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Simulation of the Effect of Using Gasoline and Ethanol Blend on Spark Ignition Engine Emissions and Performance by Using Ricardo wave Software

Muhsen M. Alsilbi*, Murtdha S. Imran, Abdalrazzaq K. Abbas, Hayder Jawad Kadhim, Zainab Kadhim Hasan

Mechanical Engineering Department, College of Engineering, University of Kerbala, Karbala 56001, Iraq

Corresponding Author Email: mohsin.mahdi1980@uokerbala.edu.iq

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ABSTRACT

Internal combustion engines may experience knocking at high operating temperatures due to auto-ignition of the fuel. One of the cheap treatments suggested by internal combustion engine experts to solve this problem is adding alcohols to improve engine performance during operation. These additives aim to reduce engine operating costs when using high-octane gasoline, thereby preventing knocking. In this research, an engine was simulated using Ricardo's simulation software for internal combustion engines with a gasoline-ethanol fuel mixture. The fuel mixture, consisting of gasoline and ethanol, was simulated and tested at ratios ranging from 0% to 30%, with 10% increases in each simulation. The simulation was performed on a single-cylinder, air-cooled engine. The simulation results showed that thermal efficiency, combustion chamber pressure, heat released, and exhaust heat decreased, but the specific fuel consumption and ignition delay increased with increasing alcohol content in the mixture. The emission results showed that carbon monoxide, unburned fuel, nitrogen oxides, and soot emissions decreased with increasing alcohol content in the mixture.

1. INTRODUCTION

Improving spark ignition (SI) engine performance and reducing environmental emissions have recently received strong focus. One of the main strategies to achieve this objective is to blend gasoline with alcohol-based fuels such as methanol or ethanol. Higher octane values than those of traditional gasoline, these renewable, oxygenated alcohols are being added to fuel mixtures to increase combustion efficiency, lower dangerous emissions like carbon monoxide (CO) and unburned hydrocarbons (HC), and enable engines to run at higher compression ratios without knocking.

However, there are also problems associated with alcohol gasoline mixtures, such as cold start and varying energy content, as well as perhaps higher nitrogen oxides (NO_x). Nowadays, scientists progressively use powerful engine simulation programs to study and optimize the results of such combinations. Among the best tools for simulating internal combustion engines across a wide range of fuel types and operating modes, Ricardo wave software has become a key tool for studying combustion processes, performance curves, and emission trends without relying entirely on experimental setups, which can sometimes be costly and time-consuming.

This section provides an overview of previous studies examining the effects of mixing gasoline with alcohol on the performance and emissions of SI engines. These studies included experimental research and simulation tools, such as Ricardo wave and compatible software. Many experimental studies have investigated the effect of ethanol-gasoline blends on SI engine performance and emissions.

Al-Hassan [1] investigated how four-cylinder SI engine performance and emissions were affected by unleaded gasoline–ethanol mixtures. Tests on the Toyota, Tercel-3A engine were conducted at various ethanol ratios and engine speeds (1000–4000 rpm). Ethanol inclusion increased brake power and torque, as well as thermal and volumetric efficiencies, whereas it lowered the air–fuel equivalence ratio and brake-specific fuel consumption. CO and HC emissions fell; CO_2 rose. The best overall performance was achieved with the E20 blend.

Koç et al. [2] experimentally studied how ethanol–gasoline mixes (E50 and E85) affect the performance and emissions of a single-cylinder SI engine at two compression ratios (10:1 and 11:1). The results revealed that ethanol addition increased fuel consumption; decreased CO, NO_x, and HC emissions significantly, improved engine torque and power. Moreover, ethanol-gasoline combinations validated ethanol's suitability as a clean, renewable fuel for SI engines by enabling higher compression ratios without engine knock. Gravalos et al. [3] studied the effect of different blends of gasoline, ethanol, and methanol on a spark-ignition engine (E5–E80, M5–M80). Their results showed that the best gasoline mixture was ethanol, with blends up to [E40], which improved torque and braking performance and decreased brake specific fuel consumption (BSFC), while the methanol mixture led to lower engine performance and higher fuel consumption. Both fuels significantly reduced emissions of CO, HC, NO_x, and CO_2. In this experimental study, Elfasakhany [4] investigated the effects of ethanol-gasoline blends on the performance and emissions of a single-cylinder SI engine, with blend ratios ranging from E0 to E10. The study revealed that improved combustion resulted in reduced CO and HC emissions, a slight increase in CO_2 emissions, and improvements in torque, power, and combustion efficiency.

Compared with previous work (such as Al-Hassan 2003), the study provided a wider range of mixtures and validated ethanol's superior performance and emissions behavior compared with methanol. Low-percentage ethanol-gasoline mixes (5–15%) were used in Pal's [5] study to assess the performance and emission properties of a four-stroke, four-cylinder SI engine. Tests on a Maruti-Suzuki Wagon R-engine evaluated brake power, thermal efficiency, and emissions (CO, HC, NO_x, and CO_2). It is worth noting that their results showed a little improvement in thermal efficiency and braking effectiveness, along with a slight increase in specific fuel consumption. Also, they noticed that ethanol blends decreased CO, HC, and NO_x emissions, which they attributed to the ethanol's oxygen content. They concluded that low-ethanol blends show promising potential as a clean fuel alternative.

Studies on the performance and emissions of internal combustion engines using ethanol-gasoline blends continued, with Liew et al. [6] using a single-cylinder, off-road engine running on an ethanol-gasoline blend (E0-E20). Their study reaffirmed the benefits of reducing emissions (E20) by up to 45.3% in CO and 25.4% in HC compared to previous studies.

In this study, Joshi et al. [7] investigated the performance and emissions of a multi-cylinder 4-stroke SI engine operating at a steady 2000 rpm on ethanol-gasoline mixtures (E10, E20, E30, E40). Without engine modifications, E20 outperformed all other tested mixtures, achieving the highest mechanical efficiency (92.77%) and thermal efficiency (34%) as well as good emission reductions (CO: 4.22%, HC: 78 ppm). The study also highlighted the advantages of ethanol's high latent heat and its oxygen content for improving combustion. They concluded that ethanol blends, especially E20, provided a realistic balance between engine efficiency, emissions, and fuel compatibility.

An experimental study examining the effects of ethanol-gasoline blends on a single-cylinder spark-ignition engine at fixed speed was conducted by Igbokwe et al. [8]. The study focuses solely on real engine testing using ethanol obtained from Nigerian feedstock, and testing a wider variety of blends (E10 to E30) is the innovation. Contrary to earlier efforts, this study shows that E30 achieved the highest thermal efficiency (43.2%) and significantly reduced CO and HC emissions. Nwufo et al. [9] broadened their experimental study to ethanol-petrol blends across a large blending range (from E10 to E60) to assess combustion behavior, emissions, and performance of a single-cylinder SI engine. The study found that E40 and E60 blends using ethanol extracted from raffia trunks achieved a brake thermal efficiency (BTHE) of up to 47.6%. A decrease in CO and HC emissions was also observed compared to previous results, along with an increase in CO_2 concentration and higher peak pressure, indicating more complete combustion. An experimental investigation by Sasongko and Wijayanti [10] assessed the impact of ethanol–gasoline mixtures (E10–E100) on a small single-cylinder spark-ignition engine. The research confirmed that while increasing ethanol content reduced CO and HC emissions, it also decreased effective power and increased BSFC because ethanol has a lower heating value. Notably, this study tested up to pure ethanol (E100), unlike most prior research, which ended at E20–E30, and found the engine's optimum operating speed shifted toward lower RPMs with higher ethanol concentrations.

In 2017, Doğan et al. [11] experimented on the efficiency of the emission characteristic of a 4-cylinder SI engine with a full load using ethanol-gasoline blends (E0, E10, E20, and E30). The study utilized exergy analysis to examine the energy distribution on thermodynamic losses of the engine. Results showed that ethanol blends reduce CO_2, CO, and NO_x emissions without a notable power loss compared to gasoline. Ethanol, however, raised HC emissions by reducing cylinder temperature.

For higher ethanol ratio studies, Delvi et al. [12] conducted an experimental study on the effects of E25–E35 ethanol gasoline blends in a single-cylinder SI engine. The results demonstrated that the E35 blend increased BTHE by 19.92%, while E25 yielded the highest net heat release of 42.47 J/deg. Both CO and HC emissions were significantly reduced with ethanol addition. Utilizing gasoline (G100), ethanol–gasoline (E10), and methanol–gasoline (M10) blends, Doğan et al. [13] carried out experimental and thermodynamic analysis on a single-cylinder SI engine. Although E10 and M10 decreased CO and HC emissions by up to 39% and 35%, respectively, they also boosted BSFC by almost 8.8–9.1% and approximately 2.4–3.6% vis-à-vis G100. Unlike prior studies, this one presented energy, exergy, and sustainability indicators to demonstrate that G100 had the greatest exergy efficiency (21%) and E10 showed better emission behavior. Mohammed et al. [14] experimentally investigated ethanol–gasoline mixtures (E10–E40) on a single-cylinder SI engine at 1500–2500 rpm. With a 25.8% increase, E40 blends exhibited the highest BTHE; BSFC decreased by 17.21%. Outstanding emission drops were observed in CO, CO_2, HC, and NO_x reduced by up to 31.05%. Unlike previous studies, this one used ultrasonic mixing to enhance fuel uniformity.

Nimbalkar et al. [15] reviewed the performance and emissions of SI engines using different ethanol-gasoline blends. Blends ranging from E10 to E35 improved BTE and decreased CO and HC emissions, according to the analysis, with E35 having the highest BTHE at 1800 rpm. Given the overall emissions balance, the study recommended using E10, despite the higher CO_2 emissions from improved combustion.

In addition to experimental work, several studies have used simulation programs such as Ricardo wave to analyze the performance and emissions of SI engines under ethanol or methanol gasoline blends. Al-Baghdadi [16] prepared a combined theoretical and experimental study on the Ricardo E6/US engine to evaluate ethanol–gasoline mixtures. The research reveals that combining up to 30% ethanol boosts engine power, thermal efficiency, and octane number while reducing emissions and combustion length. ASTM standards were applied, and a quasi-dimensional approach was used. By comparing the performance of Ricardo wave and AVL-boosts and modelling SI and homogeneous charge compression ignition type (HCCI) engines, Alqahtani et al. [17] demonstrated the benefits of using Ricardo wave in terms of faster modelling, easier calibration, and support. When variation and IMEP are within ±10%, Ricardo wave correlates with experimental results. Using ethanol-gasoline mixtures, the program accurately anticipated emission decreases, showing up to 96% NO_x and 100% CO reduction. These findings point out how well Ricardo wave is able to maximize engine settings and fuel policies. Its effectiveness makes it a perfect way to assess alternative fuels without the expense of prototyping. Serrano and Chalaça [18] presented an experimental and simulation-based study aimed at the optimization of an E85-fueled competition-grade engine through Ricardo wave modelling. In contrast to previous studies, they reported quantified optimization through achieving a 3% increase in torque via compression ratio adjustment (12.5 → 15.5), and 4% improvement by retarding the ignition timing (40 ℃ → 24 ℃) in the 6000–8000 rpm range. The study's merit is in the calibrated software validation with an error of <10% and its specific application to motorsport engine development.

Iliev [19] evaluated ethanol, methanol, and butanol blends with gasoline (up to 50%) in a simulation study using AVL Boost. Higher alcohol content decreased performance and raised BSFC, but methanol blends (M5–M10) slightly increased brake power. All blends presented a decrease in CO and HC emissions, with M50 exhibiting the lowest levels of NO$_x$ behavior.

Using Ricardo wave and real-engine testing, James and Ojapah [20] conducted a combined experimental and simulation study to assess the effects of E15 ethanol-gasoline blends on emissions in a typical Nigerian production engine. In contrast to previous research, this study evaluated emission behavior at different engine speeds and verified that E15 increased NO$_x$ and CO$_2$ emissions while only slightly reducing CO and UHC emissions (< 5%). In the previous study, the author used engine dynamometer tests and Ricardo wave simulations to investigate how E85 and E10 affected SI engine performance. Real-world testing favored E10, even though WAVE results indicated slight torque improvements and earlier delivery with E85.

This study has some important differences. Compared to steady-state studies of common ethanol blending ratios, real engine loads investigate more application-relevant blending alternatives. The results apply to engines more than ideal test benches due to operational unpredictability. Although most studies quantify efficacy by measuring emissions reductions, this one also considered other considerations. A thorough performance–environmental trade-off study includes BTHE, combustion characteristics, fuel consumption, and emissions. The strategy combines the gasoline-alcohol blending with appropriate application processes, making the gasoline-alcohol blends more visible. In a third segment, an oxygenator is used to promote the combustion of the alcohol. This study, however, looks deeply into the influences of gasoline and alcohol physicochemical interactions on flame speed, vaporization, and energy release. The mechanism analysis explains some performance differences and provides more details than size. Many studies are carried out using simulation or theoretical thermodynamic analysis. Confirming them under controlled but realistic circumstances increases empirical support. By means of experiment correlation, the repeatability and dependability of the model. Evaluation methods differ; the comparative normalization and statistical verification demonstrate that the patterns observed in this study are statistically significant and not measurement errors. Rigorous methods improve the credibility of outcomes and science. Other studies focus on short-term engine performance, but this study also examines operational stability and practical implementation challenges, including combustion consistency and system flexibility. For this engineering method, training is necessary in both academic and practical aspects.

2. ENGINE MODELING

The simulation was conducted on a single-cylinder, four-stroke, spark-ignition, and naturally aspirated engine. This engine is mounted on a test platform containing a dynamometer for engine load measurement, and pollutants are also measured by an exhaust gas analyzer, as shown in Figure 1 (it should be noted that the experimental setup was employed solely for collecting the engine geometrical parameters and boundary condition data required for the simulation model rather than for conducting an experimental performance comparison). The details of engine specifications are provided in the corresponding Table 1. In parallel, a single-cylinder engine model was developed using Ricardo wave software to support the theoretical analysis, as shown in Figure 2. The performance and emission tests were carried out with pure gasoline (B0) and an ethanol–gasoline blend. The ethanol was mixed with gasoline at volumetric percentages of 10%, 20%, and 30%. All simulations were performed at different throttle openings to obtain corresponding variations in engine speed, as direct load measurement was not feasible. Tests were conducted over a speed range of 1000 to 4000 rpm, in increments of 500 rpm. The performance of the engine (BSFC, BTHE, heat release rate (HRR), exhaust gas temperature (EGT), and in cylinder pressure (ICP)) as well as the emissions of CO, unburned hydrocarbons (UHC), smoke, and NO$_x$ were analyzed and compared between the fuel blends. The fuel properties were tested practically as listed in Table 2 to prepare the fuel file.

Table 1. Characteristics of the spark ignition (SI) engine

Description	Data	Description	Data
Bore (mm)	70	Piston cup diameter (mm)	51.31
Con rod length (mm)	103.4	Piston bowl depth (mm)	10
Stroke (mm)	55	Piston cup rim diameter (mm)	39.43
Piston pin offset (mm)	2	Inlet valve diameter (mm)	25.05
Clearance height (mm)	1	Exhaust valve diameter (mm)	25
Number of cylinders	1	Intake valve lash (mm)	1
Compression ratio (CR)	19.9	Exhaust valve lash (mm)	1
EVO (CAD)	45° bBDC	Rocker ratio	1
IVO (CAD)	4.5° bTDC	Injection pressure (bar)	200

Table 2. Fuel blend properties

Properties	B0	B10	B20	B30	Method
Density (kg/m³)	747	754	761	765	ASTM D4052
Viscosity (mm²/s)	0.54	0.56	0.6	0.62	ASTM D445
Calorific Value (MJ/kg)	44	42.2	40.6	39	ASTM D240
Octane Number	80	83	86	90	ASTM D2699
Boiling point (°C)	95	92	88	85	ASTM D86

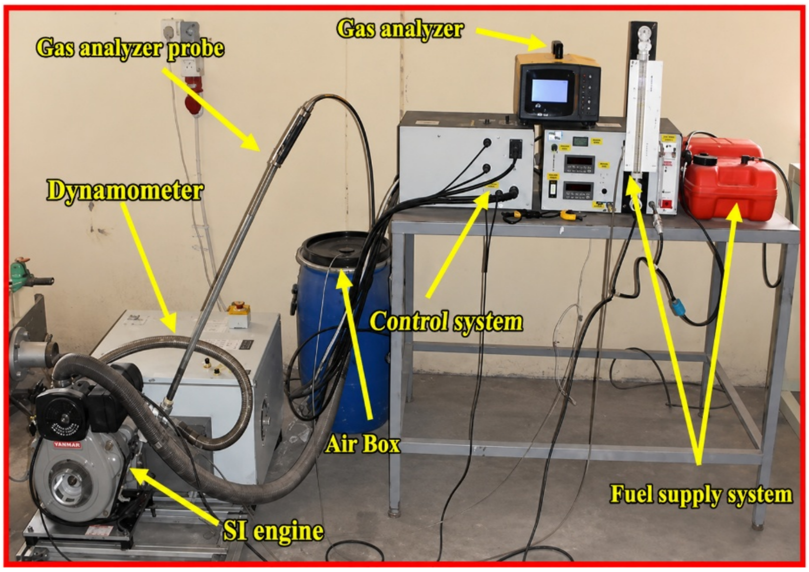

Figure 1. Combustion system test rig

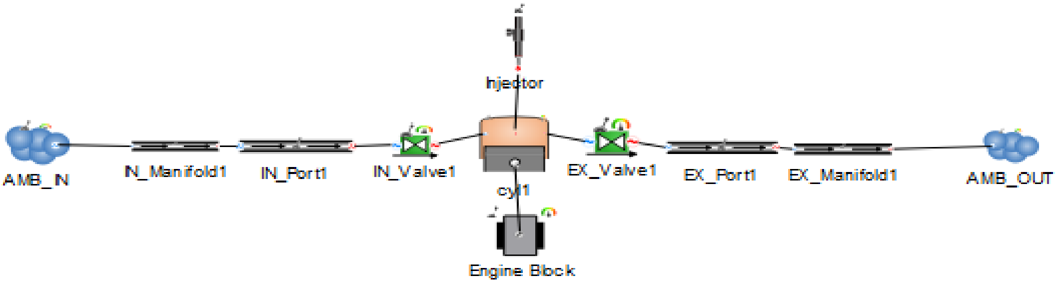

Figure 2. Screen of engine simulation model in RW 19.1

3. SIMULATION RESULTS AND DISCUSSIONS

Ricardo wave was used to generate simulation results through its post-processing interface for a single-cylinder, four-stroke, port fuel injection (PFI), SI engine operating on pure gasoline (B0) and different types of gasoline and ethanol blends. The purpose of the simulation was to evaluate the engine's performance and emission characteristics and to examine their relationship with engine speed when fueling with blends of ethanol and gasoline at B10, B20, and B30 blend ratios. The engine model was developed within the Ricardo wave environment based on a state-of-the-art Ricardo single-cylinder [3]. Following model development, preliminary test runs were conducted to ensure accuracy and stability before performing the final simulation runs. The results of engine performance and emissions are as follows.

3.1 Effect of fuel blend on brake specific fuel consumption

Figure 3 shows the variation in BSFC with engine speed for gasoline and its ethanol blends (B10, B20, and B30). In general, BSFC decreases as engine speed increases from 1000 rpm to around 4000 rpm, reaching its minimum value due to improved combustion efficiency and reduced relative losses. Beyond this speed, a slight increase in BSFC is observed at 4000 rpm, mainly because of higher mechanical losses and a shorter combustion duration. At all speeds, neat gasoline constantly has the lowest BSFC, but BSFC progressively increases as the ethanol percentage escalates, with B30 displaying the peak values. It occurs due to the lower heating value of the fuel blend compared to gasoline.

3.2 Effect of fuel blend on brake thermal efficiency

The interaction between engine speed and BTHE for gasoline fuel and its ethanol blends (B10, B20, and B30) is presented in Figure 4. For all fuels, the BTHE rates are comparatively low at low engine speeds, often ranging from 9% to 10%. The reason is due to incomplete combustion and relatively high heat loss at low rotation speeds. A noticeable enhancement in BTHE is demonstrated as engine speed increases, indicating improved combustion conditions and greater energy conversion efficiency. This enhancement reveals higher in-cylinder temperatures and more effective fuel–air mixing, leading to more complete combustion. The engine BTHE decreased with increasing the volumetric ethanol percentage in the fuel mixture. The main reason for this decrease is that ethanol has lower thermal conductivity.

3.3 The effect of gasoline and ethanol blend on in cylinder pressure

Figure 5 demonstrates the variants of ICP relative to crank angle with higher engine speed based on the ethanol and gasoline combination. The influence on ICP is mainly evident at high loads, when the fuel mixture may significantly affect the combustion rate. The ignition delay may cause it to rise when gasoline is blended with ethanol, because ethanol regularly has a higher octane number compared with gasoline. Cylinder pressure could be affected by a delayed combustion start due to a longer ignition delay. The pressure inside the cylinder may decrease progressively or later in the combustion cycle, and the volumetric percentage of ethanol in the blend increases. The decrease in ICP is attributed to the fact that ethanol has a low calorific value.

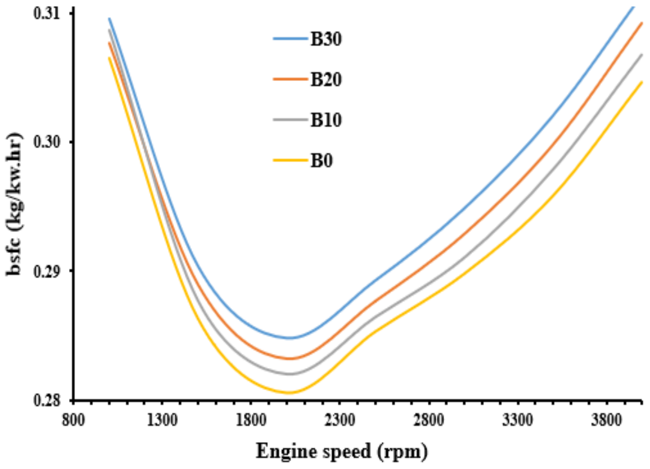

Figure 3. The relation between engine speed and brake specific fuel consumption (BSFC) for a different fuel blend type

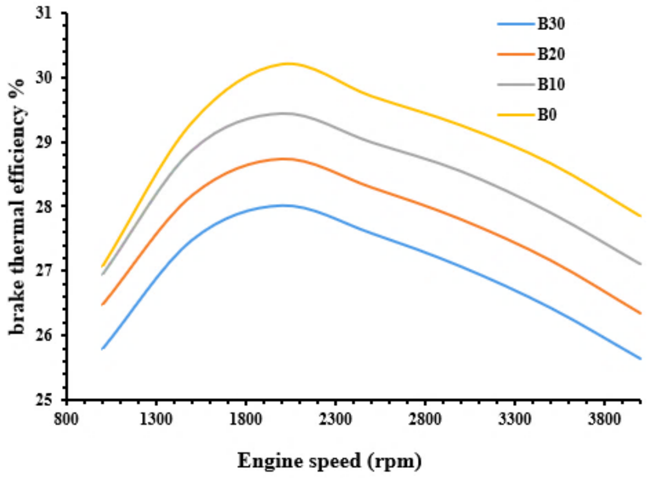

Figure 4. The relation between brake thermal efficiency (BTHE) and engine speed for a different fuel blend type

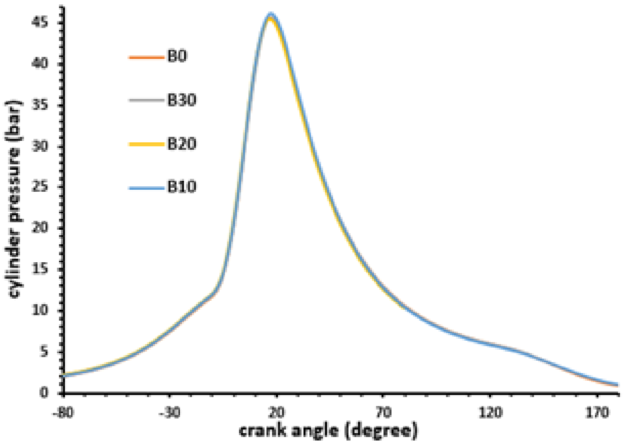

Figure 5. The relation between in cylinder pressure (ICP) and engine crank angle for a different fuel blend type

3.4 The effect of gasoline and ethanol blend on heat release

Figure 6 was analyzed to ascertain the amount of heat required for combustion. The HHR decreased with increasing ethanol concentration in the blend. This is decreasing because the ethanol has a greater oxygen concentration and octane number than gasoline and a low calorific value, facilitating complete combustion. This results in a delayed ignition as it permits a greater fuel-air mixture prior to ignition. This leads to decreased heat release and reduced in cylinder pressure and temperature during the second phase of combustion.

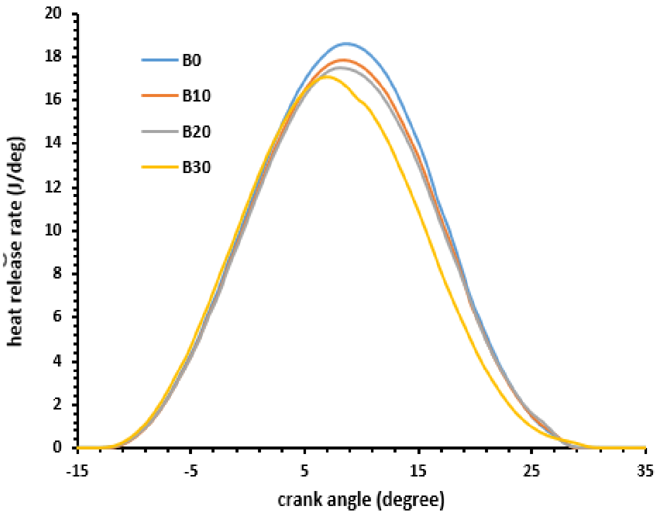

Figure 6. The relation between heat release rate (HHR) and engine crank angle for a different fuel blend type

3.5 The effect of gasoline and ethanol blend ratio on brake mean effective pressure

Figure 7 illustrates that the brake mean effective pressure (BMEP) of a gasoline and ethanol mixture diminishes as the volumetric percentage of ethanol increases. Consequently, the combustion temperature decreases, leading to a reduction in BMEP. Upon blending gasoline with ethanol at B10, B20, and B30 ratios, the reductions in BMEP were 0.027%, 1.19%, and 1.91%, respectively, at maximum engine speed. The reduction in the values of BMEP is attributed to the fact that ethanol has a lower heating value than gasoline fuel.

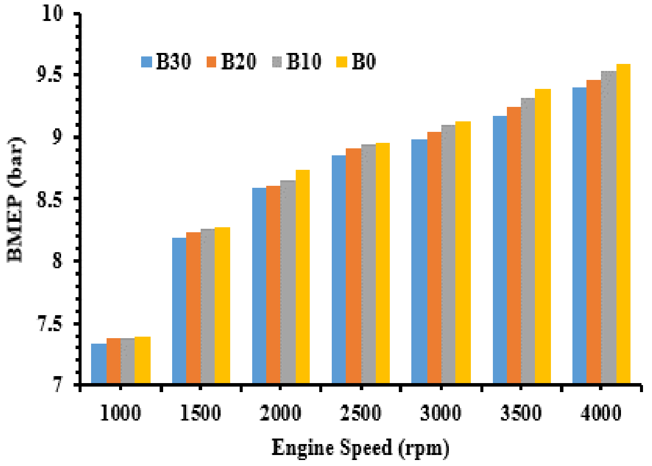

Figure 7. The relation between brake mean effective pressure (BMEP) and engine speed for a different fuel blend type

3.6 Effect of gasoline and ethanol blend ratio on ignition delay

Figure 8 shows that incorporating ethanol into gasoline increased ignition delay, with the increased volumetric percentage of ethanol in the blend at maximum engine speed. An increase in ignition delay time results in a reduction in knock level. This increase in ignition delay time is attributable to ethanol's superior octane number and increased ignition temperature relative to gasoline. Nonetheless, enhancing blending qualities may mitigate this impact. Ethanol has a higher auto-ignition temperature than gasoline, which may lead to a longer ignition delay. Upon blending gasoline with ethanol at B10, B20, and B30 blend ratios, the percentage increase in ignition delay was 0.98%, 0.17%, 1.20%, and 0.41%, respectively, at maximum engine speed.

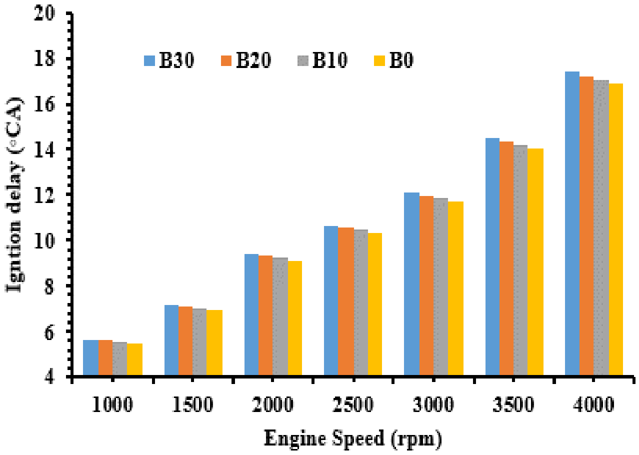

Figure 8. The relation between engine speed and ignition delay for a different fuel blend type

3.7 Effect of gasoline and ethanol blend on engine exhaust gas temperature

Figure 9 illustrates the variation in EGT in relation to changes in engine speed and the volumetric percentage of ethanol in the fuel blend. The EGT rises with engine speed as the air-to-fuel ratio decreases. The increased ratio of ethanol has reduced EGT in comparison to gasoline fuel across all engine speeds. The oxygen content in the gasoline-ethanol blend enhances combustion, leading to a lower EGT and a higher high-octane number. This reduces the time required for premixing and improves the efficiency of combustion in the combustion chamber, allowing a larger amount of fuel to combust entirely before departure through the exhaust port.

3.8 Effect of gasoline and ethanol blend on engine HC emissions

The impact of a gasoline and ethanol mix on the emissions from hydrocarbons can be influenced by both engine speed and blend ratio, as displayed in Figure 10. Generally, adding ethanol to gasoline fuel can decrease hydrocarbon emissions by improving combustion efficiency, especially when gasoline combustion is incomplete. Since ethanol is an alcohol that has undergone oxidation, incorporating it into the mixture can promote more complete combustion. Hydrocarbon emissions may possibly drop as a result, especially at higher concentrations of ethanol. The increased oxygen levels facilitate more thorough fuel decomposition during combustion, hence reducing the production of unburned HCs. The reduction in HC emissions for the combustion of B10, B20, and B30 gasoline and ethanol was 1.23%, 1.88%, 0.56%, and 5.15%, respectively, at maximum engine speed. The exact effect depends upon varying factors such as engine load, velocity, and combustion temperature.

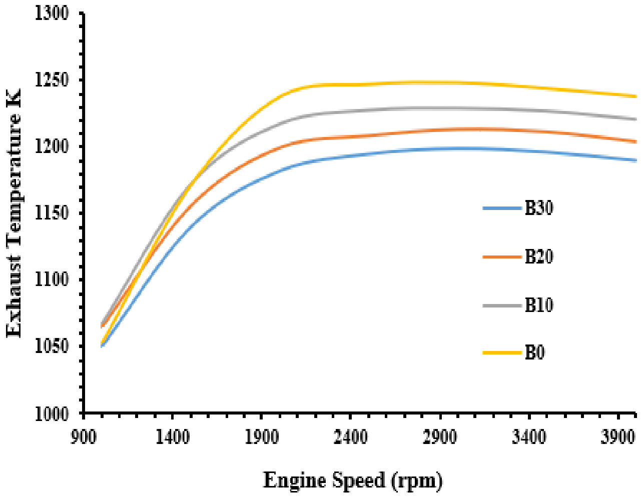

Figure 9. The relation between engine speed and exhaust gas temperature (EGT) for a different fuel blend type

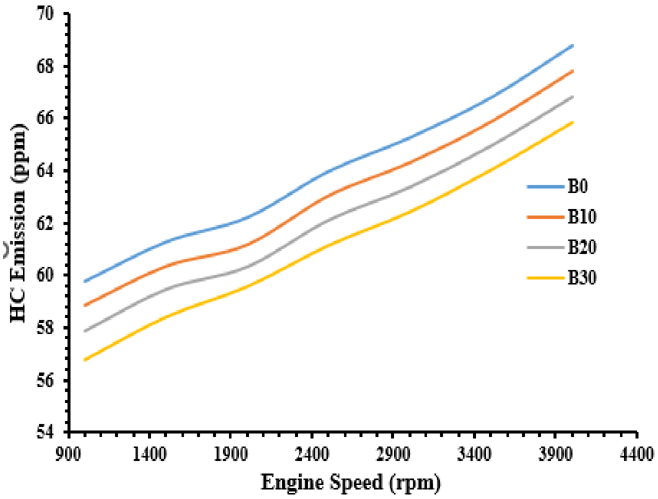

Figure 10. The relation between HC emissions and engine speed for a different fuel blend type

3.9 Effect of gasoline and ethanol blend on engine CO emissions

The deficiency of oxygen in the combustion chamber during the combustion process leads to incomplete combustion. Incremental and varied additions of ethanol result in a reduction in CO emissions and increased CO_2 emissions from the exhaust system. The CO emissions increase with engine load, attributed to the elevated fuel-to-air ratio due to higher engine operating conditions. The carbon monoxide emissions decrease with the increasing volumetric percentage of ethanol in the fuel blend, with the most significant reductions under full load conditions for B0, B10, B20, and B30 being 0.47%, 10.27%, 20.34%, and 29.30%, respectively, at maximum engine speed, as shown in Figure 11. The decrease in CO emissions is attributable to the presence of oxygen atoms in the chemical structures of gasoline and ethanol fuel, which oxidize CO to CO_2, thereby generating more heat during this oxidation process.

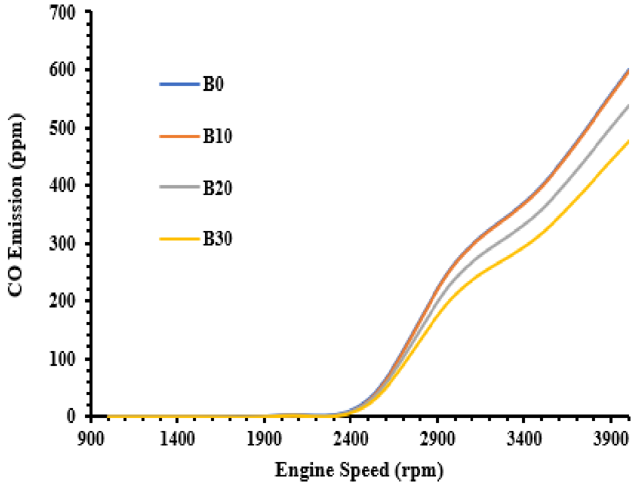

Figure 11. The relation between CO emissions and engine speed for a different fuel blend type

3.10 Effect of gasoline and ethanol blend ratio on NO_x emissions

Figure 12 illustrates the correlation between engine speed and NO_x emissions. The incorporation of ethanol into gasoline lowers NO_x emissions by enhancing combustion, facilitated by ethanol's oxygen content; however, there is a modest increase in NO_x emissions at higher engine speeds due to elevated combustion temperatures. NO_x emissions decreased as the ethanol volume fraction increased. The reductions in NO_X emissions with a mix of gasoline and ethanol at B10, B20, and B30 ratios were 4.46%, 8.67%, 12.37%, and 16.04%, respectively, at maximum speed, when a balance between enhanced combustion and decreased emissions is achieved. The reduction in the NO_x emission with increasing ethanol concentration is attributed to the fact that the ethanol has a low calorific value, which plays an essential role in combustion temperature reduction.

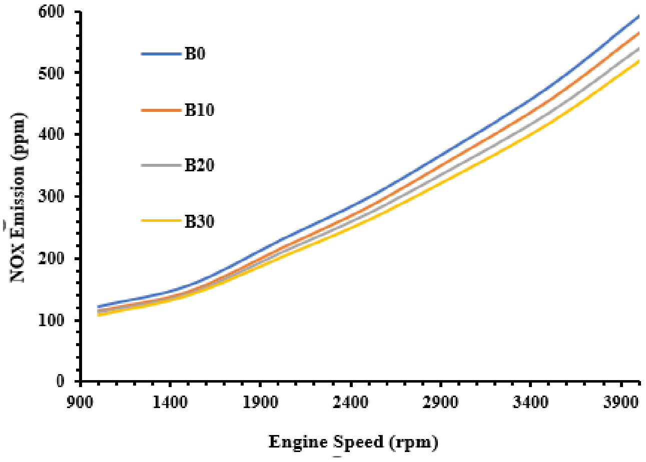

Figure 12. The relation between NO_x emissions and engine speed for a different fuel blend type

3.11 Effect of gasoline and ethanol blend ratio on smoke emissions

Figure 13 illustrates that the impact of combining gasoline with ethanol on smoke emissions is mostly influenced by the mixture ratio. Low to moderate ethanol concentrations (20-30%) often result in reduced smoke emissions owing to enhanced combustion efficiency and ethanol's oxygen content. The blending ratios of B10, B20, and B30 result in reductions in smoke emissions by 2.97%, 6.22%, 9.45%, and 12.70%, respectively, at maximum speed. An increased ethanol concentration in gasoline reduces smoke emissions. Gasoline fuel is an intricate mixture of hydrocarbons characterized by a high carbon content, which can lead to incomplete combustion and soot formation. Hydrocarbons have a lower oxygen concentration than Ethanol, facilitating more complete combustion by aiding the oxidation of carbon molecules, hence reducing soot production and smoke emissions. The impact of the gasoline and ethanol mixture ratio on smoke emissions depends on the concentration of ethanol in the mixture.

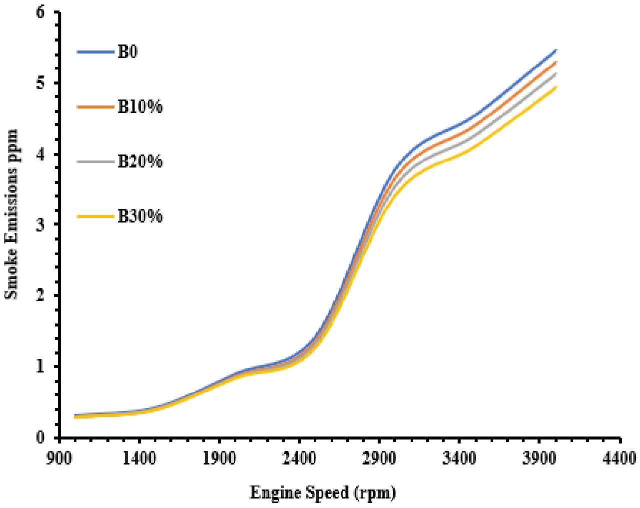

Figure 13. The relation between smoke emissions and engine speed for a different fuel blend type

4. CONCLUSIONS

This study included a simulation of a naturally aspirated, single-cylinder, four-stroke internal combustion engine (DCE) using the Ricardo wave (WAVE Build 19.1) software. The simulation was conducted at speeds between 1000 and 4000 rpm, using blends of gasoline and ethanol at different ratios to evaluate engine performance and emissions associated with these fuel types.

From the data obtained from the simulation performance and emissions, we may infer the following findings from this study:

1. The incorporation of ethanol in specific proportions of 10%, 20%, and 30% leads to an escalation in BSFC as the ethanol concentration in the mixture increases.
2. The BTHE, INCP, HRR, EGT, and BMEP decreased with the rising percentage of ethanol in the gasoline-ethanol blend.
3. The ignition delay was increased with the increase in the volumetric percentage of ethanol in the fuel blend.
4. The emissions of NO_x, HC, CO, and smoke were reduced by increasing the concentration of ethanol in the blend.

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NOMENCLATURE

B10	Blend of gasoline-ethanol (10% ethanol and 90% gasoline)
B20	Blend of gasoline-ethanol (20% ethanol and 90% gasoline)

B30	Blend of gasoline-ethanol (30% ethanol and 90% gasoline)
BTHE	brake thermal efficiency, %
SI	spark ignition
HC	unburned hydrocarbon, ppm
NO_x	nitrogen oxides, ppm
CO	carbon monoxides, ppm
CO_2	carbon dioxide, ppm
BSFC	brake specific fuel consumption, $kg.kw^{-1}\cdot hr^{-1}$
HRR	heat release rate, J
ICP	in cylinder pressure, bar
M	methanol, %
VCR	variable compression ratio
Em	ethanol methanol blend, %