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THE EFFECTS OF SUGARCANE BAGASSE ETHANOL-GASOLINE BLENDS ON EXHAUST EMISSIONS AND FUEL CONSUMPTION OF A 171CC FOUR-STROKE SINGLE - CYLINDER ENGINE

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ABSTRACT

The increasing global demand for energy, driven by population growth, industrialization, and urbanization, has intensified the search for cleaner and sustainable alternative fuels. This study investigated the production of bioethanol from sugarcane bagasse and evaluated its performance in ethanol–gasoline blends for spark ignition engines. The bagasse was pretreated through acid hydrolysis, followed by enzymatic hydrolysis using cellulase and fermentation with *Saccharomyces cerevisiae*. The produced ethanol, with a purity of 99.53%, was blended with gasoline to obtain (E0–E30) mixtures. Engine performance and emission characteristics were tested using a 171 cm^3 single-cylinder, four-stroke spark ignition engine operating at a constant speed of 3000 rpm. Results showed that fuel consumption decreased progressively from 0.225 cm^3/sec for E0 to 0.201 cm^3/sec for E30, indicating improved fuel efficiency with increasing ethanol content. Carbon monoxide (CO) emissions remained constant at 1.0 ppm across all blends, while carbon dioxide (CO_2) emissions decreased from 6.47 ppm (E0) to 5.00 ppm (E30), contrary to common literature trends. Total volatile organic compounds (TVOC) emissions also showed a general reduction, with the lowest value observed at E25, suggesting enhanced combustion efficiency. Overall, the findings demonstrate that bioethanol derived from sugarcane bagasse is a viable and sustainable fuel additive, with blends between E20 and E30 offering optimal performance and emission benefits in spark ignition engines.

Keywords: Bioethanol, Sugarcane bagasse, Ethanol–gasoline blends, Engine performance, Exhaust emissions.

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1. INTRODUCTION

Energy use around the world is increasing due to population growth, expanding industries, and rising urban development. Reports from organizations such as the International Energy Agency (2022) indicate that energy demand is expected to keep growing steadily in the coming years. This has led to continued dependence on fossil fuels like coal, crude oil, and natural gas. However, these energy sources are limited and becoming more expensive to extract. In addition, burning them releases large amounts of carbon dioxide (CO_2), which contributes to global warming and climate change. As a result, there is increasing global interest in cleaner and renewable energy sources that can reduce environmental damage and dependence on fossil fuels.

One important renewable option is biomass, which can be used directly for heat and electricity or processed into liquid fuels for vehicles. According to the International Renewable Energy Agency (2022), the use of liquid biofuels in transportation has grown steadily in recent years, even though there was a short decline during the COVID-19 period. Among these biofuels, ethanol is widely studied because it burns more cleanly than gasoline, can be produced from many raw materials, and has a high octane value that supports engine performance. Many researchers have shown that mixing ethanol with gasoline can improve engine operation and reduce harmful emissions. Studies by Venktesh et al. (2023) found better engine power and efficiency with blends like E20. Similarly, Made and Made (2024) reported lower carbon monoxide and hydrocarbon emissions as ethanol content increased.

Research by Maciej et al. (2025) showed that higher ethanol blends reduced pollutants, although pure ethanol affected engine power. Other studies, including those by Jai and Shashi (2025) and Yanshuai et al. (2023), also confirmed better combustion and cleaner emissions at suitable blend levels. In addition, Menelik et al. (2025) used advanced modeling techniques to show that E30 blends can improve combustion efficiency and reduce fuel use. Even with these findings, there is still a need to study different biomass materials for ethanol production. This research focuses on producing ethanol from sugarcane bagasse and testing its performance when mixed with gasoline in a spark-ignition engine running at constant conditions. The experimental work was carried out at Luco Chemical Laboratory Ltd., located in Benin City, Edo State, Nigeria.

2. MATERIALS AND METHODS

2.1 Materials

Sugarcane bagasse was selected as the raw material for producing ethanol in this study. The material was collected from a sugar processing facility and carefully packed in plastic-lined bags before being transported to a laboratory in Benin City, Edo State, Nigeria, where all experiments were carried out. Various chemicals were used during the process, including sodium hydroxide, Sulphuric acid, benzene, nitric acid, and hydrochloric acid, all of high purity and obtained from standard chemical suppliers. Clean distilled and deionized water was also used for sample preparation and dilution. An enzyme (cellulase) was applied to break down the biomass into simpler sugars, while common baker's yeast (*Saccharomyces cerevisiae*) was used for fermentation. The experimental setup involved several laboratory instruments. These included a magnetic stirrer for mixing, a hot air oven for drying, an analytical balance for accurate weighing, and an autoclave for sterilization. Other basic laboratory tools such as measuring cylinders, conical flasks, beakers, sieves of different sizes, and droppers were also used. In addition, a pH meter was used to monitor acidity levels, filter paper for separation, a digital refractometer for concentration measurement, and a UV–visible spectrophotometer for analysis.

2.2 Methods

2.2.1 Preparation of Sugarcane Bagasse

Sugarcane bagasse was used as the main raw material for producing ethanol. The bagasse was first washed to remove dirt, and then dried under the sun for about three days. After that, it was placed in an oven at 105 °C for 24 hours to remove any remaining moisture. The dried sample was ground into smaller particles, sieved to about 250 µm, and kept at room conditions for further use.

2.2.2 Optimization of Acid Pretreatment

The material was then treated with acid to break down its structure. This pretreatment process was optimized using a statistical method by adjusting factors like acid strength, temperature, and reaction time to get the highest sugar yield.

2.2.3 Enzymatic Hydrolysis

Following pretreatment, the pH of the hydrolysate was adjusted to 4.5–5.0 using a pH meter. A cellulase solution was prepared by dissolving 2 g of cellulase powder in 50 mL of distilled water at 40 °C. The enzyme solution was then added to the hydrolysate and incubated in a water bath at 40 °C for 24 hours to facilitate enzymatic hydrolysis.

2.2.4 Fermentation

Fermentation was carried out using baker's yeast (Saccharomyces cerevisiae). A yeast suspension was prepared by dissolving 2 g of dry yeast in 50 mL of distilled water, which was then added to the hydrolysate in a sealed fermentation vessel. Fermentation was allowed to proceed for 5 days, during which the vessel was gently swirled daily to ensure proper yeast activity.

2.2.5 Distillation

The fermented broth was distilled using a conventional distillation apparatus consisting of a heating mantle, boiling flask, condenser, thermometer, and receiving beaker. The mixture was heated to approximately 80°C, slightly above the boiling point of ethanol, and distillation continued until the temperature reached 100 °C.

2.2.6 Preparation of Ethanol–Gasoline Blends

Ethanol and gasoline were mixed to produce blends with a total volume of 100 ml. The required volume of ethanol was determined using:

$$volume\ of\ ethanol\ = \frac{desired\ \ percentage}{100} \times Total\ volume\ of\ mixture \qquad 1$$

The blends was labeled as E0, E5, E10, E15, E20, E25, E30, the E designates ethanol and the digits designates the volume percentage of ethanol thus, E0 means a blend containing 0% pure gasoline by volume.

2.2.7 Engine Performance Testing

Engine performance testing was conducted using a FIRMAN engine–generator set consisting of a 171 cm^3, four-stroke, single-cylinder, air-cooled spark-ignition engine coupled to a 2 kW generator. The engine was operated at 3000 rpm under a 500 W load. Fuel consumption was measured by recording the time required to consume 100 cm^3 of fuel using a calibrated burette, while emissions were recorded using an emission analyzer. The technical specifications of the tested engine and electrical generator are shown in Tables 1 and 2. Six different fuel samples were examined in this study. Base gasoline (109 research octane

number) was obtained from a local fuel station. The fuel blends were prepared immediately before the experiment to ensure homogeneity. The engine was started using a recoil starter, and once started, the choke valve was fully opened. The engine was allowed to run for 10–15 minutes to warm up and reach steady-state conditions. The experiment was conducted at a constant speed of 3000 revolutions per minute (rpm) and a constant load. The tested fuels included gasoline (E0) and ethanol–gasoline blends (E5, E10, E15, E20, E25, and E30). Tests were first carried out using pure gasoline (base fuel) to establish baseline data, followed by testing of the ethanol blends under identical operating conditions. The engine was not modified for any of the fuels. After reaching stable operating conditions, performance parameters were recorded. Before testing a new fuel blend, the engine was allowed to run for sufficient time to purge any remaining fuel from the previous test. The main parameters studied were carbon monoxide (CO), carbon dioxide (CO_2), and total volatile organic compounds (TVOC) and fuel consumption using standard thermodynamic equations as described by Rajput (8th edition). The setup used for the experiment is shown in a Figure 1, while the results are presented in Tables 3 and graphs for better understanding in Figure 2- 5.

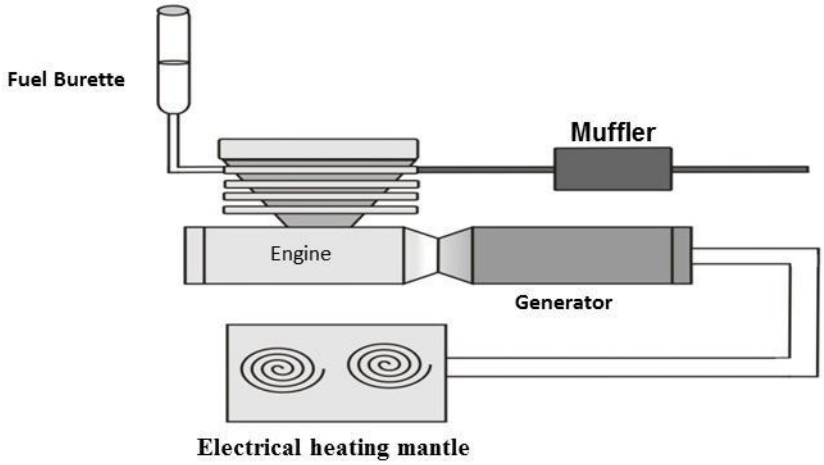


Figure 1: Shows the Schematic Diagram of the Experimental Set up

Volume Flow rate:

$$Q = \frac{V}{T}\frac{Cm^3}{Sec} \qquad 2$$

Where: Q = flow rate (Cm^3/Sec)

V = volume (Cm^3)

T = time (Sec)

Table 1: Specifications of the Tested Engine

Engine type	4-stroke single cylinder, OHV, air cooled.
Displacement volume	171cc or 171Cm3
Bore x stroke	66mm x 50mm
Fuel delivery system	Conventional carburetor
Compression ratio	8:5:1
Rated output power	2kw at 3000rpm
Engine oil capacity	1.1liter
Fuel tank capacity	15liter

Table 2: Single Phase AC Generator Specifications

Type	Single phase
Rated frequency	50Hz
Rated current	9.09 or 9.1A
Rated voltage	220V
Rated output power	2Kw at 3000rpm
Maximum power	2.2Kw

3. RESULTS AND DISCUSSION

Different ethanol–gasoline blend ratios were evaluated to determine their effects on fuel usage rate and exhaust emissions, including CO, CO_2, and TVOC.

3.1 Engine Performance Characteristics

Table 3: Show the Results obtain from Engine Performance

Fuel Blends	Time (sec)	Q(cm^3/sec)	EXHAUST GAS EMISSION DATA		
			CO (PPM)	CO_2 (PPM)	TVOC (PPM)
E0	444.44	0.225	1.0	6.47	0.579
E5	454.55	0.220	1.0	6.36	0.509
E10	465.12	0.215	1.0	6.26	0.499
E15	476.19	0.210	1.0	6.10	0.483
E20	485.44	0.206	1.0	6.08	0.481
E25	490.20	0.204	1.0	5.68	0.441
E30	497.51	0.201	1.0	5.00	0.373

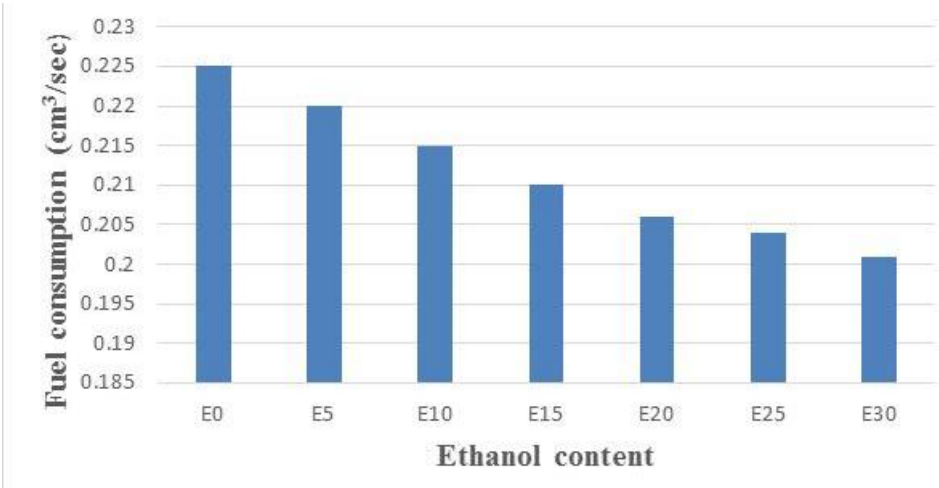


Figure 2: Fuel consumption (cm^3/sce)

From Figure 2, it can be seen that the fuel flow rate (Q) decreases steadily as the ethanol content increases from E0 to E30. The highest fuel consumption was observed at E0 with 0.225 cm³/sec, while the lowest fuel consumption was recorded at E30 with 0.201 cm³/sec, representing an approximate 10.7% reduction in fuel flow rate. This indicates that the addition of ethanol improves fuel utilization efficiency, likely due to better combustion characteristics. This trend is in agreement with several literature findings. For instance, Hamza et al. (2019) reported that ethanol-gasoline blends, particularly E25, exhibited lower fuel consumption and improved brake-specific fuel consumption compared to pure gasoline,

which aligns with the decreasing trend observed in this study. Similarly, Made and Made (2024) and Menelik et al. (2025) also observed that fuel consumption decreases as ethanol content increases, attributing this to enhanced combustion efficiency. Furthermore, Venktesh et al. (2023) and Karib and Sobahan (2023) reported reductions in brake-specific fuel consumption and improvements in engine efficiency with increasing ethanol blends, especially around E20, which supports the progressive reduction in fuel flow rate seen in your results. The findings of Olawore et al. (2021) and Elfasakhany (2014) also confirm that ethanol addition improves combustion due to its oxygenated nature, thereby reducing the amount of fuel required for the same power output. However, a slight contrast is noted with Dhirajsingh and Hanumant (2018) and Hakan et al. (2018), who reported an increase in specific fuel consumption with higher ethanol blends. This difference may be due to variations in engine configuration, operating conditions, and the lower heating value of ethanol, which sometimes requires more fuel to produce equivalent energy despite improved combustion. Overall, the reduction in fuel flow rate observed in this study can be attributed to the high oxygen content of ethanol, which enhances air–fuel mixing and promotes more complete combustion. This leads to improved thermal efficiency and reduced fuel demand. Hence, the present results largely agree with the majority of the literature, confirming that ethanol-gasoline blends contribute to more efficient fuel consumption in spark ignition engines.

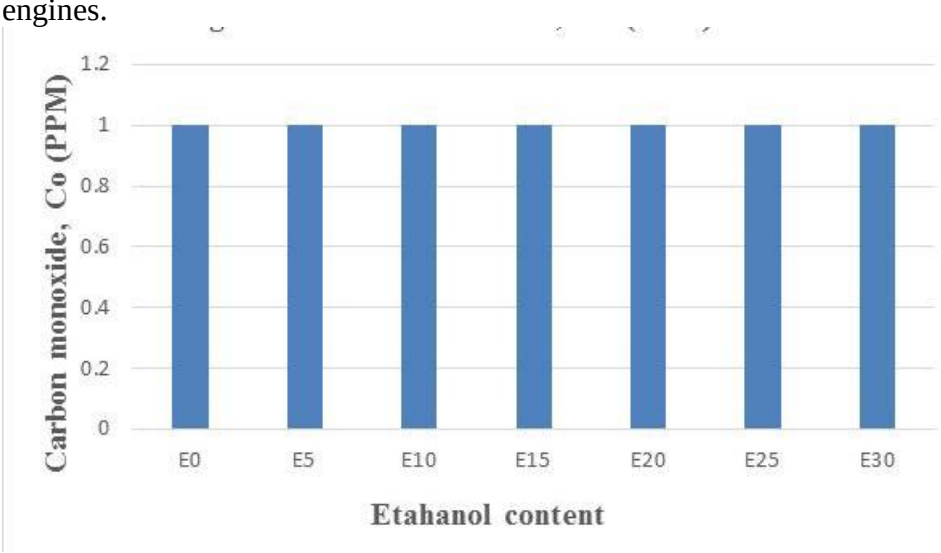


Figure 3: Carbon monoxide, CO (PPM)

From Figure 3, it can be observed that the carbon monoxide (CO) emission remains constant at 1.0 ppm for all fuel blends (E0–E30), indicating no reduction or increase in CO emissions with the addition of ethanol. This implies that ethanol blending, under the conditions of this experiment, did not significantly influence CO formation in the combustion process. This result is not in agreement with most literature findings. For instance, Laminu et al. (2014) reported that CO emissions decrease with increasing ethanol content due to the oxygenated nature of ethanol, which enhances complete combustion. Similarly, Elfasakhany (2014) and Suresh and Porpatham (2019) observed significant reductions in CO emissions with ethanol addition, attributing this to improved air–fuel mixing and the lean-burn effect. In addition, Made and Made (2024) and Maciej et al. (2025) also confirmed that higher ethanol blends lead to lower CO emissions, especially around E20–E30 blends. However, the constant CO emission observed in this study may be due to complete combustion already occurring in the base fuel (E0) or limitations in measurement sensitivity and equipment calibration, which could mask small variations in CO levels. It may also suggest that engine operating conditions (such as air–fuel ratio and load) were maintained in a way that minimized CO

formation across all blends. In conclusion, while literature widely supports that ethanol blending reduces CO emissions due to its high oxygen content and improved combustion efficiency, the present study shows no observable change, and therefore does not agree with the majority of previous studies. This suggests that further investigation or recalibration of experimental setup may be necessary to capture the expected emission trends.

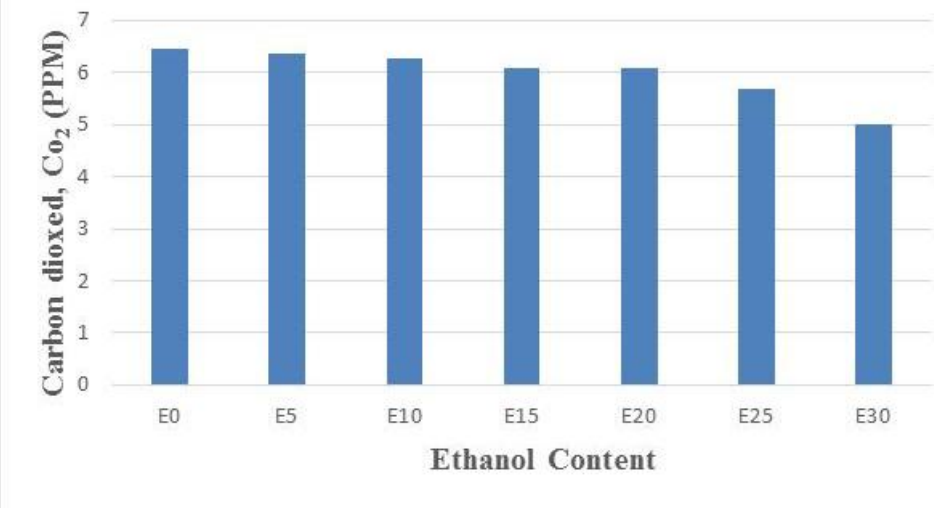


Figure 4: Carbon dioxide. CO_2 (PPM)

From Figure 4, the CO_2 emission results, it is observed that the lowest CO_2 value was 5.00 ppm for the E30 blend, representing a clear reduction compared to the highest value of 6.47 ppm obtained with E0 (pure gasoline). This indicates a steady decrease in CO_2 emissions as the ethanol content in the fuel increases from E0 to E30.However; this trend is not in agreement with most literature findings. Studies such as Laminu et al. (2014), Olawore et al. (2021), and Elfasakhany (2014) reported that CO_2 emissions increase with higher ethanol content due to more complete combustion facilitated by the oxygenated nature of ethanol. Similarly, Suresh and Porpatham (2019) also observed increased CO_2 emissions with ethanol blending, attributing it to improve in-cylinder combustion and higher oxidation rates of carbon compounds. The contradiction observed in this study may be explained by several factors such as engine operating conditions, air–fuel ratio, measurement basis (ppm vs percentage), or incomplete combustion at certain blend ratios. Although ethanol contains oxygen, which typically enhances complete combustion and increases CO_2 formation, a reduction in CO_2 as seen here may suggest lower overall carbon content in the fuel blend or possible variations in combustion efficiency. Furthermore, studies like Maciej et al. (2025) noted that CO_2 emission trends can vary depending on engine control strategies and operating conditions, supporting the possibility of such deviations. The experimental results show a decreasing trend in CO_2 emissions with increasing ethanol content, which contradicts the majority of literature that reports an increase in CO_2 due to more complete combustion. This suggests that, while ethanol blending improves certain emission characteristics, the CO_2 behavior in this study may be influenced by specific experimental conditions and should be interpreted with caution.

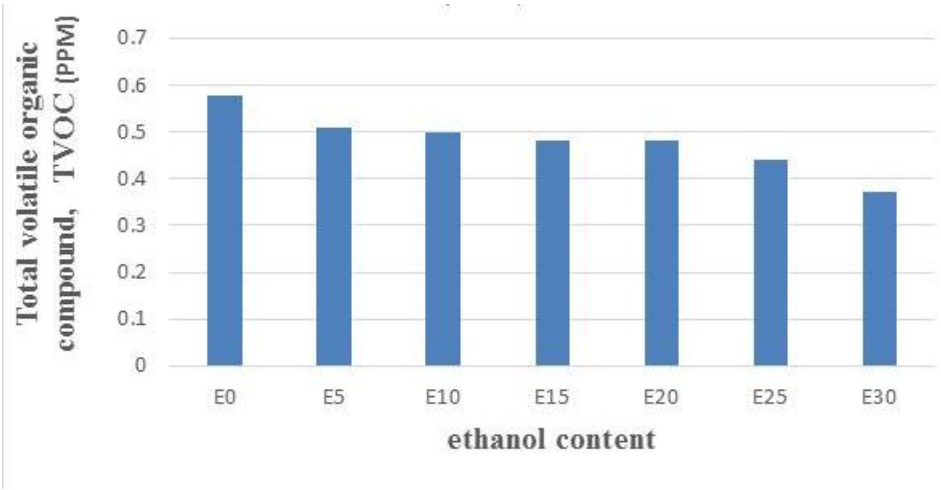


Figure 5: Total volatile organic compounds, TVOC (PPM)

From Figure 5, the TVOC emission results, it is observed that the lowest total volatile organic compound (TVOC) value was 0.441 ppm for the E25 blend, representing a clear reduction compared to the highest value of 0.579 ppm obtained with E0 (pure gasoline). This indicates a progressive decrease in TVOC emissions as the ethanol content in the fuel increases (from E0 to E25), although there appears to be a slight inconsistency or data entry issue at E30 that should be clarified. Overall, the trend suggests that ethanol blending improves combustion quality and reduces unburned hydrocarbon-related emissions. This result is in agreement with several literature findings. For instance, Hamza et al. (2019) reported that ethanol–gasoline blends improve combustion efficiency and engine performance due to the oxygenated nature of ethanol, which enhances fuel oxidation. Similarly, Laminu et al. (2014) and Elfasakhany (2014) observed significant reductions in hydrocarbon (HC) emissions when ethanol is blended with gasoline, attributing this to more complete combustion. Since TVOC is closely related to unburned hydrocarbons, the reduction observed in this study aligns well with their findings. In addition, Olawore et al. (2021) and Suresh and Porpatham (2019) also confirmed that increasing ethanol content reduces HC and CO emissions due to improved air–fuel mixing and the lean-burn characteristics of ethanol. Furthermore, more recent studies such as Maciej et al. (2025) and Yanshuai et al. (2023) support this trend, reporting that higher ethanol blends (especially around E20–E30) significantly reduce total hydrocarbon emissions in spark ignition engines. The reduction in TVOC emissions can be explained by the higher oxygen content of ethanol, which promotes more complete combustion inside the engine cylinder. This enhanced combustion process reduces the formation of partially oxidized compounds and unburned hydrocarbons, thereby lowering TVOC emissions. Additionally, ethanol has a lower carbon-to-hydrogen ratio compared to gasoline, which further contributes to cleaner combustion. However, the anomaly observed at E30 suggests either experimental variation or recording error, and this should be carefully reviewed before drawing a definitive conclusion for that blend. The experimental results generally agree with the literature, showing that increasing ethanol content in gasoline reduces TVOC emissions due to improved combustion efficiency. The E25 blend appears to be the most effective in minimizing TVOC emissions in this study, supporting the widely reported conclusion that moderate ethanol blends (E20–E30) provide optimal emission benefits in spark ignition engines.

4. CONCLUSION

Based on the results obtained from this study, several conclusions can be drawn. The fuel consumption decreased progressively with increasing ethanol content, with the lowest value

of 0.201 cm³/sec recorded at E30, representing a 10.7% reduction compared to the highest value of 0.225 cm³/sec at E0. Carbon monoxide (CO) emissions remained constant at 1.0 ppm across all blends (E0–E30), indicating no significant effect of ethanol addition on CO formation under the test conditions. The lowest carbon dioxide (CO_2) emission was observed at E30 with 5.00 ppm, showing a reduction compared to the highest value of 6.47 ppm recorded at E0, although this trend differs from most literature findings. Total volatile organic compound (TVOC) emissions decreased with increasing ethanol content, with the lowest value of 0.441 ppm recorded at E25, representing a significant reduction compared to 0.579 ppm at E0, though a slight inconsistency was noted at E30. Overall, the results indicate that ethanol produced from sugarcane bagasse improves fuel efficiency and reduces hydrocarbon-related emissions. Blends within the range of E20–E30 are therefore recommended as optimal for achieving better engine performance and cleaner exhaust emissions, although further investigation is needed to validate the observed CO and CO_2 trends.

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