 kW, followed by F30 with 28.0 kW and F20 with 27.2 kW. Meanwhile, G fuel or RON95 still showed a lower figure of 24.4 kW. Overall, at 2000 RPM, fusel oil blend fuels such as F10, F20, and F30 provided higher Brake Power performance than RON95 or ethanol, especially at high engine loads, which shows the great potential of using this alternative fuel in improving engine performance.

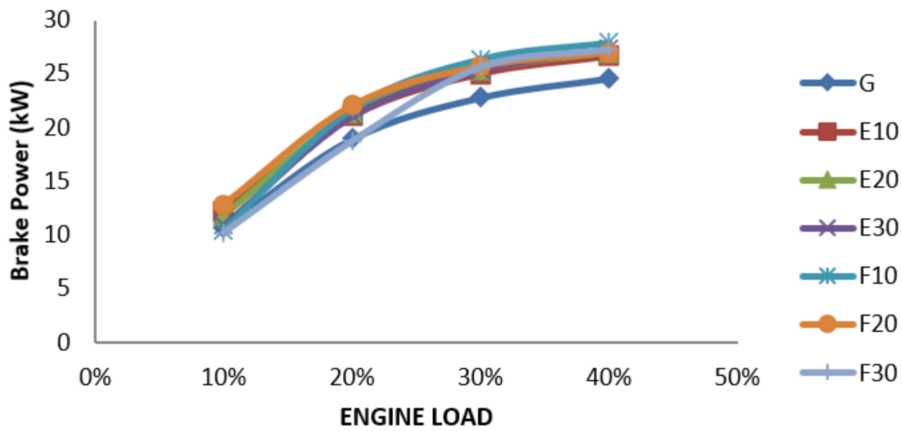

Figure 7: Brake Power vs. Engine Load at 2000 RPM for Various Fuels

Figure 8 shows the relationship between Brake Power (BP) and Engine Load at 3000 RPM engine speed for various fuel types. At 10% engine load, Brake Power is still relatively low, with values ranging from 9.5 kW to 10.4 kW. The lowest value is found in G fuel (RON95) at 9.5 kW, while F20 performs better with the highest value of 10.4 kW. A significant increase is seen at 20% load, where F20 again records the highest figure of 33.2 kW, followed by F30 at 31.4 kW and E10 at 30.9 kW. In contrast, G

fuel only produces 28.7 kW, indicating that fusel oil blend fuels contribute more to increasing Brake Power at high speeds. Increasing Brake Power is increasingly apparent at higher engine loads, namely 30% to 40%. At 30% load, F20 remains superior with a Brake Power of 49.3 kW, followed by F30 and E30 with 48.5 kW and 47.8 kW, respectively.
Meanwhile, G fuel lags far behind with a value of only 43.6 kW. At a maximum load of 40%, F30 recorded the highest value of 54.6 kW, followed by F20 at 52.1 kW and E10 at 51.2 kW. G fuel again recorded the lowest value of 46.0 kW. Overall, at 3000 RPM engine speed, the fusel oil-based fuel mixture (F20 and F30) showed the best Brake Power performance compared to other fuels, especially at high engine loads. This indicates that using fusel oil mixtures is increasingly effective in improving engine performance at higher RPM.

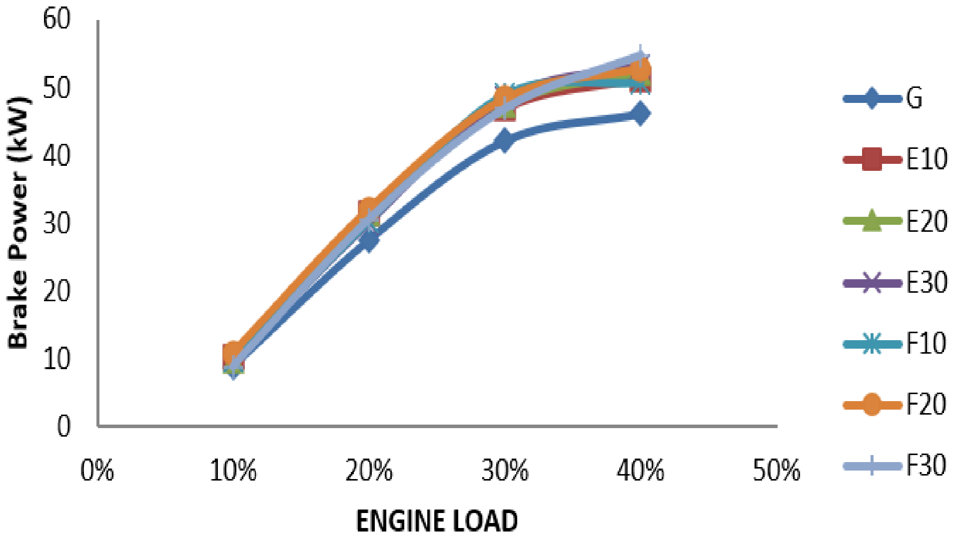

Figure 8: Brake Power vs. Engine Load at 3000 RPM for Various Fuels

Based on the research results, it can be concluded that the addition of a mixture of fusel oil (F10, F20, and F30) and ethanol (E10, E20, and E30) to gasoline fuel can improve engine performance in terms of Brake Power (BP) and Brake Mean Effective Pressure (BMEP) compared to the use of pure gasoline (RON95). This performance increase is increasingly significant at higher engine loads and faster engine speeds. At 3000 RPM conditions with a 40% load, F30 can achieve the highest Brake Power of 54.6 kW and BMEP of 7.6 bar, far exceeding RON95 fuel, which only produces 46.0 kW and 7.1 bar. In addition, the increasing trend is also seen evenly across all engine speeds, where the mixture of F20 and F30 consistently provides optimal results, making it a promising alternative fuel candidate for improving the performance of gasoline-fueled engines.
The novelty of this article lies in the use of fusel oil concentration variations up to 30% combined with gasoline as an alternative fuel, as well as its direct comparison with a mixture of ethanol and pure gasoline at various engine load and speed conditions. This study is essential in answering the need for more environmentally friendly fuels that still perform well. In addition, this article shows the real potential of utilizing industrial alcohol waste in the form of fusel oil as an efficient alternative energy. With comprehensive testing at three RPM levels (1000, 2000, and 3000), this study successfully shows that fusel oil is suitable for use and can significantly improve engine performance, which was previously minimally explained in previous studies.

4. Conclusion

This study uses an experimental method by testing the performance of a RON95 gasoline engine mixed with variations of ethanol (E10, E20, E30) and fusel oil (F10, F20, F30) under engine dyno test conditions with three variations of engine speed, namely 1000 RPM, 2000 RPM, and 3000 RPM, and a gradual engine load of 10% to 40%. The test results show that the addition of fusel oil and ethanol to gasoline can increase Brake Power (BP) and Brake Mean Effective Pressure (BMEP) compared to pure gasoline (RON95). At 3000 RPM with a load of 40%, F30 fuel recorded the highest Brake Power of 54.6 kW, followed by F20 at 52.5 kW, while RON95 only produced 46.0 kW. Under the same conditions, BMEP F30 reached 7.6 bar, higher than F20 (7.3 bar) and RON95 (7.1 bar). Meanwhile, at 1000 RPM with 40% load, E20 showed the best performance with Brake Power of 10.5 kW and BMEP of 4.5 bar, exceeding RON95, which only recorded 9.4 kW and 4.4 bar. Overall, the increase in engine performance was more pronounced when using fusel oil compared to ethanol, especially at high engine speeds (3000 RPM). F30 consistently gave maximum results at all test levels, while RON95 experienced limited performance increases, especially at high loads. This proves that mixing alternative fuels such as fusel oil up to a concentration of 30% effectively improves engine performance without significant modification. Thus, fusel oil has great potential to become an alternative fuel to replace partial gasoline, improving engine performance and utilising industrial alcohol waste, making it an efficient and environmentally friendly energy solution.

Acknowledgement

The authors would like to acknowledge the support provided by the Centre for Automotive Engineering, Universiti Malaysia Pahang Al Sultan Abdullah, in conducting this research.

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