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Understanding the Influences of Different Ethanol-Petrol-Polyisobutylene Ratios to the Performance of a Single-Cylinder S.I. Engine

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ABSTRACT

The paper is focused on the use of polyisobutylene (PIB) additive in ethanol-blended fuels (E5P1, E5P5, E25P1, E25P5) for a 150-cc spark-ignition engine. The experiments tested different fuel compositions at road speeds from 30 to 90 km/h under part-load (PL) and wide-open throttle (WOT) conditions. The results show that E5P5 achieved optimal torque at 60 km/h, while E25P1 had the highest torque at 50 km/h under WOT. For fuel consumption, E0 had the lowest BSFC at part-load, but E5P5 consumed 26% less fuel than E0 at 90 km/h. Ethanol's higher octane allowed for a leaner mixture without sacrificing performance. BMEP data showed E25P5 generated 30% greater BMEP than E0 at 50 km/h PL. In terms of BTE, E5P1 had the highest BTE at PL, while E25P5 had the highest at WOT. Ethanol's oxygen content improved combustion. As speed increased, E25P5 had lower emissions than other blends and gasoline, though it was not always the "lowest" polluting option.

1. Introduction

The development of blended fuels that can lessen dependency on conventional petroleum-based fuels has become a key area of research and innovation as the focus on renewable and sustainable energy sources has grown (Lawal et al.). To evaluate the effects of ethanol and polyisobutylene (PIB) on a single-cylinder engine scooter's performance and gas emissions, this article investigates the feasibility of blending these fuels with conventional petroleum-based fuels. Ethanol, a renewable alcohol fuel derived from agricultural feedstocks (Nwufo et al., 2018; Özcan et al., 2018), has demonstrated promise as a gasoline additive due to its ability to improve combustion efficiency and lower emissions(Agarwal & Mustafi, 2021; Zaharin et al., 2017). Similarly, PIB, a synthetic hydrocarbon polymer, has properties that may complement and improve petroleum fuel performance.

Firstly, investigating ethanol-petrol blending dynamics involves determining optimal ratios to enhance combustion efficiency and overall engine performance (Andrianary & Antoine, 2019; Hsu,

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C.S., & Robinson, 2017; Kareddula & Puli, 2018). This is essential for achieving an efficient balance in combustion dynamics(Dhande et al., 2021; Vijay Kumar et al., 2018). This knowledge is crucial for maximizing engine performance while minimizing environmental impact. As the automotive industry explores alternative fuels, understanding the dynamics of ethanol-petrol blends is key to optimizing their use (Mohammed et al., 2021; Özcan et al., 2018)

Then, the study explores the role of polyisobutylene (PIB) as a potential combustion enhancer in ethanol-petrol blends. The inclusion of polyisobutylene addresses a gap in research by examining the potential benefits of a specific fuel additive in ethanol-petrol blends. Understanding how polyisobutylene influences combustion characteristics provides valuable insights into its role as a combustion enhancer, potentially contributing to developing more effective fuel formulations.

Thirdly, the project analyses crucial engine performance parameters, including power output, thermal efficiency, fuel consumption, and combustion stability, under various fuel compositions. Analyzing key engine performance parameters under different fuel compositions is fundamental for assessing the viability of alternative fuels. This objective directly addresses optimising power output, thermal efficiency, and combustion stability to pursue more sustainable and efficient internal combustion engines.

Lastly, the research involves emissions analysis to evaluate the environmental implications, specifically assessing NOx, CO, and HC emissions associated with different fuel ratios. With increasing regulatory pressure to reduce emissions, this analysis provides actionable insights into the environmental sustainability of ethanol-petrol-PIB blends. These objectives aim to comprehensively understand the complex interactions within alternative fuel blends and their impact on internal combustion engine performance.

2. Materials and Methods

2.1 Materials

This study uses various materials, including polyisobutylene, ethanol, and gasoline, combined to create blended fuel. Different proportions of ethanol and polyisobutylene are combined with gasoline to create blended fuel. Table 1 displays the specifics of the blended fuels that were tested, regarding the engine specifications displayed in Table 2.

Table 1: Details of tested blended fuels

Sample Code	Gasoline %	Ethanol %	Additive
E0	100	0	0 mg/L PIB
E5P1	95	5	100 mg/L PIB
E5P5	95	5	500 mg/L PIB
E25P1	75	25	100 mg/L PIB
E25P5	75	25	500 mg/L PIB

Table 2: Specification of the test motorcycle

Parameter	Description
Make & Model	Demak Transtar
Engine	4-stroke, single cylinder, Single Overhead Camshaft (SOHC)
Displacement	150 cc
Bore x Stroke	57.4 mm x 57.8 mm

2.2 Flowchart

The experiment's flowchart is displayed in Figure 1 from beginning to end. This describes the approach taken to meet the goals of the study.

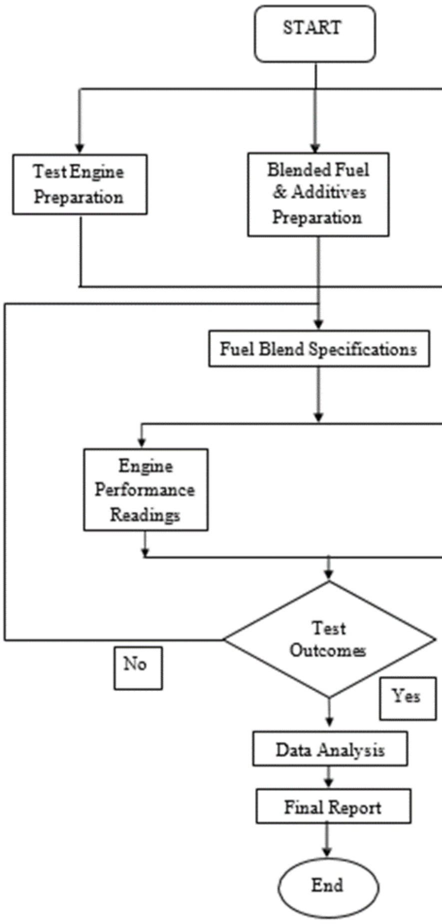

Figure 1: Experiment flow chart

The process begins with test engine preparation, followed by blended fuel and additives preparation. Next, the dynamometer is calibrated to ensure accurate engine performance measurements. The fuel blend specifications are then documented, and the engine performance readings and exhaust emissions assessment are conducted. The test outcomes are evaluated, and if satisfactory, the data is analyzed. Finally, a final report is generated, and the process concludes.

2.3 Evaluation of engine performance

2.3.1 Torque Output

To understand the power and performance characteristics when using the ethanol-PIB-petroleum blended fuel in the target application and to make well-informed recommendations about the potential deployment of the blended fuel, it is imperative to analyze the engine's torque output.

2.3.2 Brake-Specific Fuel Consumption (BSFC)

The amount of gasoline used for each engine power unit produced is known as the BSFC. It demonstrates how well an engine converts fuel into useful output. It is measured in grams of fuel per kilowatt-hour (g/kWh), or fuel consumption per power unit.

$$BSFC = \frac{\text{Fuel Flow Rate } \left({}^{m^3}\!/_{s} \right)}{\text{Brake Power (kW)}}$$

2.3.3 Brake Mean Effective Pressure (BMEP)

Internal combustion engine efficiency is assessed using BMEP. It essentially displays the average pressure on the piston during the power stroke, providing a measure of the engine's efficiency in converting fuel into electrical power. Kilopascals (kPa) are used to measure BMEP.

$$BMEP = \frac{2\pi nT}{V_d}$$

Where T is torque, the displacement value is 150 cc, and n is the number of revs per cycle (for a 4-stroke engine, n = 2)

2.3.4 Brake Thermal Efficiency (BTE)

Brake Thermal Efficiency (BTE) measures how efficiently an engine converts fuel energy into mechanical work. BTE directly reflects the engine's fuel efficiency by indicating the percentage of the fuel's energy content that is converted into usable power. Analyzing the BTE of the engine running on the blended fuel compared to baseline petroleum fuel can reveal the impact of the ethanol and PIB additives. BTE is calculated using the formula:

$$BTE = \frac{\text{Brake Power}}{\text{Calorific Value}} \times 100\%$$

The experimental setup is shown in Figure 2 below.

Figure 2: Motorcycle testing set up

2.4 Evaluation of Exhaust Emissions

The gases and solid particles released into the atmosphere because of combustion processes are known as exhaust emissions. When these fuels burn, several pollutants are released. The airflow rate is essential for an accurate assessment of the engine's emissions. CO_2, CO, HC, and NO_X emissions are all measured in this experiment. The emissions are measured using the QGA gas emissions analyzer – refer to the schematic diagram in Figure 3.

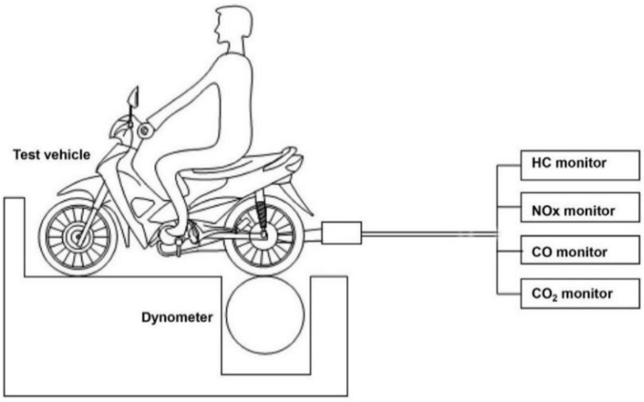

Figure 3: Schematic of exhaust gas emissions measurement set-up

3. Results and Discussion

3.1 Effect of blended fuel on engine performance

After the experiment, all the data were gathered into a table and displayed graphically in a graph. Several tests were conducted to study the engine performance based on the blended fuel, including full load (WOT) and part-load (PL). Brake Mean Effective Pressure (BMEP), Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), and torque were among them. The evidence supporting blended fuel's impact is covered in the following section.

3.1.1 Torque

Figure 4 displays the torque data for each of the five blended fuels at different part-load speeds. The maximum torque of 6.2 Nm at 60 km/h was attained by E5P1, indicating that fuel composition affects power delivery and combustion. Similar torque was produced at 30 km/h by E5P1 and E25P1, suggesting similar combustion. The E25P5 had the maximum torque at 40 km/h, maybe because the ethanol allowed for a leaner mixture. At 50 km/h, E5P1 exhibited the maximum torque, while E25P5 displayed the highest torque at 90 km/h. Inadequate calibration or errors can be the cause of imprecise torque measurements.

The wide-open throttle (WOT) torque data analysis is displayed in Figure 5 below. The value of torque for E0 is relative the same for all 4 speeds except at 40 km/h which reduces much more than other speeds. For E5P1, the value of torque shows significant increment from 30 km/h to 60 km/h until it decreases at 90 km/h. For E5P5, the value of torque remains almost the same from 30 km/h to 40 km/h, then began increasing at 60 km/h and just like E5P1, it reduces at 90 km/h. For E25P1, the value of torque increases twice at 40 km/h and 60 km/h and decreases also twice at 50 km/h and

90 km/h. For the last blended fuel E25P5, it shows increasing value from 30 km/h to 60 km/h and only decreases at 90 km/h.

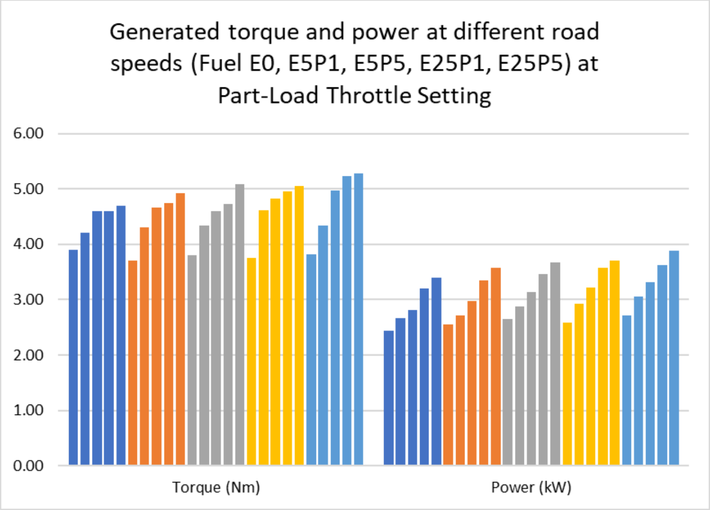

Figure 4: Data analysis of torque value for part-load

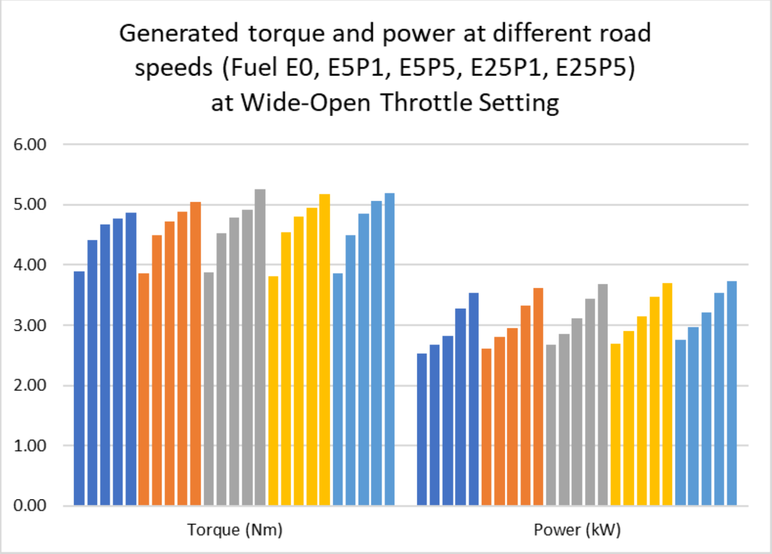

Figure 5: Data analysis of torque for wide-open-throttle

3.1.2 Brake-Specific Fuel Consumption (BSFC)

Figure 6 shows brake-specific fuel consumption (BSFC) at 30, 40, 50, 60, and 90 km/h under part-load, where from left to right representing E0, E5P1, E5P5, E25P1 and E25P5. At 30 km/h, E0 had the lowest BSFC at 244 g/kWh, while E25P5 had the highest at 885.32 g/kWh, likely due to gasoline's higher energy density. At 40 km/h, E5P1 had the lowest BSFC at 535 g/kWh, and E25P5 had the highest at 716 g/kWh. For 50 km/h, E25P1 had the lowest BSFC at 422 g/kWh, and E0 had the highest at 567 g/kWh. At 60 km/h, E0 had the lowest BSFC at 459 g/kWh, and E5P5 had the highest at 537 g/kWh. Lastly, at 90 km/h, E5P1 had the lowest BSFC at 336 g/kWh, and E25P1 had the highest at 380.8 g/kWh. Lower BSFC generally correlates with higher fuel energy density.

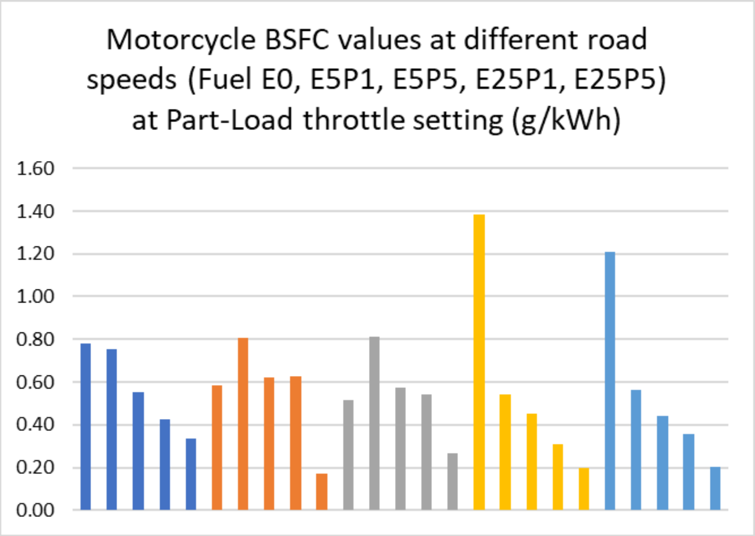

Figure 6: BSFC value for part-load (PL)

The brake-specific fuel consumption for wide-open-throttle (WOT) conditions is shown in Figure 7 below at speeds of 30 km/h, 40 km/h, 50 km/h, 60 km/h and 90 km/h. Data was gathered at a speed of 30 km/h, with the lowest BSFC value being 516.08 g/kWh, which is E5P5, and the highest value is 1386 g/kWh produced by E25P1, while E25P5 has the second highest. At 40 km/h, the value of BSFC for E5P1 decreases from 804.8 g/kWh to 172.8 g/kWh at 90 km/h. Fuel blend E5P5 also replicates the pattern, where the BSFC value is reduced from 809.96 g/kWh at 40 km/h to 264.24 g/kWh at 90 km/h. For fuel blend E25P1, the value of BSFC decreases from 543.28 g/kWh at 40 km/h to 198 g/kWh at 90 km/h. According to the graph, E25P1 has the highest BSFC at 1386 g/kwh at 30 km/h, and E25 PIB500 has the lowest BSFC at 172.8 g/kwh at 90 km/h.

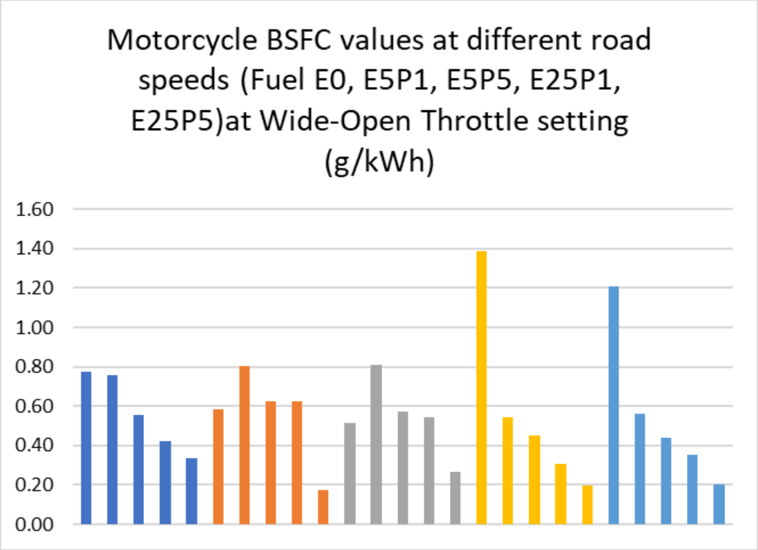

Figure 7: BSFC value for wide-open-throttle (WOT)

3.1.3 Brake Mean Effective Pressure (BMEP)

Figure 8 shows brake mean effective pressure (BMEP) under part load at 30, 40, 50, 60, and 90 km/h. At 30 km/h, E25P5 had the highest BMEP at 428.5 kPa, followed by E25P1 and E5P1. E5P5 had the lowest at 344.47 kPa. At 40 km/h, E25P5 again had the highest at 420.08 kPa. At 50 km/h, E5P1 produced the highest BMEP at 487.3 kPa, while E25P5 remained the lowest. At 60 km/h, E5P1 had the highest BMEP at 520.9 kPa, and E25P5 was the lowest. At 90 km/h, E25P5 had the highest BMEP. BMEP is generally higher for blended fuels under part load, enabling more power and torque, but incomplete combustion can lead to higher emissions with low BMEP.

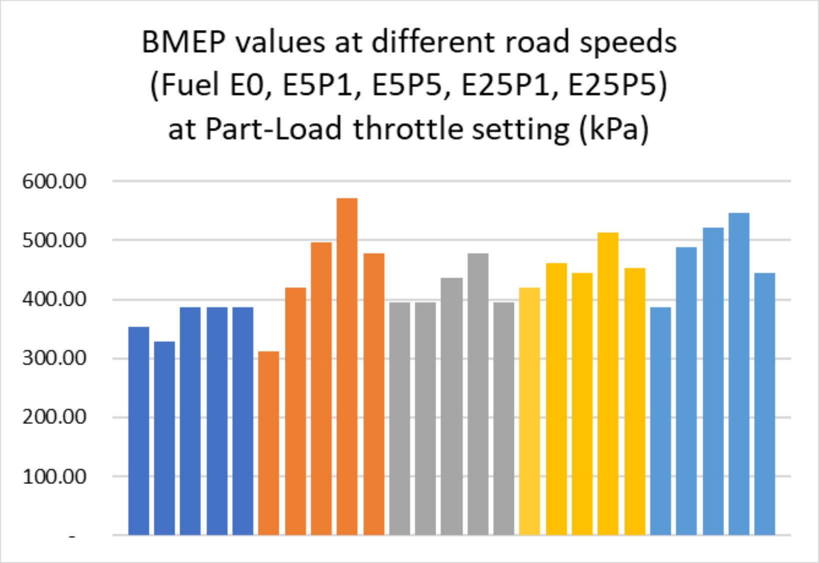

Figure 8: BMEP value for part-load (PL)

Figure 9 shows BMEP at 30, 40, 50, 60, and 90 km/h under wide-open-throttle. Except at 30 km/h, E0 had the lowest BMEP, ranging from 327.7 to 386.5 kPa. E5P1 started at 310.86 kPa at 30 km/h, increased to 571.317 kPa at 60 km/h, then decreased to 478.9 kPa at 90 km/h. E5P5 showed little change from 30-40 km/h, then increased to 478.9 kPa at 60 km/h before decreasing to 394.88 kPa at 90 km/h. E25P1 ranged from 420.08 to 512.5 kPa, higher than E0. E25P5 increased from 386.48 kPa at 30 km/h to 546.11 kPa at 60 km/h, then decreased to 445.29 kPa at 90 km/h. Ethanol-blended fuels generally produced higher BMEP than pure gasoline.

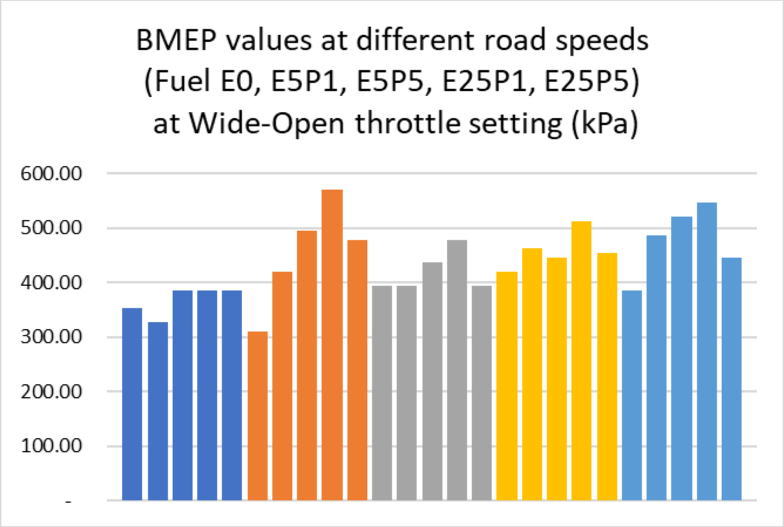

Figure 9: BMEP value for wide open throttle (WOT)

3.1.4 Brake Thermal Efficiency (BTE)

Figure 10 shows the BTE for E0, E5P1, E5P5, E25P1, and E25P5 fuels at 30, 40, 50, 60, and 90 km/h under part-load conditions. E0 had the lowest BTE, ranging from 8.73% to 4.97%. E5P1 showed a slight BTE increase, from 9.2% to 4.84%. E5P5 had lower BTE, from 9.05% to 3.95%. E25P1 had a significant BTE range of 8.38% to 3.82%. E25P5 had BTE from 9.02% to 3.76%. The higher octane and anti-knock properties of ethanol blends can improve combustion stability, especially at part-load when engines are more susceptible to knock. Figure 11 shows the BTE for E0, E5P1, E5P5, E25P1, and E25P5 fuels at 30, 40, 50, 60, and 90 km/h under wide-open throttle conditions. E0 had the lowest BTE, ranging from 8.91% to 5.57%. E5P1 had higher BTE than E0, from 9.33% to 4.92%. E5P5 had lower BTE than E0 and E5P1. E25P1 had significantly lower BTE than the other blends. E25P5, the highest ethanol and PIB blend had the highest BTE across all speeds. The higher octane of ethanol blends helps prevent knock at WOT, improving combustion and BTE.

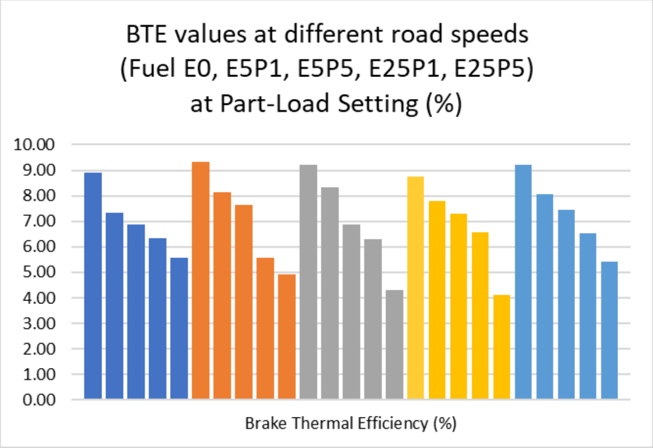

Figure 10: BTE value for part load (PL)

Figure 11 shows BTE at 30, 40, 50, 60, and 90 km/h under wide-open throttle. E0 had the lowest BTE, ranging from 4% at 30 km/h to 11% at 90 km/h. Lower octane fuels like pure gasoline are more prone to pre-ignition and knock under high load and temperature conditions, reducing BTE. E5P1 performed better than E0, ranging from 4% at 30 km/h to 14% at 90 km/h. E5P5 had greater BTE than E0 and E5P1. E25P1 had significantly lower BTE than the other blends. E25P5, with the highest ethanol and PIB content, had the highest BTE, over 10% at all speeds and reaching 16% at 90 km/h.

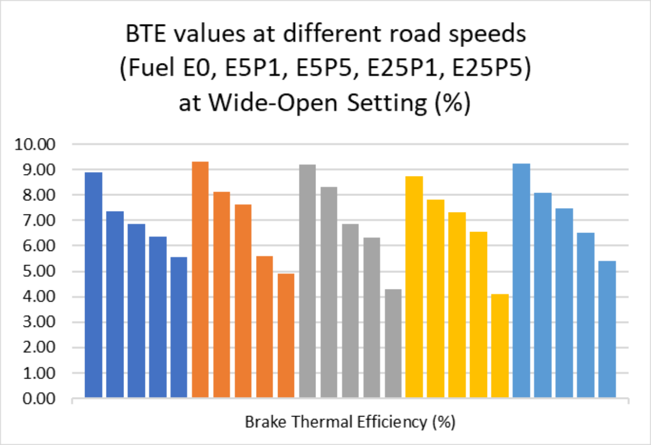

Figure 11: BTE value for wide open throttle (WOT)

3.2 Effect of blended fuel on exhaust emissions

Figure 12 shows carbon monoxide (CO) emissions (kg/h) at 30-90 km/h under part load. At 30 km/h, E0 had the lowest CO. Blended fuels had higher CO emissions at low speeds. By 40 km/h, blended fuels like E5P1 and E25P1 reduced CO to 0.083 and 0.089 kg/h. At 50 km/h, E5P1 and E25P5 had the lowest CO at 0.089 and 0.094 kg/h, while E0 and E25P1 were the highest. At 60 km/h, E25P1 and E25P5 had the highest CO. At 90 km/h, E25P5 and E0 produced the most CO. E5P1 had the lowest CO at 0.168 kg/hr. The oxygen content in ethanol promotes more complete combustion at part-load, reducing CO emissions compared to pure gasoline. Figure 13 shows CO emissions (kg/h) at 30-90 km/h under wide-open throttle. At 30 km/h, E5P5 had the lowest CO at 0.102 kg/h, while E25P5 was highest at 0.228 kg/hr. At 40 km/h, E25P5 and E25P1 had the lowest CO, while E5P5 and E5P1 were the highest. At 50 km/h, E0 had the lowest CO at 0.164 kg/h, followed by E25P5 and E25P1. At 60 km/h, E25P5 had the lowest CO at 0.132 kg/h, while E5P5 and E5P1 were the highest. At 90 km/h, E5P5 had the lowest CO at 0.176 kg/h, and E0 was the highest. Fuels with higher ethanol content generally produced lower CO emissions compared to lower ethanol blends and pure gasoline.

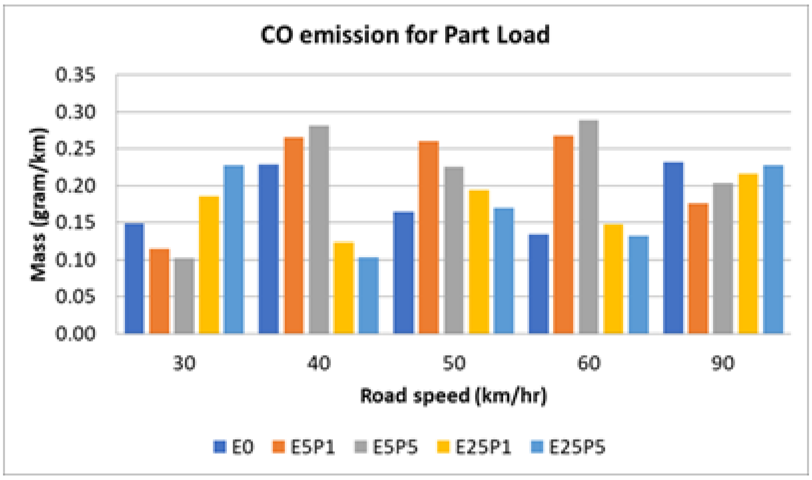

Figure 12: Carbon monoxide (CO) gas emission for part load (PL)

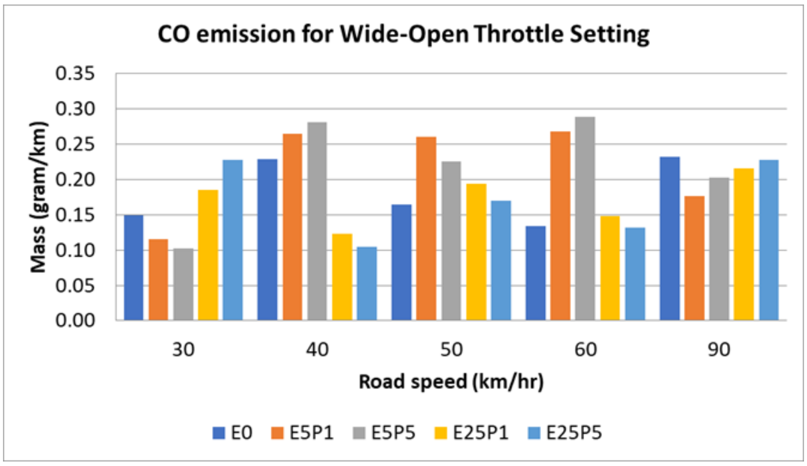

Figure 13: Carbon monoxide (CO) gas emission for wide-open throttle (WOT)

Figure 14 shows CO_2 emissions (kg/h) at 30-90 km/h under part-load. Pure gasoline E0 had the lowest CO_2 emissions, ranging from 0.05 to 0.128 kg/h. E5P1 had the highest CO_2 emissions, 0.136-0.232 kg/hr. E5P5 had moderate CO_2 emissions, 0.129-0.183 kg/h. E25P1 and E25P5 had high CO_2 emissions, 0.139-0.246 kg/h and 0.149-0.228 kg/h respectively. Figure 15 shows CO_2 emissions (kg/h) at 30-90 km/h under wide-open throttle. E0 had the lowest CO_2, 0.024-0.171 kg/h. E25P1 and E5P1 had the highest CO_2, 0.095-0.246 kg/h and 0.117-0.238 kg/h. E5P5 had moderate CO_2, 0.098-0.204 kg/h. E25P5 had the lowest CO_2 of the blended fuels, 0.098-0.178 kg/h.

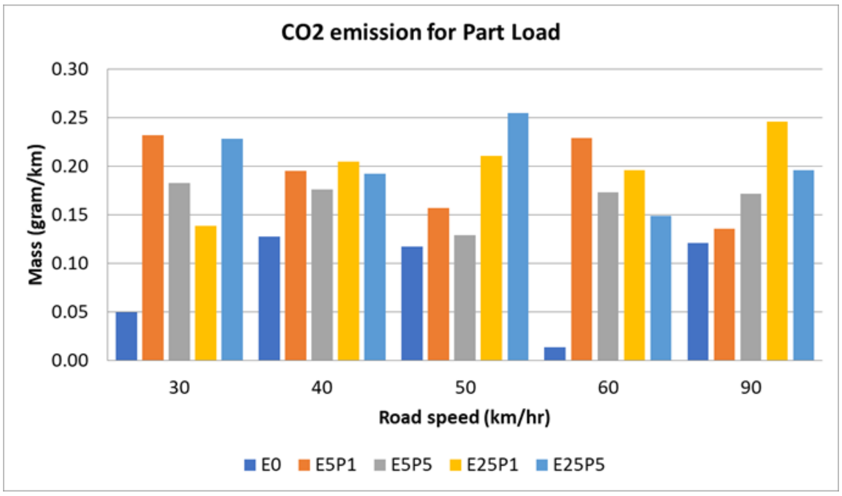

Figure 14: Carbon dioxide (CO_2) gas emission for part-load throttle (PL)

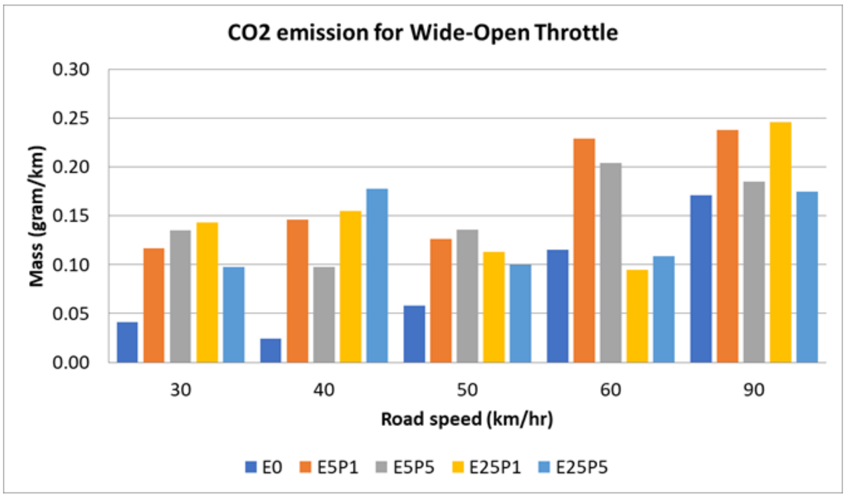

Figure 15: Carbon dioxide (CO_2) gas emission for wide-open throttle (WOT)

Figure 16 shows the hydrocarbon (HC) emissions (kg/h) of different blended fuel types at part-load throttle settings and 30-90 km/h road speeds. Pure gasoline E0 had the lowest HC at 30 km/h but the highest at 40 km/h before decreasing. The lower ethanol blends E5P1 and E5P5 produced significantly high HC at 30 km/h but lower emissions at 40-90 km/h. The higher ethanol blends E25P1 and E25P5 had moderate and similar HC at 30 km/h, then decreasing at 40 km/h but increasing again at 50-90 km/h. Figure 17 shows different blended fuels' HC emissions (kg/h) at wide-open throttle and 30-90 km/h. The high ethanol blends E25P5 and E25P1 had the highest HC at 30 km/h, followed by pure E0. The low ethanol blends E5P5 and E5P1 had the lowest HC at 30 km/h. E0 had increasing

HC emissions from 40-90 km/h. All the blended fuels had lower HC than E0 at 40 km/h. E5P1 had the highest HC emissions at 50-90 km/h.

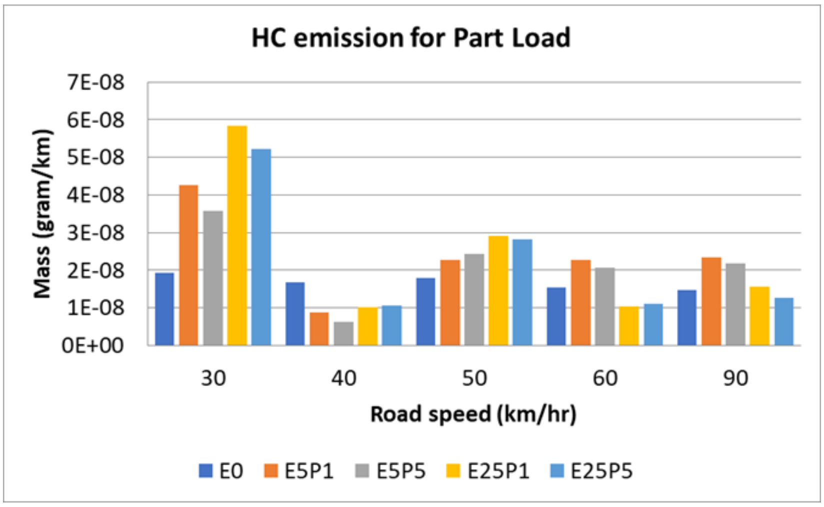

Figure 16: Hydrocarbon (HC) gas emission for part-load (PL)

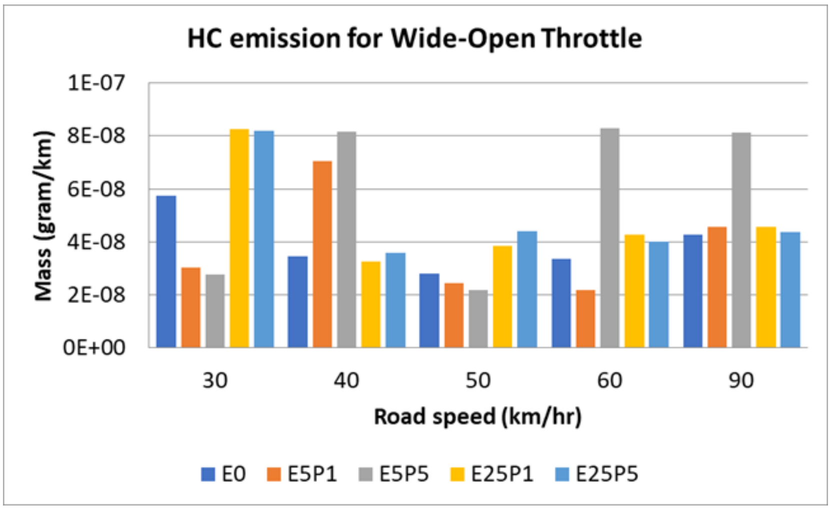

Figure 17: Hydrocarbon (HC) gas emission for wide-open throttle (WOT)

Figure 18 shows the nitrogen oxide (NO_X) emissions (kg/h) of different blended fuels at part-load and speeds of 30-90 km/h. Pure gasoline E0 had the highest NO_X emissions across all speeds. The lower ethanol blends E5P1 and E5P5 had higher NOx than other blends at 30 km/h but lower than E0, and then low NO_X at 40-90 km/h. The higher ethanol blends E25P1 and E25P5 had low NO_X at 30 km/h, decreasing further at 40 km/h, then gradually increasing at 50-90 km/h but still lower than E0. The higher combustion temperatures of pure gasoline E0 tend to produce more NO_X. At the same time, ethanol in the blended fuels lowers combustion temperatures and prevents NO_X formation, and particulate matter additives can improve mixing and stability and reduce NO_X. Figure 19 shows different blended fuels' NO_X emissions (kg/h) at wide-open throttle and 30-90 km/h. E0 had the lowest NO_X at 30 km/h, then the highest at 40 km/h before reducing again at 50 km/h, increasing and peaking at 60 km/h, then reducing at 90 km/h. The high ethanol blends E25P1 and E25P5 had high NO_X at 30-50 km/h, but the lowest NOx at 60 and 90 km/h. The oxygen content in ethanol promotes more complete combustion, which tends to reduce NO_X formation, especially when combined with particulate matter additives.

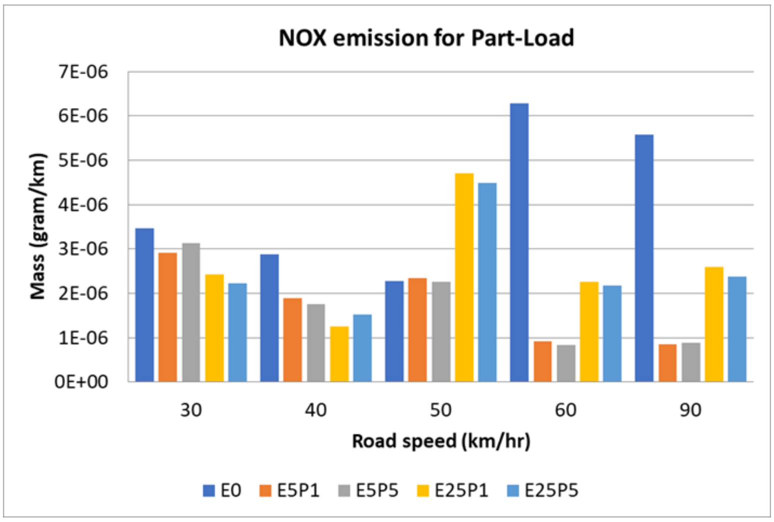

Figure 18: Nitrogen oxide (NO_x) gas emission for part-load (PL)

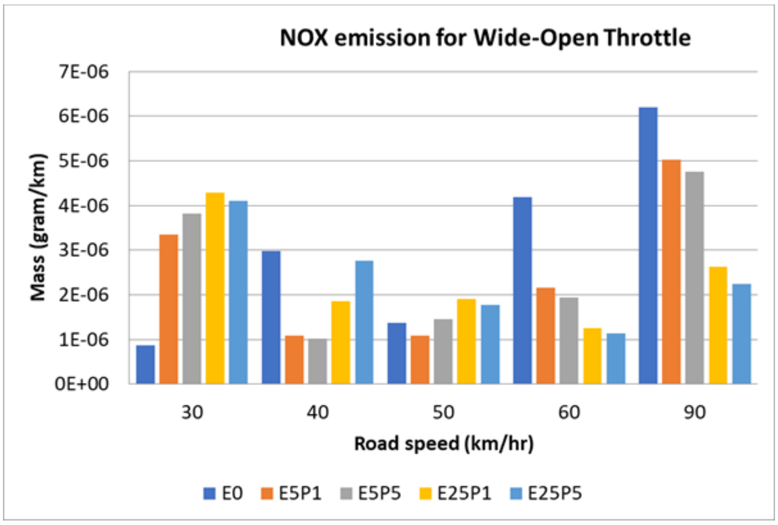

Figure 19: Nitrogen oxide (NO_x) gas emission for wide-open throttle (WOT)

4. Conclusion

This study analyzed the results of applying various fuel blends to a single-cylinder engine, finding that using a fuel blend of 25% ethanol and 5% PIB additive (E25P5) improved engine performance, increasing torque by 16%, reducing fuel consumption by 20%, and increasing brake mean effective pressure and brake thermal efficiency, while also producing the lowest overall exhaust emissions, compared to pure gasoline (E0) and other blended fuels, due to ethanol's higher octane rating allowing for more efficient combustion, despite the engine potentially experiencing decreased performance over time due to idling before the experiment, and with the E5P1 blend having the highest torque at 60 km/h in WOT settings, as the amount of ethanol in the mixture was a crucial factor, with higher ethanol blends generally enabling greater emissions reductions influenced by the engine's response to the fuel.

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