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Emission Reduction Potential of Sorghum-Based Bioethanol Blends in Small Engine Applications

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ABSTRACT: *Indonesia's dependence on fossil fuels poses a serious problem in the form of exhaust emissions that contribute to air pollution and global warming. One solution being studied is the use of bioethanol from sorghum (Sorghum bicolor L.) as a fuel blend. In this study, 96% ethanol from sorghum sap distillation was mixed with pertalite fuel RON 90 in a GX 160 generator engine to determine its effect on exhaust emissions and fuel consumption. Test results showed that adding up to 10% ethanol was able to reduce carbon monoxide (CO) emissions due to more efficient combustion. However, when the ethanol concentration exceeded 15%, emissions tended to increase again due to the lower calorific value of ethanol, resulting in less complete combustion. Thus, a blend of up to 10% ethanol proved optimal in reducing harmful emissions without affecting engine performance. Meanwhile, a 5% ethanol blend proved to be the most efficient with the lowest fuel consumption.*

Keywords: *ethanol, pertalite fuel, fuel consumption, air pollution, exhaust emission.*

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I. INTRODUCTION

In Indonesia, the use of fossil fuels remains the primary choice and has not been replaced in various aspects of life. Although the negative impacts of excessive use of fossil fuels are very damaging to the environment, the high combustion capacity and energy contained in fossil fuels, which is greater than other fuels, remain the main reasons for their sustainability. Indonesia's dependence on fossil fuels reaches more than 60 percent of total energy consumption. Currently, oil reserves in Indonesia reach 86.9 billion barrels with reserves of 9.1 billion barrels and annual production of 387 million barrels. Based on this calculation, it is estimated that oil resources will only be sufficient for the next 23 years [1].

Study of performance and exhaust emissions of 4-stroke gasoline generator engines with premium fuel mixed with ethanol, premium-ethanol mixture, and premium-ethanol-hydrogen. Testing was carried out by weighing the fuel, measuring voltage, current, engine speed, and fuel exhaust time [2, 3]. The results showed that optimum power was achieved up to a load of 1000 Watts, except for pure ethanol which was only capable of 600 Watts. The best specific fuel consumption was obtained in the premium-ethanol-hydrogen mixture, namely 836.2369 g/kW.h, more efficient than premium and pure ethanol.Another study examined the effect of adding ethanol to biodiesel (B35) on the performance of a 3000 W diesel generator. The ethanol variations used were 5%, 10%, 20%, and 30%. The results showed that a 20% ethanol blend provided the best performance, with the highest power, the most fuel-efficient fuel consumption, and the lowest specific consumption. Adding up to 20% ethanol increased power by 16.29% at maximum load and reduced specific fuel consumption by up to 59.27% [4]. Thus, the quality of biodiesel (B35) currently used can still be improved by adding ethanol, with an optimal limit of 20%.

Study on the effect of ethanol concentration in pertamax fuel on generator fuel consumption [5]. The purpose of mixing the fuel is to reduce the use of petroleum fuel. One of the energy sources for pertamax fuel mixing is ethanol. The mixture of ethanol with pertamax fuel for testing on a gasoline generator engine uses a mixture variation of 5%, 10%, 20%, and 30% of the total volume of pertamax. The addition of ethanol is used to test fuel consumption, power, and specific fuel consumption of a 2200 Watt generator engine. The results of the test where the optimum point of power produced by the generator engine is at a mixture of 20% is able to increase power by 0.155% at the highest load, at the use of a mixture of 30% the engine power tends to decrease, and also the value of the specific fuel consumption produced is also able to decrease to 0.265% at a mixture of 20% ethanol.

Kusuma [6] conducted a study on the effect of adding ethanol to RON 90 pertalite fuel on the performance of a 2200 Watt generator set. By testing the addition of ethanol to RON 90 pertalite fuel on the performance of a 2200 Watt generator set, it is expected that fuel consumption in the generator set will be lower or more efficient. The method used in this study is an experimental method using a variety of mixed fuels, namely BE0, BE5, BE10, BE20 and BE30. The fuel mixture variations were tested on the generator set using a load of 500 Watts, 1000 Watts, 1500 Watts, 2000 Watts. The test was carried out on a variety of engine speeds. The results of this test are that the addition of 20% bioethanol to RON 90 pertalite, in each variation of engine speed and each load given has the lowest fuel consumption value. With a reduction percentage of 56.31% in pertalite RON 90, it is able to increase the performance of a 2200 Watts generator set, which makes it more economical in fuel consumption.

Dependence on fossil fuels has encouraged research into alternative energy sources, one of which is bioethanol. Muharnif M. et al. [7] studied the performance of a 150 cc 4-stroke engine powered by a mixture of pertalite and ethanol from organic waste. The results showed that the addition of ethanol increased torque and power, while specific fuel consumption decreased with increasing ethanol percentage. Previous studies have shown that ethanol as a blended fuel can improve combustion efficiency, engine performance, and reduce emissions and fuel consumption [8, 9]. However, research on the effect of variations in the concentration of ethanol from sorghum sap distillation in commercial fuel mixtures such as pertalite on generator engine performance is still limited. Sorghum (Sorghum bicolor L.) is a plant with broad agroecological adaptation, drought tolerance, and relatively resistant to pests and diseases. Its high carbohydrate content, around 73 g/100 g of material, mainly in the form of amylose and amylopectin, makes it a potential source for ethanol production [10, 11].

II. EXPERIMENTAL SETUP

This study uses an experimental quantitative method, using two research variables, namely dependent variables and independent variables. The method was conducted experimentally using a GX 160 generator engine fueled by a mixture of pertalite fuel RON 90 and 96% hydrous ethanol from sorghum sap. The variations in the ethanol mixture tested ranged from 0–30% with an electrical load of 200–1400 W. The parameters observed included fuel consumption, engine temperature, and exhaust emissions (CO, HC, CO_2) using a gas analyzer. The research was conducted at the Laboratory of the Faculty of Engineering, University of Mataram with a 4-stroke, 1-cylinder gasoline engine as the test object. This test was conducted to determine the effect of the mixture on the GX 160 generator set engine. The test equipment scheme includes one main component, namely the GX160 generator engine, as well as several supporting components such as a gas analyzer, digital scales, and a temperature measuring instrument. The complete test equipment scheme can be seen in Figure 1 below.

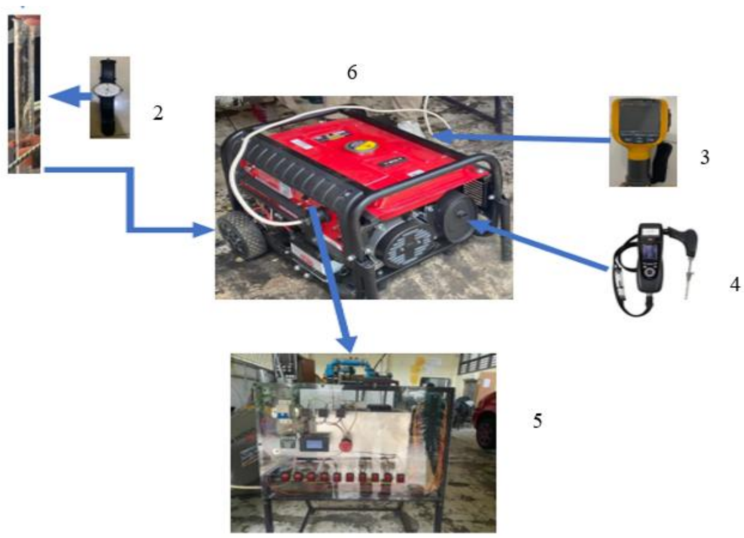

Figure 1. Schematic diagram of the research 1. Burette 2. Stopwatch 3. Thermogun, 4. Gas analyzer, 5. Heater 6. Engine Generator set GX 160

III. RESULTS AND DISCUSSION

3.1 Fuel consumption

Data analysis was performed by applying the formulas contained in the theoretical basis to calculate fuel consumption for each fuel variation. The fuel consumption calculations presented below are an analysis using loading variations and hydrous ethanol variations. By using the same calculation method for each variation, fuel consumption values were obtained for loading variations and ethanol variations in ml/s units. Each fuel variation was tested three times and then averaged as presented in table 1.

Table 1 Average fuel consumption data (ml/s).

Engine Load (Watt)	Ethanol content						
	0%	5%	10%	15%	20%	25%	30%
0	0.14	0.13	0.15	0.15	0.15	0.15	0.16
261	0.17	0.15	0.16	0.17	0.18	0.18	0.20
476	0.19	0.18	0.19	0.19	0.20	0.21	0.22
719	0.22	0.21	0.21	0.21	0.22	0.23	0.27
941	0.24	0.22	0.23	0.23	0.25	0.25	
1140	0.26	0.24	0.25	0.26	0.27	0.29	
1340	0.28	0.24	0.27	0.28	0.28	0.29	

Figure 1 shows the relationship between fuel consumption in ml/s and variations in ethanol content and engine load. The graph illustrates the effect of variations in ethanol content on fuel consumption in engines under different loads. The graph shows that fuel consumption (ml/s) increases with increasing engine load, from no-load conditions to a maximum load of 1140 Watts. At each load level, fuel consumption tends to increase as the ethanol content in the mixture increases from 0% to 30%. It can be seen that fuel consumption increases with increasing engine load, indicating a greater energy requirement to maintain engine performance.

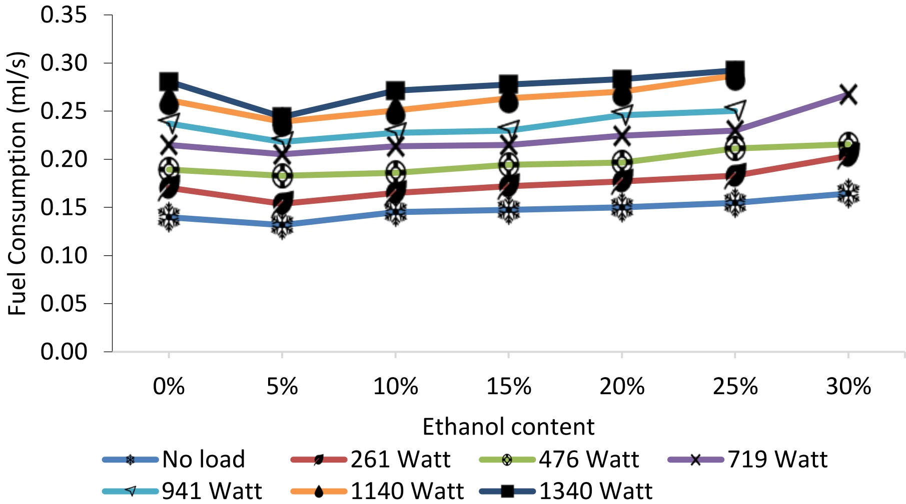

Figure 2 Relationship between fuel consumption produced by a mixture of pertalite fuel and ethanol.

Figure 2 shows the relationship between ethanol variations and fuel consumption. In this study, the 5% hydrous ethanol variation resulted in lower fuel consumption compared to the other variations, as seen in the graph. Fuel consumption in the generator showed a different pattern depending on the load level. Under no-load conditions, consumption was relatively low but increased with increasing ethanol content. Low loads (261–719 W) showed small fluctuations with an upward trend, while at medium loads (941–1140 W) consumption was more stable although still increasing at ethanol content ≥20%. At high loads (1340 W), consumption reached its highest value, with a similar increasing pattern to the ethanol variation. However, at 30% concentration with medium to high loads (941–1340 W), the generator failed to operate due to disruption of the fuel supply to the carburetor.

Overall, a small amount of ethanol mixture (5%-10%) can reduce fuel consumption, but if it is increased beyond 15%-20%, fuel consumption actually increases significantly. Higher loads cause fuel consumption to increase, but at a certain level it can be more stable due to more optimal combustion efficiency. Therefore, the use of more than 20% ethanol in the fuel mixture needs to be carefully considered because it can cause increased fuel consumption due to the lower energy content of ethanol compared to Pertalite. This study is in line with [12] showing that mixing ethanol in gasoline can maximize the amount of energy produced from the fuel burned in the engine. Combustion efficiency increases when more fuel is burned completely, resulting in greater power with less fuel consumption. However, at higher levels, fuel consumption tends to increase due to the lower energy content in ethanol compared to pertalite. This occurs because the fuel with a 5% variation that matches the correct compression of the generator engine can produce more efficient combustion and reduce the risk of premature detonation.

Generator load affects fuel consumption (mL/s), with a visible pattern of fuel consumption changes with increasing ethanol content in the fuel mixture. At 0% ethanol content or pure pertalite, fuel consumption tends to be higher compared to 5%-10% ethanol mixtures. This is due to increased combustion efficiency because ethanol has a higher oxygen content. However, at 10%-20% ethanol mixtures, fuel consumption begins to increase gradually. This is due to the lower energy content of ethanol compared to pertalite, so more fuel is needed to produce the same power. The increase in fuel consumption is more significant at 25%-30% ethanol content, which can be explained by its lower calorific value compared to pertalite [5, 13].

3.2 Exhaust gas emission

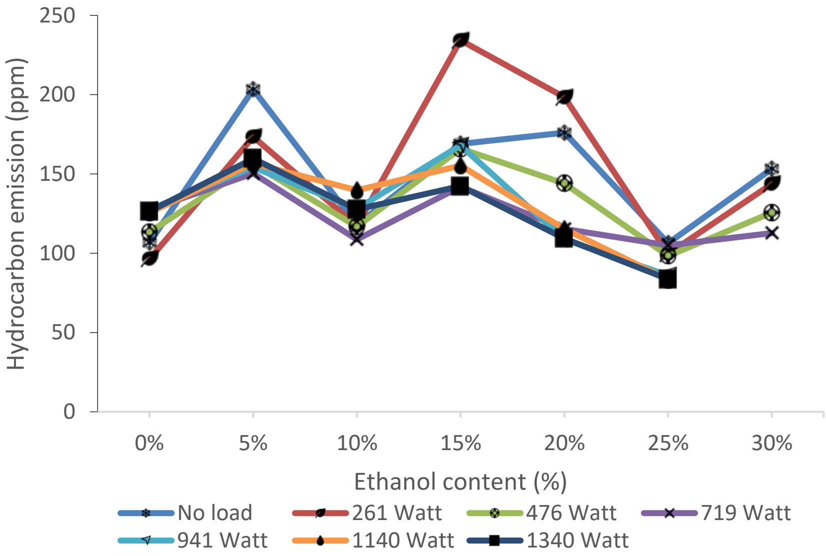

Figure 3. Comparison of hydrocarbon exhaust emissions produced by a mixture of pertalite fuel with ethanol.

Figure 3 shows a comparison of the magnitude of hydrocarbon exhaust emissions produced by the GX 160 generator engine using pertalite fuel with all variations of ethanol addition. Based on Figure 2 above, the addition of ethanol affects the hydrocarbon value. This study is in line with [12], which found that hydrocarbon emissions in ethanol mixtures in gasoline do not always decrease linearly, but can increase at certain concentrations due to changes in AFR and incomplete combustion. There are significant fluctuations in the levels of hydrocarbons produced. At 0% ethanol, hydrocarbon emissions are at an initial level that varies according to the given load. When ethanol is mixed at 5%, there is a spike in hydrocarbon emissions at almost all load levels, which is caused by incomplete combustion due to differences in fuel characteristics and differences in the calorific value of ethanol compared to pertalite without ethanol.

At 10% ethanol, hydrocarbon emissions tended to decrease compared to 5% ethanol, indicating that moderate ethanol blending can improve combustion efficiency by providing more oxygen in the combustion process. However, at 15% ethanol, hydrocarbon emissions increased again, especially at low to medium loads. This is due to the higher ethanol content, which means that not all of the fuel is completely burned. The highest peak hydrocarbon exhaust emissions occurred at 15% ethanol with a load of 261 W, reaching 234.3 ppm, indicating that under these conditions, combustion is less efficient and produces a lot of unburned hydrocarbons. After that, at 20% and 25% ethanol, there was a significant decrease in hydrocarbon emissions, indicating that at these levels, combustion becomes more stable again. However, at 30% ethanol, hydrocarbon emissions increased again, which could be caused by limitations in the optimal fuel-to-air ratio, as well as the possibility of incomplete combustion due to the high ethanol content that reduces the fuel's energy density.

In terms of load variations, hydrocarbon emissions tend to be higher at low loads (no load and 261 W) compared to higher loads. This indicates that at low loads, the combustion process is not optimal, resulting in more unburned hydrocarbons. At medium to high loads (941 W - 1340 W), hydrocarbon emissions tend to be more stable and lower, indicating that combustion is more complete at these loads due to increased pressure and temperature in the combustion chamber.

Overall, these results indicate that blending ethanol into the fuel significantly affects hydrocarbon emissions, with ethanol levels of 5%-15% tending to increase hydrocarbon emissions, while ethanol levels of 20%-25% tend to decrease emissions before increasing again at 30% ethanol. Overall, these findings also deviate from the literature, which states that higher ethanol content improves combustion, thus leading to a continued decrease in hydrocarbon emissions [14, 15].

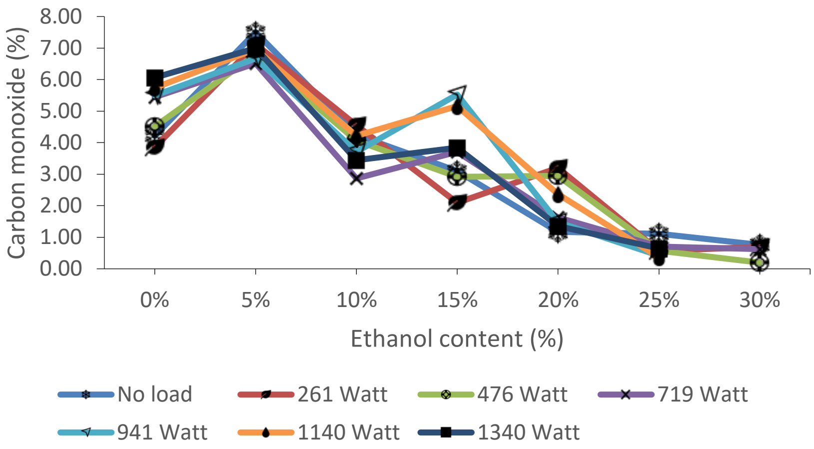

Figure 4. Comparison of carbon monoxide exhaust emissions produced by a mixture of pertalite fuel with ethanol.

Figure 4 shows a comparison of the carbon monoxide values produced by the GX 160 generator engine using pertalite fuel with all variations of ethanol addition. As seen from the graph above, the addition of ethanol affects the carbon monoxide values produced. Furthermore, variations in generator load affect CO emissions. At low to medium loads, the engine tends to be more stable than at idle (no load), so that with pure fuel (0% ethanol) there is sometimes a decrease in CO compared to when the engine is idling. As the load continues to increase, fuel requirements increase and CO emissions generally increase as well when using only pertalite. The addition of ethanol to the mixture can suppress this increase in CO. For example, at 15% ethanol and above, CO values are consistently lower than pure pertalite at every load level. In fact, when ethanol reaches 25%–30%, CO emissions are below 1% at almost all load ranges, including at the maximum load of 1340 Watts. Thus, the oxygen content in ethanol is able to compensate for the increase in fuel supply and maintain more complete combustion, so that CO exhaust gases are significantly reduced even though the engine load is increasingly heavy. From these test results, it can be concluded that the addition of 96% ethanol (hydrous ethanol) to pertalite has a positive effect in reducing CO emissions, especially when the ethanol content reaches 15% and above. This reduction in emissions is most noticeable at medium to high loads, as the engine utilizes the extra oxygen from the ethanol to burn the fuel more efficiently. Meanwhile, at lower blends (around 5% ethanol), CO increases can occur due to the less-than-ideal air-fuel ratio for such blends.

This study is in line with [16], which shows that mixing ethanol in gasoline fuel can increase combustion efficiency at certain levels due to the higher oxygen content. Carbon monoxide (CO) is one of the main exhaust gases produced by gasoline-fueled engines, including when the engine is used to drive an electric generator. In this study, CO content was measured in various variations of 96% ethanol (hydrous ethanol) mixtures with pertalite and at various load levels (no load to 1340 Watts). In general, the test results show that the higher the percentage of ethanol in the mixture, the lower the CO emissions tend to be. This occurs because ethanol contains oxygen which can help the combustion process to be more perfect, so that CO formation is reduced. However, there is an anomaly in low ethanol mixtures (around 5%), where CO emissions actually increase quite significantly. This is caused by changes in evaporation characteristics and an unbalanced air-fuel ratio when the ethanol percentage is still small. If the ethanol mixing is not accompanied by optimal injection system settings and air-fuel ratio, combustion can be imperfect and actually increase carbon monoxide levels [17, 18].

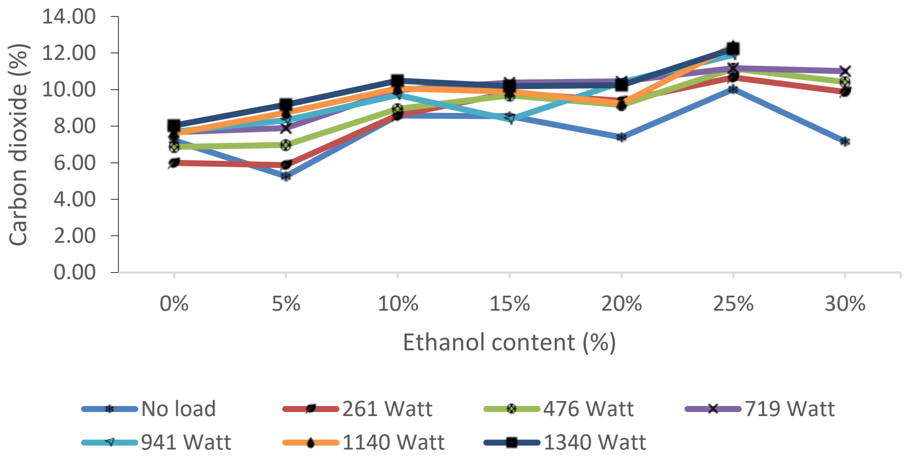

Figure 5. Comparison of carbon dioxide exhaust emissions produced by a mixture of pertalite fuel with ethanol

Figure 5 shows a comparison of the carbon dioxide values produced by the GX 160 generator engine using pertalite fuel with all variations of ethanol addition. Carbon dioxide (CO_2) is one of the exhaust gases produced from a more perfect combustion process, so a higher CO_2 value generally indicates more efficient combustion. This study is in line with [12], which shows that mixing ethanol in gasoline generally increases CO_2 emissions due to more perfect combustion. However, this study also noted that at certain concentrations, if the fuel-air ratio is not optimal, CO_2 production can decrease temporarily due to incomplete combustion. In this study, CO_2 was measured from the combustion results of a mixture of pertalite with 96% ethanol (hydrous ethanol) at various percentages (0%–30%) and various load levels (no load to 1340 watts). The test results showed that the addition of ethanol can increase CO_2 emissions, especially when the ethanol content is quite high (25%–30%) and the engine load is at medium to high levels. For example, at a load of 1340 Watts, a 25% ethanol blend produces the highest CO_2 (13.05%), exceeding the CO_2 value of pure pertalite (9.18%) at the same load. This indicates that the additional oxygen from the ethanol makes combustion more complete, resulting in more carbon being oxidized to CO_2.

However, at low ethanol percentages (around 5%), CO_2 can actually decrease compared to pure pertalite at idle or light load conditions. However, a temporary decrease can occur if the combustion temperature drops or if there is a shift in the fuel-air ratio that leads to incomplete combustion [19]. This occurs because the engine settings are not yet ideal for low ethanol, resulting in an inappropriate air-fuel ratio and resulting in suboptimal combustion. Once the ethanol percentage increases to the 10%–15% range, CO_2 emissions typically rise again as the oxygenation effect of the ethanol becomes significant. At medium loads (476–719 Watts), 20%–25% ethanol concentrations appear to produce a higher CO_2 spike than pure pertalite, indicating more efficient combustion. However, there are fluctuations at some load points, especially at 30% ethanol, which can be slightly lower than 25% ethanol.

IV. CONCLUSION

The conclusion of this study shows that variations in the mixture of ethanol with pertalite have a significant effect on fuel consumption and exhaust emissions in the GX 160 generator engine. A mixture of 5% ethanol proved to be the most efficient with the lowest specific fuel consumption, especially at high loads, indicating optimal combustion. Conversely, ethanol levels above 10% increased consumption due to decreased combustion efficiency. HC emissions tended to fluctuate and peaked at 15% due to incomplete combustion, while CO emissions decreased with increasing ethanol, indicating improved combustion efficiency. CO_2 emissions slightly increased at higher ethanol levels, indicating more complete combustion under certain conditions.

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