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Research Article

Performance and emissions assessment of a spark-ignition engine fueled with ethanol-, methanol- and acetone-gasoline blends

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ABSTRACT

Alternative fuels have the potential to reduce exhaust emissions in the transportation sector. This research investigates the use of oxygen-enriched fuel mixtures as practical alternatives to pure gasoline in spark-ignition engines. Unlike previous studies that only focused on individual or paired oxygenated fuel comparisons, this study analyzes simultaneously three oxygenated fuels (ethanol, methanol, and acetone) at identical blending ratios. Experiments were performed with an engine testing rig under full load conditions at varying engine speeds. The tested fuel blends included pure gasoline and blends, with 10% ethanol, acetone, and methanol by volume. The results indicated that all the tested fuel blends led to slight improvements in engine performance. The methanol blend provided the highest increases in brake torque, power, and mean effective pressure, with enhancements of up to 19%. Meanwhile, the ethanol blend notably enhanced fuel consumption and thermal efficiency by 25% and 40%, respectively. Regarding the exhaust emissions, it was observed that all the oxygenated fuel blends reduced the carbon monoxide and carbon dioxide emissions. The best achievement was obtained with the ethanol blend, which reduced carbon monoxide and carbon dioxide emissions by 35% and 15%, respectively. However, nitrogen oxide emissions increased with both alcohol blends. On the other hand, it decreases with the acetone blend across all engine speeds. Thus, this work proposes innovative pure gasoline alternatives that can reduce hazardous emissions without requiring technical interventions or loss in engine power.

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INTRODUCTION

Nowadays climate change and global warming are the most common issues that require urgent solutions [1]. It is vital to focus on these problems as they directly impact human health and the continuity of life on Earth [2]. Air pollution is caused primarily by the combustion of fuels to produce energy. Humans exploit oil, gas, and petrol to feed their energy needs, which makes the climate worse [3], [4].

Furthermore, the surge in the global demand for products (GDP) pushes global energy demand to increase and subsequently increases greenhouse gas (GHG) emissions [5]. Burning conventional fuels, like gasoline and diesel, contribute to increased carbon dioxide (CO_2) emissions, causing the earth's atmosphere to warm and leading to changes in the climate as seen today[6]. The transport sector contributes significantly to CO_2 and other GHG emissions [7]. Gasoline and other petrol-based fuels are non-renewable energy sources [8], [9]. Replacing conventional fuels with renewable ones in internal combustion engine applications shows great benefits [10]. Many studies demonstrated the effectiveness of alternatives, like oxygenated ones, as fuels [11].

Oxygenated fuels' rapid growth has occurred over the last decades [12]. The high oxygen content in oxygenated fuels makes them cleaner than conventional ones, which produce less CO_2 and GHG emissions [13]. The combined use of alternatives and fossil-based fuels in the form of blends in spark-ignition (SI) engines showed important benefits as demonstrated in many studies, regarding the reduction of exhaust emissions and the improvement of engine performance [14]. They are gaining attention as a potential replacement for gasoline. These fuels could reduce the dependence on fossil ones and increase energy security. Also, they are cost-effective and easy to produce [12].

Several studies investigated the effects of oxygenated fuel, such as ethanol, methanol, and acetone on SI engines' performance and exhaust emissions.

The present study will focus on ethanol, methanol, and acetone, which are among the best-suited oxygenated fuels for SI engine applications.

Ethanol blends have become a common alternative to gasoline in SI engines. It could be produced in renewable ways or through fermentation. It has a higher octane rating, which could improve combustion efficiency when utilized alone or blended with pure gasoline [15]. Many investigations have evaluated SI engines fueled with ethanol blends. Feng et al. [16] found that alcohol additives improve thermal and exergy efficiencies. These findings peak at a certain point and then decline by increasing the proportion of alcohol in the bend. Qian et al. [17] demonstrated that in a dual-fueled SI engine, 20% ethanol port-injected reduced in-cylinder pressure and temperature. Setyono and Arifin [18] reported optimal engine performance and reduced specific fuel consumption with a 45% ethanol blend. Chen et al. [19] demonstrated that lower ethanol-gasoline blends reduce particulate matter (PM) emissions and enhance combustion.

In addition, methanol has gained considerable attention as a compelling alternative fuel for SI engines [20], [21]. Compared to ethanol, methanol production is less expensive, but it is characterized by its high toxicity and low energy density [22]. Tian et al. [23] reviewed methanol's role in SI engines, highlighting its potential to reduce carbon-based emissions, PM, and nitrogen oxide (NOx) levels. Cesur [24] evaluated a SI engine fueled with M15. Results showed an improvement in fuel consumption and thermal efficiency, with reduced unburned hydrocarbon (HC) emissions. In their experimental study, Zhang et al. [25] observed that higher methanol content in gasoline increased fuel consumption and reduced carbon monoxide (CO), CO_2, HC, NOx, and PM emissions. Nuthan et al. [26] tested a SI engine powered by M50 at dissimilar compression ratios (CR), (8, 9, 10), finding that CR10 improved combustion efficiency, increased brake thermal efficiency (BTE) by 25%, and reduced brake specific fuel consumption (BSFC) by 19%. They also found that M50 reduces CO and HC emissions and raises NOx levels.

Following the interest in alcohol fuels, acetone has also emerged as a promising additive for SI engines due to its high volatility and potential to enhance combustion performance and reduce emissions. Usman et al. [27] analyzed a SI engine powered by gasoline blended with 10% of acetone (A10). Results showed an enhancement in engine power, torque, and BSFC. They also noted a reduction in exhaust emissions. Kantaroğlu et al. [28] tested in a SI engine acetone-gasoline blends (A2, A5, A10, A20), containing 2%, 5%, 10%, and 20% of acetone in gasoline, respectively. Their study showed a reduction in engine torque and volumetric efficiency with higher acetone content. The A10 blend offered the lowest BSFC. For all blends, they noticed a reduction of CO, CO_2, and HC emissions, along with lower NOx levels. Alahmer et al. (2023) conducted a numerical and experimental study on acetone-gasoline blends, showing a significant reduction in CO, HC, and NOx emissions. Roslan et al. [29] demonstrated that increasing the acetone blending ratio enhanced engine performance.

While previous studies have explored the impact of individual oxygenated fuel or paired comparisons, there remains a gap in the literature concerning the simultaneous analysis of such multiple additives at identical blending ratios.

The current work aims to provide an evaluation of three commonly discussed oxygenated fuels (Ethanol, Methanol and Acetone) blended with gasoline at a fixed blend ratio. This approach tries to identify whether one of these blends offers the best benefits, thus providing a clear direction for future fuel development. Through an experimental investigation, this study analyzes and compares the effects on engine performance (power, mean pressure, efficiency, and fuel consumption) and on pollutant gases (CO, CO2 and NOx) of the three oxygenated fuels, at the same time. To observe and assess these effects, an identical percentage (10% by volume) in pure gasoline was fixed for the three fuel blends. The tested blends labeled: pure gasoline (G0), ethanol blend (E10), methanol blend (M10), and acetone blend (A10). Choosing a 10% blending ratio aligns with many existing fuel regulations and standards. Comparing oxygenated fuels at a fixed blending ratio is crucial due to their diverse physicochemical properties. Methanol contains more oxygen and is characterized by higher latent heat of vaporization than ethanol and acetone, which leads to a more complete combustion. On the other hand, acetone has a higher octane rating, which improves the octane rating and fuel efficiency. At the same time, ethanol is characterized by moderate characteristics [30].

MATERIALS AND METHODS

Engine Specifications

A single-cylinder SI engine, fueled by alternative fuel blends was evaluated across different engine speeds and under full load conditions. The engine specifications are detailed in Table 1.

Table 1. Engine specifications

Parameters	Value
Cycle (stokes)	4
Compression factor	8:1
Cylinder diameter (cm)	8.95
Stroke length (cm)	6.985
Engine size (cm^3)	360
Engine power (HP)	5
Cooling	Water

Fuel Blend Preparation

This work examined the impact of incorporating a small amount of oxygenated fuels into gasoline on the characteristics of a SI engine. The investigated fuel blends were G0, E10, M10, and A10 where G0 represents pure gasoline, and E10, A10, and M10, respectively represent the ethanol-gasoline, methanol-gasoline, and acetone-gasoline blends. Table 2 presents the fuel blends' specifications. Each fuel blend was freshly prepared and mixed immediately before each experiment.

Table 3 illustrates the properties of the tested blends. Each fuel blend property such as lower heating value, density, octane number, oxygen content, and latent heat of vaporization are calculated as follows:

$$Pr_b = X_a \frac{\rho_a}{\rho_b} Pr_a + (1 - X_a)\frac{\rho_g}{\rho_b} Pr_g \tag{1}$$

Where: Pr_b is the fuel blend considered property. Pr_a and Pr_g denote the additive property and the pure gasoline property, respectively. X_a is the volume fraction of the fuel additive. ρ_a and ρ_b are the density of gasoline and the fuel blend, respectively, where the fuel blend's density is calculated using the following equation:

$$\rho_b = X_a\rho_a + X_g\rho_g \tag{2}$$

Experimental Set-up

The DIDACTA-T85D test bed consisted of a control unit panel, a dynamometric unit, a cooling circuit, and a fuel supply system. The engine speed was adjusted to 1000, 2000, and 3000 rpm, for each test. Testes were taken under full load conditions. Figure 1 shows the schematic diagram of the experimental setup.

All the measured data was logged after ten minutes of engine operation. An average of three test data was used for this study. Emissions were measured under full load

Table 2. Detailed Characterization of Gasoline Blend Properties [22], [31], [32]

Parameters	Gasoline	Ethanol	Acetone	Methanol
Chemical formula	**CxHy (x = 5-10, y = 12-22)**	**C_2H_5OH**	**C_3H_6O**	**CH_3OH**
Lower heating value (MJ/kg)	41	26.8	29.6	20.09
Density (kg/m^3)	715-765	790	790	792
Energy density (kJ/m^3)	32.20	21.17	23.38	21.17
Octane number	92	100	117	108.7
Oxygen content (wt.%)	0	35	27	49.93
Latent heat of vaporization (25°C) (kJ/kg)	380-500	904	518	920
Stoichiometric air-fuel ratio	14.7	9.0	9.5	6.4
Auto-ignition temperature (°C)	~300	420	465	423
Boiling temperature (°C)	25-215	78	56.2	78
Laminar flame speed (cm/s)	~33	~48	~34	~52

Table 3. Tested fuel blends properties

Blend	G0	E10	A10	M10
Lower heating value (MJ/kg)	41.00	39.57	39.86	38.89
Density (kg/m^3)	774	745	745	745.2
Octane number	92	92.8	94.5	93.77
Oxygen content % v/v	0	3.5	2.7	5.31
Latent heat of vaporization (25°C) (kJ/kg)	440	486.4	447.8	491

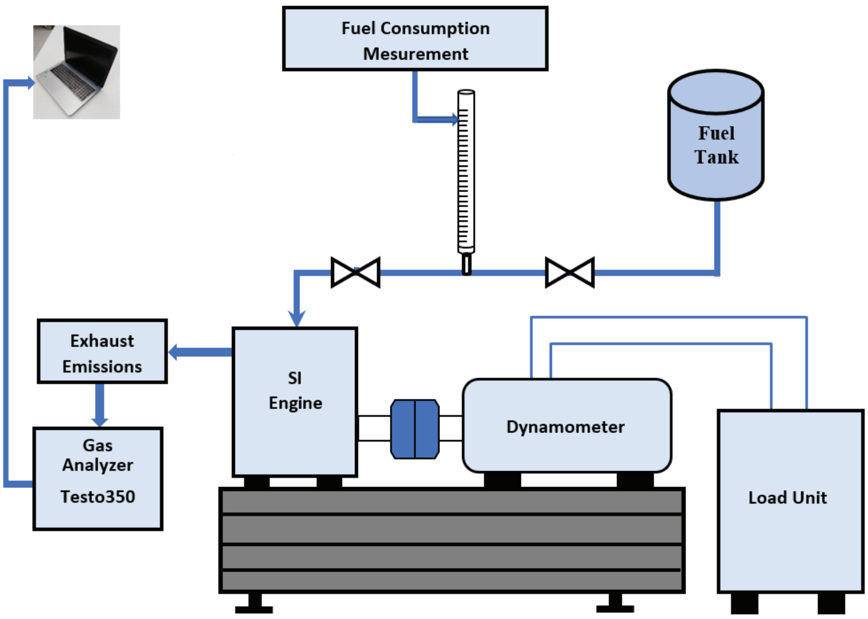

Figure 1. Schematic diagram of the DIDACTA-T85D test bench.

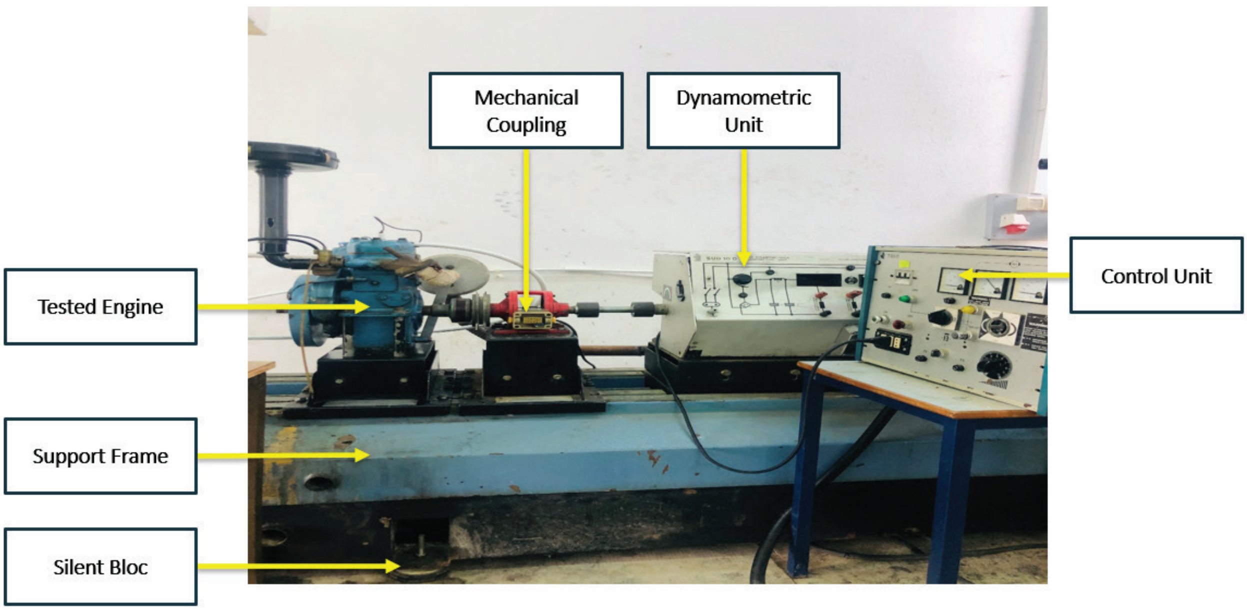

Figure 2. Engine test bench.

Table 4. Measurement Instrument Uncertainties

Device	Tolerance (±)
RPM sensor	0.3
Power dynamometer	1.0
Fuel flow meter	1.0
Carbon monoxide detector	3.7
Carbon dioxide detector	1.3
Nitrogen oxides detector	0.25

conditions at engine speeds ranging from 1000 to 3000 rpm, with intervals of 500 rpm. The gas analyzer TESTO 350 was used for emissions measurements. All measuring types of equipment and sensors were calibrated to the manufacturing standards. The test bench is given in Figure 2.

Uncertainty analysis

An uncertainty analysis was conducted to evaluate the reliability and accuracy of the experimental results. The overall uncertainty was determined through the standard deviation approach, referencing the specifications of the devices.

$$OU(\%)=\sqrt{(0.3)^2+(1.0)^2+(1.0)^2+(3.7)^2+(1.3)^2+(0.25)^2} \quad (3)$$

Where: OU refers to the overall uncertainty.

The uncertainty sum stands at 4.18%, which falls within the acceptable limits for experimental research.

RESULTS AND DISCUSSION

This part discusses the blending effects of ethanol, acetone, and methanol-gasoline blends on the performance and emissions of an SI engine. Pure gasoline was considered the base fuel in this comparative study.

Effects on Engine Performance

The engine performance metrics, including power output, torque, BMEP, and BSFC are crucial to evaluate the engine's overall efficiency. A dynamometer was used to measure engine power, typically at full load. Equation 4 was used to determine the BMEP metric. While, equations 5 and 6 explain how to obtain the BSFC and the BTE metrics, respectively.

$$BMEP = \frac{2\pi \cdot n \cdot BT}{\frac{\pi \cdot D^2}{4} \cdot L \cdot n'} \quad (4)$$

Where: BMEP is the brake mean effective pressure (bar), BT is the brake torque (N.m), n' is the number of cylinders ($n' = 1$), n = 2 for four-stroke engines, D is the piston diameter, and L is the stroke length.

$$SFC = \frac{1000 \cdot 3600 \cdot Cs}{BP} \quad (5)$$

Where: BSFC refers to the brake-specific fuel consumption (g/kWh), BP is the brake power (W), and Cs is the quantity of fuel consumed by the engine (g/s).

$$BTE = \frac{100 \cdot BP}{1000 \cdot Cs \cdot LHV_b} \quad (6)$$

Where: LHVb is the lower heating value of the blend (MJ/kg), and b refers to the fuel blend.

Brake Torque

The results of adding oxygenated fuels to gasoline on brake torque are presented in Figure 3. It was observed that adding oxygenated fuels to gasoline increased brake torque, due to the improvement of combustion quality by enhancing the equivalence λ. Also, a significant improvement was shown in brake torque at the highest applied speed (Figure 3). The graph reveals a synergistic effect of oxidant and speed combination upon brake torque. Among oxidative combinations of gasoline, the M10's performance was superior to others at all tested engine speeds. This superiority was more pronounced at the lowest and highest engine speeds. The enhancement varies from 3.6% to 9.4% in the case of the E10 blend, from 8.7% to 11.9% when the engine was fueled by the A10 blend, and from 12% to 19.6% for the M10 blend. This improvement could be attributed to the enhanced combustion quality by improving the octane rating. Similar results were found by Prashanth et al. [33] and Ijaz Malik et al. [34]. It was explained by the fact that oxygenated fuels, like methanol and ethanol, have higher oxygen content and faster flame speeds, leading to improved combustion efficiency before heat loss occurs through the cylinder walls. Their higher octane ratings enhance combustion stability. Additionally, the higher hydrogen-to-carbon ratio and oxygen content in these fuels

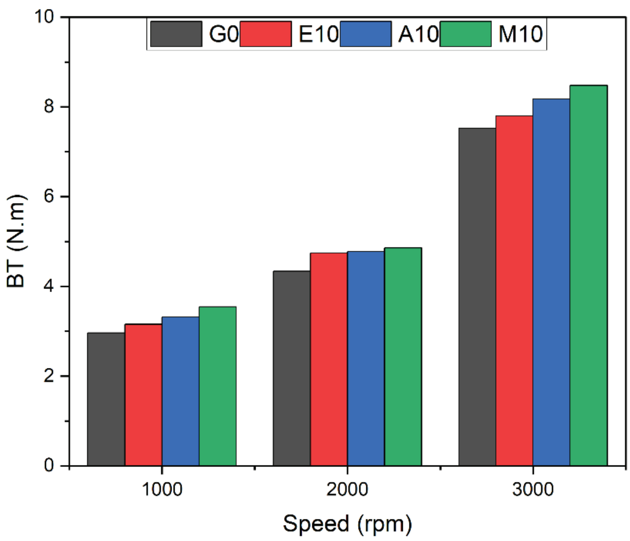

Figure 3. Brake torque vs. engine speed.

increase pressure buildup during combustion, resulting in better performance and higher torque.

Brake Power

Figure 4 presents the values of the brake power of four fuel blends as a function of engine speed. Comparable brake power results were observed across all blends at low engine speed (1000 rpm) and medium (2000 rpm) engine speed. The similar brake power performance among all tested fuel blends at low engine speeds can be attributed to the greater impact of the blend's LHV relative to the octane numbers. On the other hand, oxygenated fuel blends not only produced a higher brake power at high speed (3000 rpm) but also a promising difference within alternative fuel blends was observed. It was also observed that the M10 provided a higher brake power than the A10, and E10, at all engine speeds, particularly at 3000 rpm. This can be explained by the fact that M10 was characterized by the highest value of density, oxygen content, and octane number followed by A10, E10, and G0. These results are consistent with findings from other experimental studies from the literature: Tian et al. [23] studied the impact of ethanol, methanol, and butanol blended with gasoline on the performance and emissions of a SI engine. An increase in both brake power and heat release was observed for all the blends compared to pure gasoline. The highest power was obtained with methanol followed by ethanol blends. They explained these results by the enhanced octane rating of the oxygen-enriched mixtures.

Brake mean effective pressure

The brake mean effective pressure (BMEP) for four fuel blends is shown in Figure 5. It can be observed that oxygenated fuel blends increased the BMEP value of the SI engine. M10 showed the highest BMEP values throughout all engine speed ranges and G0 produced the lowest BMEP values. Acetone was characterized by a higher octane rating than ethanol and pure gasoline, thus A10 produced higher BMEP than E10 and G0 for all engine speeds. G0 provided the lowest BMEP value due to its lower octane rating. BMEP value is directly proportional to brake torque. Hence, the same effects were observed for the different fuel blends. Similar results were obtained by Rosdi et al. [35]. They found that ethanol-gasoline blends enhanced the BMEP. According to these authors, this result is mainly due to the higher value of the latent heat of vaporization of alcohol, which improves charge cooling and lowers the intake manifold temperature, leading to better volumetric efficiency. This allows more air to enter the engine cylinders during the suction stroke, enabling more efficient fuel combustion and higher torque output.

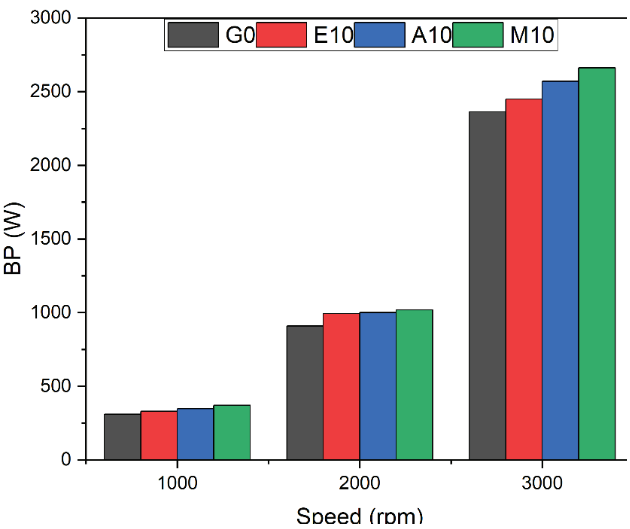

Figure 4. Brake power vs. engine speed.

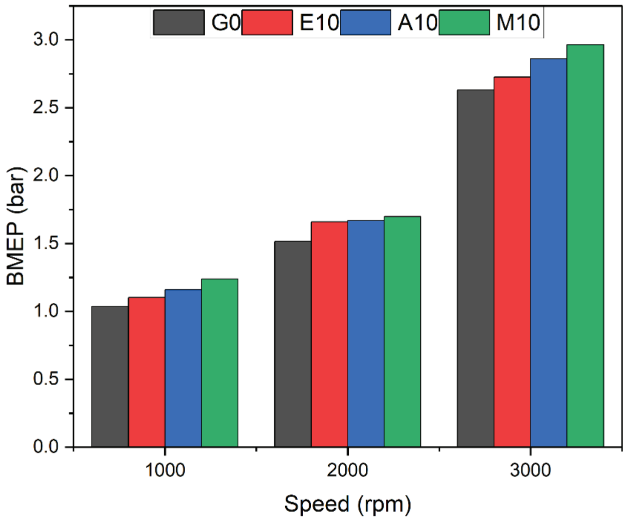

Figure 5. BMEP power vs. engine speed.

Brake-specific fuel consumption

Figure 6 shows the effect of oxygenated fuel blends on BSFC. Adding ethanol, methanol, and acetone in gasoline significantly decreased the engine fuel consumption except for A10 at high engine speed. For all engine speeds, A10 showed the highest value of BSFC among oxygenated fuels. This can be explained by the fact that A10 is characterized by the lowest values in oxygen content and flame speed, and the highest auto-ignition temperature, increasing the engine fuel consumption. However, E10 gave the lowest BSFC values. It is characterized by the lowest heating value, the higher heat of vaporization, and the more oxygen content than G0 and A10. On the other hand, using M10, characterized by the lowest heating and the highest heat of vaporization values, a low value of BSFC was obtained, comparatively to G0 and A10. Considering the relative enhancement, E10 performed the best BSFC values at all engine speed ranges. For example, at 2000 rpm, adding 10% ethanol to gasoline has decreased the BSFC by 25%.

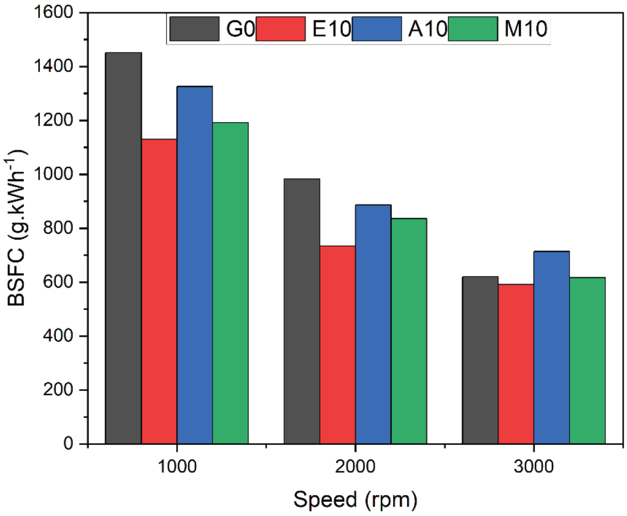

Figure 6. BSFC power vs. engine speed.

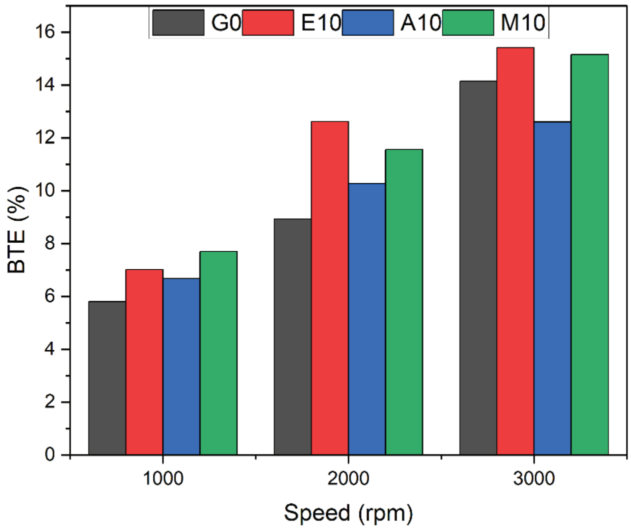

Figure 7. BTE power vs. engine speed.

Various authors have reported similar findings. Nwufo et al. [36] and Dhande et al. [37] observed a decrease in specific fuel consumption when ethanol was added to gasoline, especially at low blending ratios, which is explained by the higher oxygen content in the blends, enhancing the combustion efficiency.

Brake thermal efficiency

Figure 7 shows how using oxygenated fuels in SI engines affects brake thermal efficiency (BTE). E10 produced the highest BTE at all engine speeds, except at 1000 rpm (lower than M10). This was because, at low speeds, the high oxygen content and flame speed of M10 had a preeminent effect on BTE. As a result, an increase in BTE by 33 % compared to G0, was observed. While, at high and medium engine speeds, the combined effects of low heating value, high evaporation, and good oxy-gen content of ethanol were more influencing on BTE by an enhancement ranging from 9 to 42% obtained at 2000 rpm and 3000 rpm, respectively.

The present study demonstrated that, generally, oxygenated fuels offer more developed BTE than gasoline. This effect is due to the excellent fuel characteristics of alcohols, such as higher octane number, latent heat of vaporization, and oxygen content. As explained by Mueller et al. [38], the latent heat of vaporization directly affects the charge cooling in the intake manifold. Hence, higher latent heat of vaporization leads to an enhancement of the intake charge density, which increases the engine's volumetric efficiency. Enhanced volumetric efficiency results in complete combustion and so higher BTE.

Effects on Exhaust Emissions

CO emissions

Pure gasoline is a hydrocarbon that contains only hydrogen and carbon atoms. It has a higher heating value than the other tested blends. On the other hand, the tested fuel blends contained hydrogen, carbon, and oxygen atoms. Oxygenated fuels improve combustion characteristics and reduce CO and UHC emissions since they depend on oxygen content. Figure 8 presents the CO emissions as a function of engine speeds for the four blended fuels. Results showed a reduction in CO emissions for oxygenated fuels, comparatively to neat gasoline due to the oxygen presence in the tested fuel blends. A minor decrease in CO emission was noticed at 1000 and 2000 rpm, while, at 3000 rpm, the decline was more pronounced. This result could be attributed to the more homogeneous mixture, at high engine speed, giving better combustion characteristics.

E10 produced the lowest value in CO emissions. This is attributed to the mutual effects of the LHV and oxygen

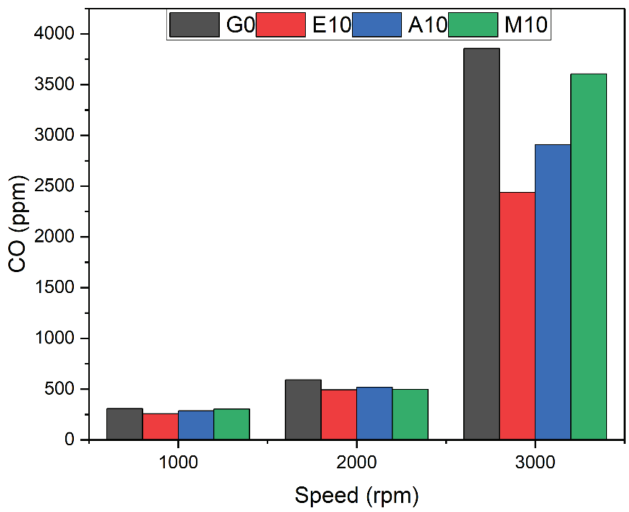

Figure 8. CO emissions vs. engine speed.

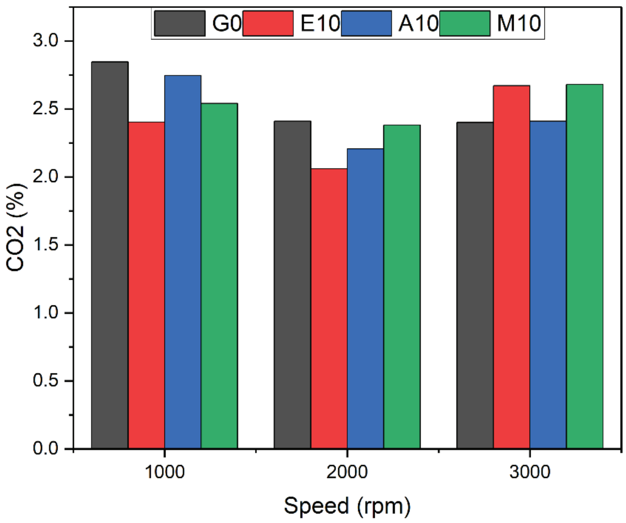

Figure 9. CO_2 emissions vs. engine speed.

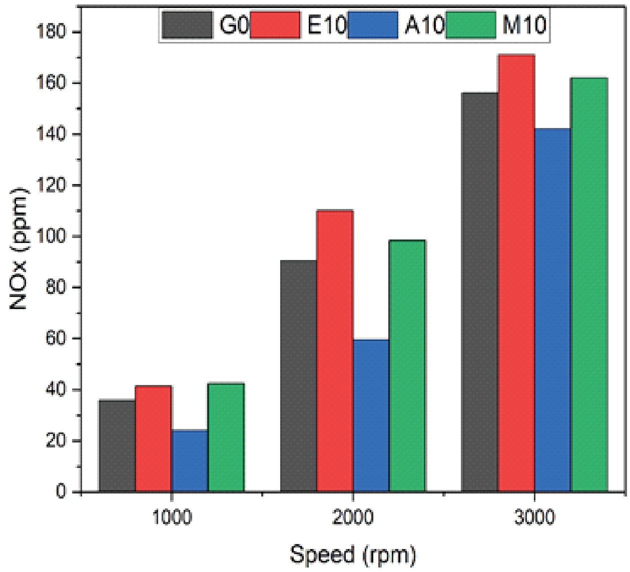

Figure 10. NOx emissions vs. engine speed.

content values of ethanol comparatively to methanol and acetone. Thus, it has better combustion characteristics and subsequently reduced CO emissions. A10 has lower CO emissions than M10, which is important at high speeds. This is due to the higher LHV of acetone compared to methanol. Mohammed et al. [39] fueled a SI engine with mixtures of ethanol and gasoline. The contents of ethanol in gasoline were 10%, 20%, 30%, and 40% by volume. They found a significant reduction in CO emissions by increasing the blending ratio.

CO_2 emissions

Figure 9 shows an opposite trend of CO_2 emissions than CO emissions for all fuel blends, due to the chemical oxidation of CO into CO_2 in the presence of O_2 during the combustion reaction. Results showed a low quantity (10%. vol) of oxygenated fuel in gasoline reduced CO_2 levels at both low and medium engine speeds. However, at 3000 rpm, E10 and M10 increased CO_2 emissions, and A10 produced a similar result to G0. These results were attributed to the beneficial effect of oxygen in the tested fuel blends, which developed better combustion characteristics. At high engine speeds, the effects of the LHV were more evident in improving combustion characteristics as stated by Balki et al. [40]. By investigating the effect of methanol-gasoline blends on SI engine emissions, they obtained a significant reduction in CO_2 emissions with all tested blends. The volume fractions of methanol in gasoline were 5%, 10%, 15%, and 20%.

NOx emissions

Figure 10 shows the obtained NOx emissions from this study. E10 and M10 produce higher NOx emissions than A10 and G0. Across all tested engine speeds, the A10 blend produces the lowest NOx levels. NOx levels reach their maximum values with E10. This result can be explained by the characteristics of these blends, which are distinct as highlighted in Tables 2 and 3. NOx emissions are produced when the temperature reaches high values, where oxygen could increase it, since its crucial role in improving combustion efficiency. Ethanol and methanol contained more oxygen than acetone and gasoline and had higher octane ratings, resulting in a higher combustion temperature. On the other hand, A10 produced the lowest NOx emissions. This could be attributed to the beneficial characteristics of acetone, which features low oxygen content and high LHV, resulting in improved combustion characteristics. Alahmer et al. [31] investigated acetone-gasoline blends in a SI engine. Their results demonstrated a reduction in NOx emissions across all engine speed ranges. Three blends were investigated (A0, A5, and A10). They found that A5 and A10 gave close results in NOx emissions.

CONCLUSION

The originality of this research work lies in the simultaneous assessment of three oxygenated fuels (ethanol, methanol, and acetone), at identical blending ratios (10% by volume), as practical and effective alternatives to pure gasoline in spark-ignition engines without requiring technical modifications.

The effects of these three fuel blends on improving gasoline engine performance have been successfully validated. The study was conducted on a single-cylinder spark-ignition engine. The impact of these mixtures on the engine characteristics such as torque, power, mean effective pressure, specific fuel consumption, and thermal efficiency, and on the exhaust gas emissions such as carbon monoxide, carbon dioxide, and nitrogen oxides were evaluated under full load and various engine speed conditions.

The findings revealed that ethanol, methanol, and acetone could be good additives to gasoline, reducing hazardous emissions while maintaining good engine power. In summary, the main findings of the current study are as follows:

- Adding oxygenated fuels to gasoline in low quantity improved the engine performance;
- Methanol blend provided the best values in the engine torque, power, and mean effective pressure, at all engine speeds. The enhancement can reach up to 20% at low engine speeds;
- Ethanol blend reduced specific fuel consumption by 25% and improved thermal efficiency 41%, both at 2000 rpm. The best specific fuel consumption was recorded, at 1000 rpm, using methanol blend;
- All the oxygenated fuel blends reduced carbon monoxide and carbon dioxide emissions;
- Acetone blend gave the lowest nitrogen oxides emissions. However, Ethanol and Methanol blends increased nitrogen oxides amounts, at all engine speeds.

The current study demonstrated that the considered oxygenated fuels effectively reduced engine emissions due to their chemical and physical properties, enhancing their environmental friendliness and sustainability. The economic benefits include the potential for cost-effective production and compatibility with existing engines without requiring technical modifications. However, challenges such as potential reactions with engine component materials, particularly copper which can easily oxidize with methanol, should be handled. Additionally, the increased amount of nitrogen oxide emissions needs further investigations.

NOMENCLATURE

BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption, *g/kWh*
BTE	Brake Thermal Efficiency, *%*
G0	Pure Gasoline
E10	Ethanol-Gasoline blend
A10	Acetone-Gasoline blend
M10	Methanol-Gasoline blend
CR	Compression Ratio
NOx	Nitrogen Oxides, ppm
GDP	Global Demand Product
GHG	Greenhouse Gaz
CO_2	Carbon dioxide, *%*
LHV	Lower Heating Value, *MJ/kg*
IMEP	Indicated Mean Effective Pressure
COVIMEP	Coefficient of Variation of Indicated Mean Effective Pressure
PM	Particulate Matter
CO	Carbon monoxide, *ppm*
HC	Hydrocarbon
SI	Spark-Ignition
EUDC	Extra Urban Driven Cycle
UDC	Urban Driven Cycle
NEDC	New European Driving Cycle
BP	Brake Power, *W*
BT	Brake Torque, *N.m*
λ	Air-Fuel Ratio Lambda
O_2	Oxygen

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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