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Experimental Study into Combustion Characteristics of IC Engines Operated with Blended Fuels

Mrs. Rana Ali Hussein[1], Mr. Atheer Saleh Hassoon[2], Dr. Audai Hussein Al-Abbas[1,*]

[1] Pumps Engineering Department, Al-Musaib Technical College, Al-Furat Al-Awsat Technical University, Babylon, Iraq

[2]Air Conditioning and Refrigeration Department, AL-Mustaqbal University College, Babylon, Iraq

[*]E-mail: audai.alabbas@gmail.com

Abstract. The sources of fossil fuels in the world are limited, driving many researchers to seek alternative solutions for fuel. In particular, there is great interest in using unconventional fuel sources for vehicles. One of the main important sources of renewable fuel is bio-fuel, and alcohol is the most appropriate type of this resource. Both ethanol and methanol are good additives to gasoline in vehicles because of the improvements they offer to combustion characteristics and engine performance. In this paper, the influence of Ethanol (ranging from E10 to E30) and Methanol (ranging from M10 to M30) as additives to gasoline are investigated in terms of improvements to the combustion characteristics and performance of the engine, in this instance, a one-cylinder, four stroke, 11kW output power IC engine. In this experiment, performance tests were carried out for brake torque, power, thermal efficiency, and consumption of specific fuels. The flue gases, including CO, HC, and CO_2 were measured and analysed under different operating conditions with various engine speeds, ranging from 1,500 to 3,000 RPM. The results demonstrated that the thermal performance of the IC engine was improved in the E10 combustion case (10% ethanol and 90% gasoline). It was also revealed that HC and CO concentrations were significantly reduced with increases in the concentration of ethanol in the fuel mixture. The combustion characteristics of methanol-gasoline fuels were not as good as those for ethanol-gasoline fuels.

Keywords: Engine performance, Blended fuels, Gasoline, Flue gas emissions

1. Introduction

Over the last decade, concern about the impact of pollutants has increased significantly around the world. The enormous use of gasoline in internal combustion engines (ICE) has made it clear that these behaviours are not environmentally friendly. Burning fuel in internal combustion engines results in climate change, mainly due to the production of carbon dioxide (CO_2) [1]. One of the main reasons for other pollution produced by gasoline is that it contains octane compounds, and the ongoing presence of these compounds is important for the fuel to achieve smooth speeds and resistance to knocking in the engine [2].

In order to test these octane compounds, tetraethyl lead (TEL), aromatics, and other chemical substances were added separately as additives to gasoline. However, these chemicals are toxic and polluting, and increase the level of exhaust gases. Of the three main additives, the latter was best because it did not increase the volatility of the fuel [3-7]. Adding alcohol especially ethanol and methanol, to gasoline has recently been seen to give good results in terms of improved combustion properties, increased combustion efficiency, and reduced concentrations of exhaust gases. The reason

for this is its increased oxygen content; alcohol also does not contain complex organic compounds or sulphur [8-13].
Adding methanol and ethanol to conventional fuel (gasoline) has been studied by several researchers in terms of the performance of internal combustion engines. The practical results in [14] were an increase in the thermal efficiency of the engine, with a clear decrease in concentrations of NO_x and CO. In similar investigations, Alvydas Pikunas et al. [15] also studied the influence of ethanol-gasoline mixtures on the combustion characteristics of IC engines, noting that adding ethanol increased the octane number of the fuel mixture and led to a decrease in the heating value of the mixture. Specific fuel consumption and engine power also increased slightly. The authors in [16] investigated the effects of using an ethanol-gasoline blend on a spark ignition engine. The experimental results were approximately similar to those of other researchers in terms of a decrease in concentrations of CO and HC at rates of 80% and 50%, respectively. They also did not notice any decrease in engine power.

Topgu et al. [17] conducted an experimental investigation to uncover the effects of adding ethanol to gasoline at different rates of addition ranging from E10 to E60 on the performance of IC engines and the concentration of flue gases. Their results showed that the concentrations of both of CO and HC decreased with ethanol-gasoline blends. They also noticed a slight increase in the brake torque with increased ethanol-gasoline blends. In another experimental study, the authors [18] used three mixing ratios, E3, E6, and E9, for all engine loads; the experimental results showed that there was a considerable decrease in exhaust gases CO, HCs, and NO_x with increases in ethanol-gasoline blends. In particular, using E6 and E9 caused a significant decrease in the concentration of exhaust gases compared with using E3 for all engine speeds.
In this study, the influences of adding different alcohol compounds, ethanol and methanol, separately and at different rates, to gasoline in automotive fuel testing were experimentally studied. The objective of this research was to improve the combustion characteristics and thermal efficiency of IC engines. The engine used in the study was designed to provide 11 kW output power, and performance tests were carried out for torque, power, consumption of specific fuels, thermal efficiency, and flue gas temperatures under various engine speeds. The concentrations of flue gases such as CO_2, CO, and HC were also measured in this experimental work.

2. Methodology and Experimental Setup

2.1 Engine Engine investigation bench, TBMC12, developed by EDIBON, which acts as training equipment to test internal combustion engines of up to 11 kW, with bores of 81 mm and 64 mm stroke, was employed in this experiment. The engine used was a one-cylinder engine with an 8.3:1 compression ratio; the cooling substance in the engine was air. The engine was operated in a speed range from 1,500 to 3,000 RPM under a load of 8 N, as shown in Figs. 1 and 2. Table 1 shows the specifications of the engine used in this investigation.

Table 1. Specification of test engine

Engine kind	**Spark ignition, Four strokes**
Number of cylinders	Single cylinder
Bore * stroke	81 mm*64 mm
Swept volume	0.000239 m^3
Compression ratio	8.3:1
Cooling	Air
Output Power	11 kW

Fig. 1: Photograph of the rig including the engine and the computer-controlled unit.

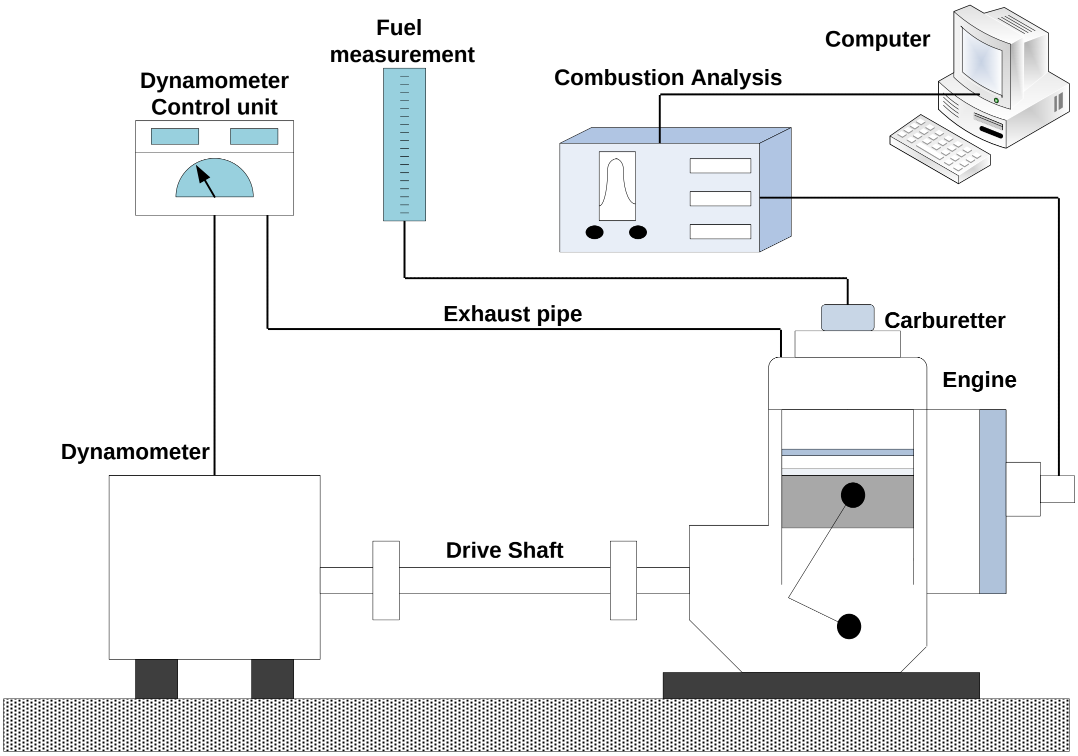

Fig. 2: Schematic diagram of the experimental setup

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2.2 Fuel

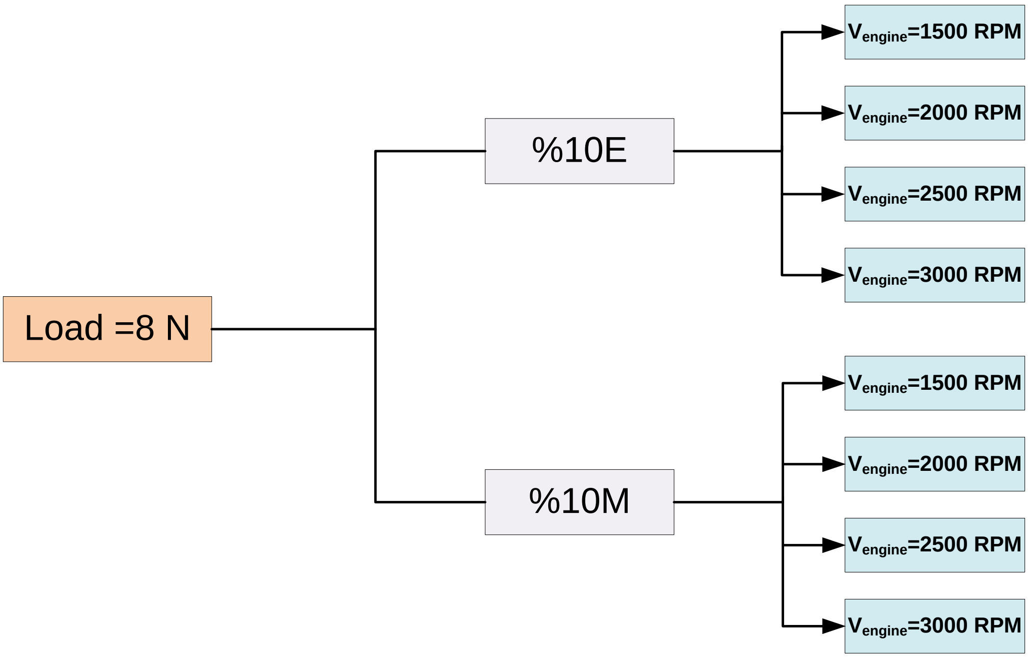
Three different types of fuel with different ratios of mixing were used in this paper. Gasoline, C_6H_6, is the main type of fuel used in automotive engines worldwide. The composition of gasoline changes extensively according to the crude oils used, but it is generally 2 to 5% alkenes, 4 to 8% alkanes, 25 to 40% isoalkanes; 3 to 7% cycloalkanes; and 20 to 50% total aromatics [19]. Ethanol, C_2H_5OH, is another type of fuel used in different ratios in this study. Ethanol is a collection of chemical composition whose particles include a hydroxyl group. Ethanol has a density of 0.789 g/mL at 293 K and melts at 158.9 K [20]. The heating value of gasoline is higher than that of ethanol. Finally, methanol, CH_3OH, was used as a third type of fuel in various ratios in this study. The temperature of ignition of methanol is 740 K, which is higher than that of gasoline (495 K). This could be caused to the high octane number of methanol: classic gasoline has an octane number from 90 to 100. Although methanol is not low-cost, the chemical characteristics are reasonable when compared to other automotive fuels [21]. Table 2 shows the fuel properties (chemical and physical) for the three fuels used.

Table 2. Fuel properties used in the experiments

Property	Ethanol	Methanol	Gasoline
Molecular formula	C_2H_5OH	CH_3OH	C_6H_6
Molecular weight (kg/k.mol)	46.07	32.04	114.15
Density (kg/m^3)	789	792	765
Latent heat of vapor. At 20(°C) kJ/kg)	840	1103	305
Stoichiometric A/F ratio	9.00	6.47	15.13
Boiling point (°C)	78	64	38-204
Auto-ignition temperature (°C)	425	465	228-470
LHV (kJ/kg)	26900	20000	44000

2.3 Procedure and Mathematical Models

The engine was initially allowed to heat up gradually, and experimental tests were carried out at 1,500, 2,000, 2,500, and 3,000 RPM engine speeds. Prior to running the engine for each new test, it was allowed adequate time to consume residual fuel from the previous experimental test. The performance of the IC engine was examined at 10E and 10M to 30E and 30M and from 1,500 RPM to 3,000 RPM, to reflect each key variable under investigation, with other variables set as constants. For all key variables, the following procedures were undertaken. Flowchart (1) shows a sample of experimental method with a constant load 8 N and variable proportions of ethanol and methanol; the same procedures were followed for all fuel blends.



Flowchart 1: Experimental procedures at 8 N load for 10% ethanol and 10% methanol

The mathematical models used in this study for calculating the thermal performance of the engine were as follows:

The brake torque is expressed in the following equation:

$$T = \frac{V_d \times P}{4\pi} \tag{1}$$

T= Torque (N.m)
V_d = Displacement volume (m^3) or swept volume of engine (m^3)
P = atmospheric pressure, (Pa)

The brake power is presented as

$$BP = T \times \left(\frac{2\pi \times N}{60}\right) \times 10^{-2} \tag{2}$$

N = speed of engine (RPM)

The consumption of the brake specific fuel is given by

$$BSFC = \frac{\dot{m}_f}{BP} \tag{3}$$

$\dot{m}_f$ = rate of mass flow for fuel, (kg /m^3)

The brake thermal efficiency of the fuel combustion is

$$\eta_{BTH} = \left(\frac{3600}{BSFC \times LHV_{bl}}\right) \times 100 \tag{4}$$

$$\rho_b = \sum \rho_i \times v \quad (5)$$
$$LHV_{bl} = \sum \frac{\rho_i \times v_i}{\rho_b} \times LHV \quad (6)$$

ρ_b = Density of fuel blend (kg/m^3)

ρ_i = Density of given component (kg/m^3)

v_i =volume fraction of given component in fuel blend (vol.%)

LHV_i = lower heating value of given component (kJ /kg)

LHV_{bl} =lower heating value of blend (kJ/ kg)

3. Results and Discussion

3.1 Brake Torque

Fig. 3 illustrates the influences of various ethanol-gasoline fuel mixtures on the torque of the engine. The results demonstrate that the torque of the engine is considerably increased when using a lower ethanol-gasoline fuel ratio (E10). In contrast, when using E20 and E30 mixes, the torque of the engine is slightly increased compared with that of gasoline, particularly at low engine speeds. This can be explained by the octane number being raised with the increase in the ratio of ethanol to gasoline mixture. As a result, the knocking behaviour is greatly decreased, leading to improvements in the pressure of fuel combustion, and thus to a higher brake torque being achieved.

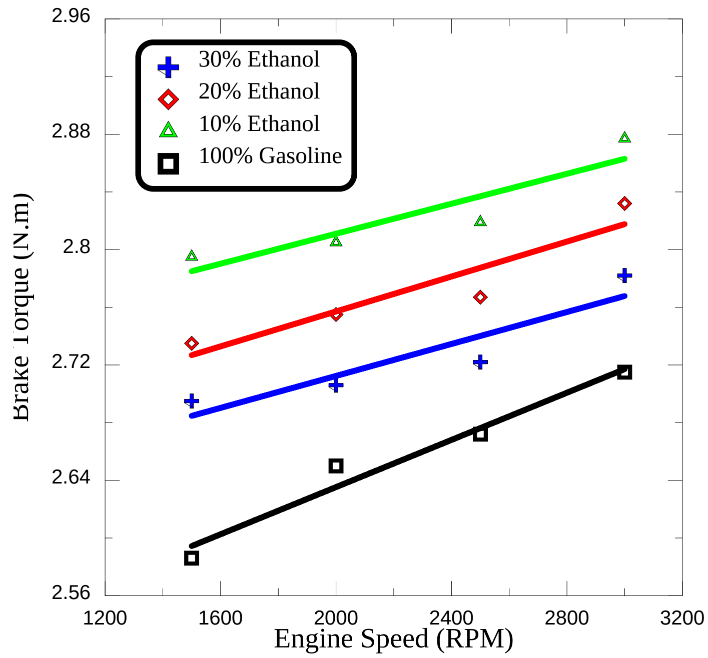


Fig. 3: Experimental results of brake torque engine performance using various ethanol-gasoline blended fuels under different engine speeds

Fig. 4 demonstrates the influence of methanol-gasoline fuel mixtures on the torque of the engine under various speeds. It can be seen that the behaviour is completely different to that with ethanol-gasoline fuel mixtures, as revealed in Fig. 3. The torque of the engine is somewhat decreased with the increase in methanol in the fuel mixture. However, the value of the brake torque of M10 is closer to that of gasoline compared with those of M20 and M30.

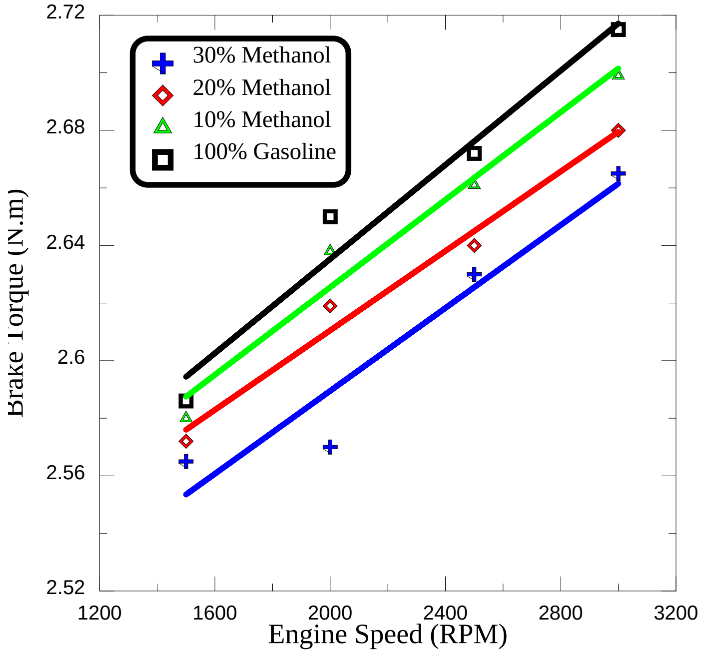


Fig. 4: Experimental results of brake torque engine performance using various methanol gasoline blended fuels under different engine speeds

3.2 Brake Power

The influence of ethanol-gasoline fuel mixtures on engine brake power under various speeds is shown in Fig. 5. Under all speeds, the values of the engine brake power were increased by using a higher ethanol amount in the fuel mixture. It can be seen that the brake power of E10 was higher than those of E20 and E30. By increasing the ethanol volume in the blended fuel, the density of the mixture and the efficiency is increased, and thus brake power increases. This result agrees with similar experimental investigations under different operating conditions [22 and 23].

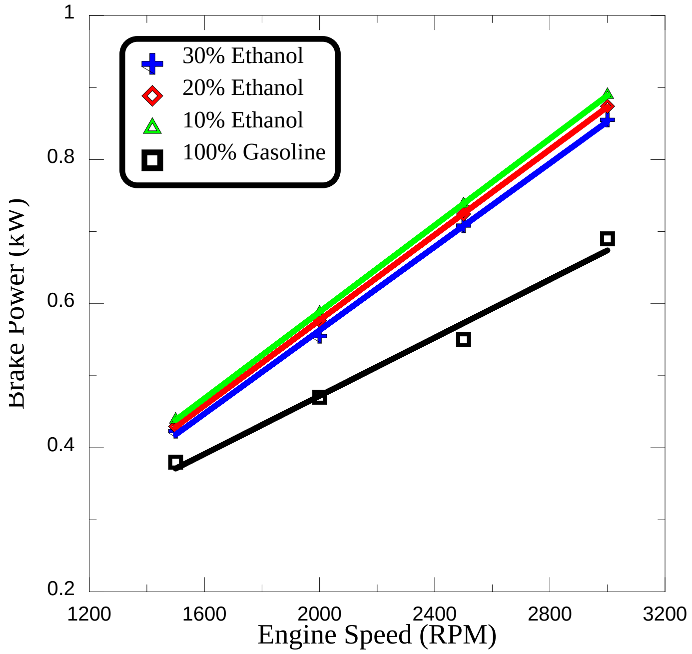


Fig. 5: Experimental results of brake power for the engine performance using various ethanol-gasoline blended fuels under different engine speeds

Fig. 6 illustrates the effect of methanol-gasoline fuel mixtures (M10, M20, and M30) on the brake power of the engine. With increases in the ratio of methanol in the fuel mixture, the power is slightly decreased under all speeds used in the tests. As seen, the power of the reference combustion case (gasoline only) is higher than those of M10, M20, and M30, in particular when the engine speed is at 2,000 RPM. As demonstrated, the engine brake power of M10 was higher in comparison with those of M20 and M30, for the same reasons.

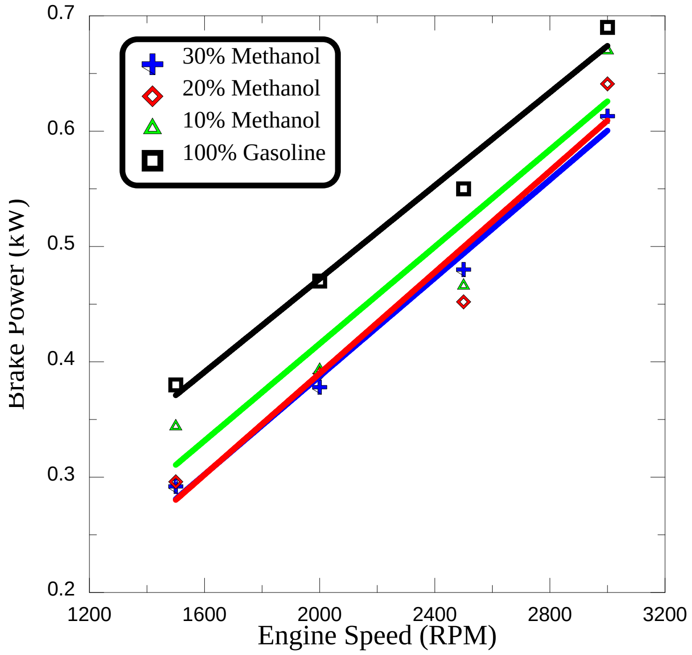


Fig. 6: Experimental results of brake power engine performance using various methanol gasoline blended fuels under different engine speeds

3.3 Consumption of Brake Specific Fuel (BSFC)

Fig. 7 shows deviations of the BSFC for various ethanol-gasoline fuel mixtures for a range of engine speeds. As seen, the amount of BSFC decreases when the ethanol proportion increases. In addition, a significant variation exists among the BSFCs using only gasoline and those using E10, E20, and E30. As engine speed increases, to around 3,000 rpm, the BSFC decreases. This may occur because of the augmentation of thermal efficiency mentioned in [24].

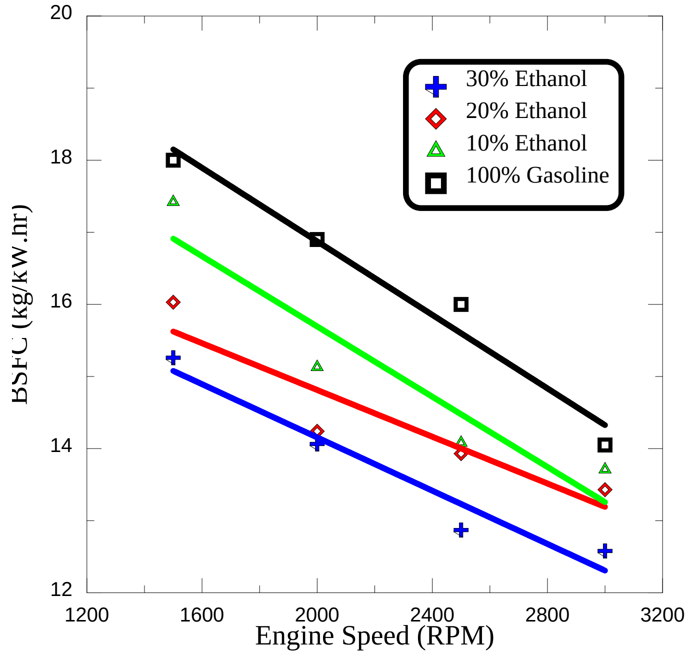


Fig. 7: Experimental results of brake specific fuel consumption engine performance using various ethanol-gasoline blended fuels under different engine speeds

Fig. 8 illustrates the differences in BSFC for methanol-gasoline fuel mixtures for a variety of engine speeds. As shown in Fig. 8, the BSFC increases when the methanol ratio increases. Furthermore, a small variation is seen between the amount of BSFC in the reference case (gasoline) and with methanol-gasoline fuel mixtures. As the speed of the engine increases, the lowest value of BSFC is reached at about 3,000 RPM.

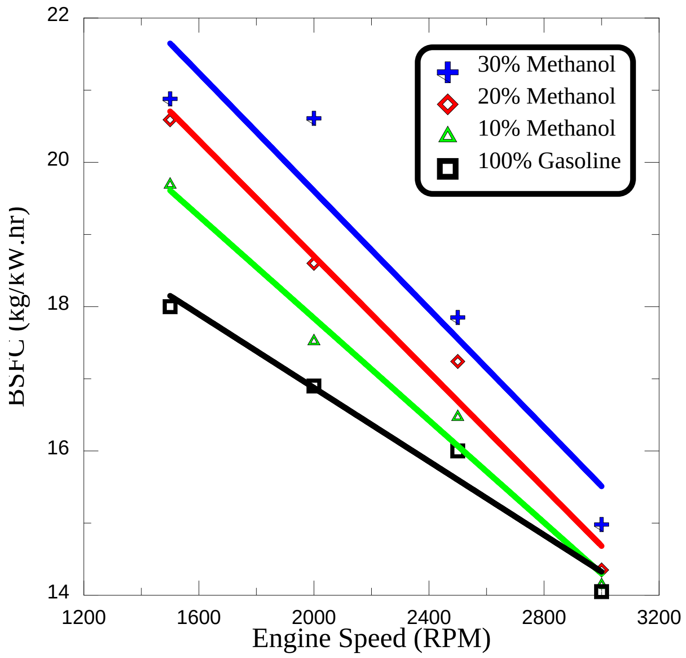


Fig. 8: Experimental results of brake specific fuel consumption engine performance using various methanol gasoline blended fuels under different engine speeds

3.4 Brake Thermal Efficiency

Figs. 9 and 10 show the values of brake thermal efficiency (BTE) using different blended fuels, at various engine speeds. In Fig. 9, the BTE increases as the ethanol blended fuels are used in comparison with pure gasoline. This also happens when increasing engine speed. Fig. 10, in contrast, shows that the BTE decreases as methanol blended fuels are used in comparison with the results of pure gasoline. The explanation for this is that the latent amount of heat in the fuel mixture used decreases with increasing ethanol percentages (E10, E20, and E30). Therefore, the BTE of E10 is better than that of E20 and E30 according to brake thermal efficiency (BTE), as explained in Eq. 4 in the previous section of this paper.

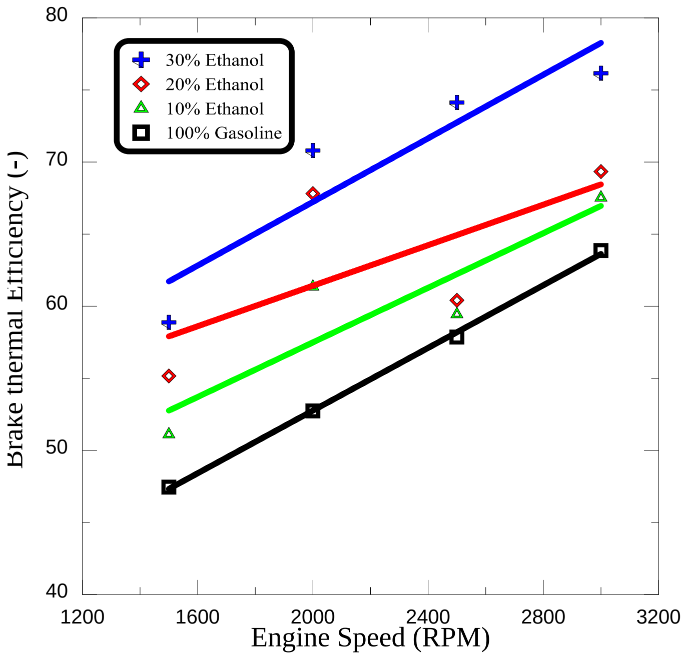


Fig. 9: Experimental results of brake thermal efficiency engine performance using various ethanol-gasoline blended fuels under different engine speeds

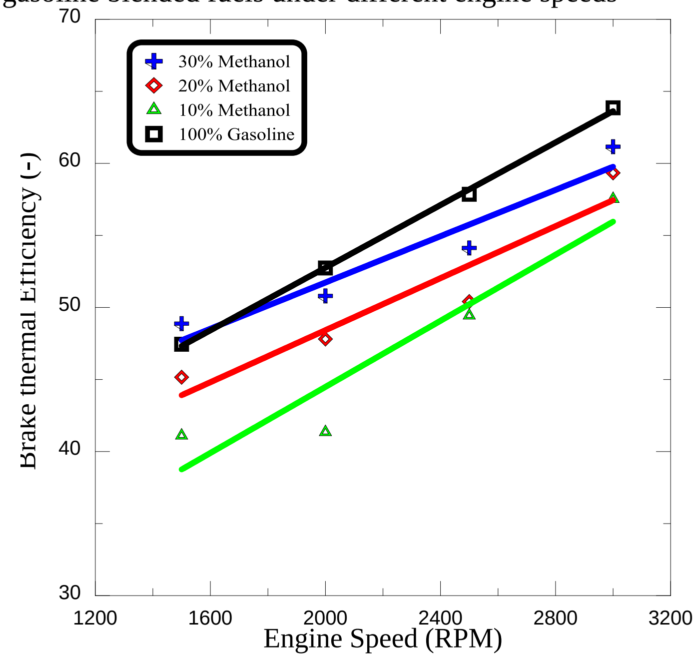


Fig. 10: Experimental results of brake thermal efficiency engine performance using various methanol gasoline blended fuels under different engine speeds

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3.5 Emissions

To examine the influence of various ethanol- and methanol-gasoline fuel mixtures on exhaust gases, the experimental results at 2,500 RPM were chosen for evaluation, as seen in Fig. 11. The end result of imperfect combustion is an increase CO in the flue gas. As ethanol and methanol contain oxygen, their mixture with gasoline causes the combustion of the fuel mixture to be improved, and as a result, CO concentration decreases. In Fig. 11, the values of the concentrations of CO are seen to be reduced by 35% and 36% at increasing percentages of ethanol and methanol, respectively.

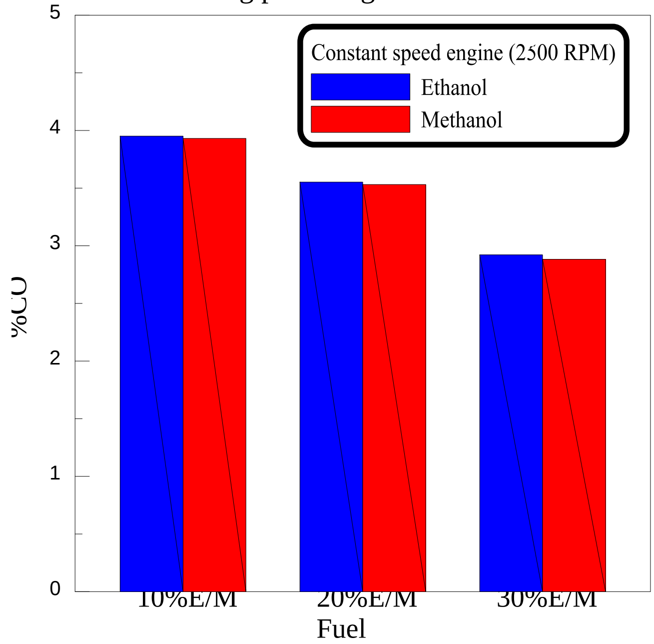

Fig. 11: Concentrations of carbon monoxide (CO) for different blended fuels used at 2,500 RPM engine speed.

The concentrations of CO_2 at 2,500 RPM using ethanol- and methanol-gasoline mixtures are decreased in contrast to the reference combustion case (gasoline only), as shown in Fig 12. This is because ethanol and methanol have fewer C atoms compared with gasoline, thus produces lesser quantities of CO_2. In general, the trend of reduction of CO and CO_2 in the present study was seen to be approximately similar to that in previous experimental work [12 and 25].

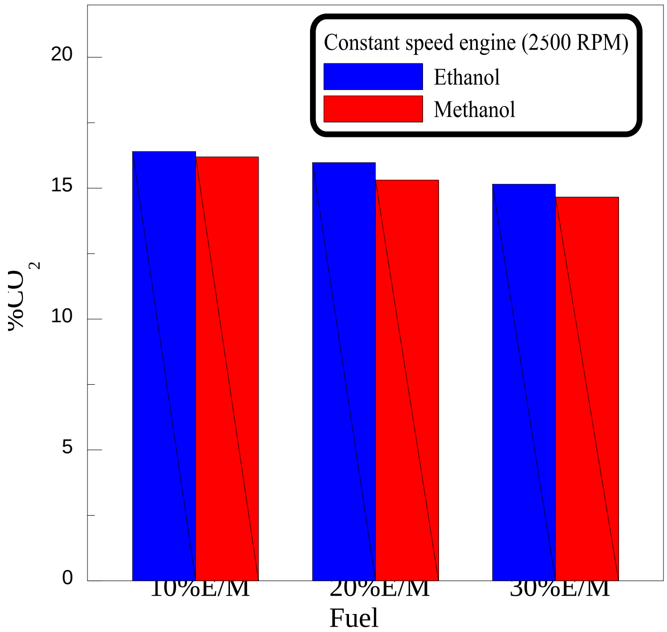

Fig. 12: Concentration of carbon dioxide (CO_2) for different blended fuels used at 2,500 RPM engine speed.

Fig. 13 shows the concentrations of HC in the flue gas mixture at 2,500 RPM for fully opened throttle valves. The measured results show that the additives (ethanol and methanol) can be treated as somewhat oxidized hydrocarbons when added to the fuel mixture. As a result, HC concentrations reduce significantly when ethanol and methanol are added to the standard fuel (gasoline).

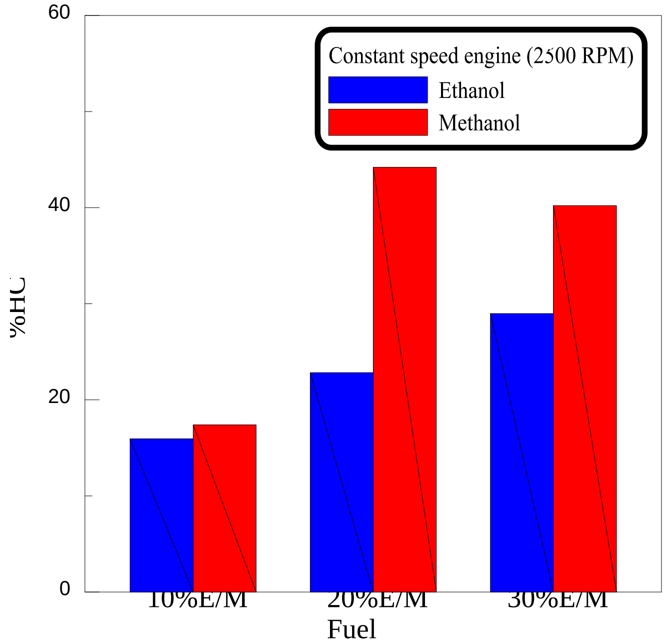

Fig. 13: Concentration of oxidized hydrocarbon (HC) for different blended fuels used at 2,500 RPM engine speed.

In order to enlarge the level of certainty of the experimental results, the error analysis method for E10, M10 and pure gasoline combustion cases are presented for all variables in Table 3.

Table 3: Error analysis for the accuracy of experimental work.

Independent variables	**Variable errors**		
	E10	M10	100% Gasoline
Brake torque	2.644∓0.07	2.8∓0.04	2.65∓0.08
Brake power	0.66∓0.11	0.46∓0.061	2.65∓0.08
Brake Specific Fuel Consumption	1.6∓2.306	1.5∓2.15	2.65∓0.08
Brake thermal efficiency	1.54∓1.87	2.113∓0.48	2.65∓0.08
CO emission	3.47∓0.53	3.44∓0.56	
CO_2 emission	5.84∓0.80	4.6∓1.19	
HC emission	2.52∓0.852	2.52∓0.418	

4. Conclusion

This study presented the effects of adding ethanol and methanol to gasoline (reference combustion case) in an SI engine to investigate combustion characteristics. The use of ethanol-gasoline fuel mixtures improved the power and torque, and also led to a decrease in the BSFC. Methanol-gasoline fuel mixtures showed lower power and torque and elevated BSFC compared with the gasoline reference case. Generally, the thermal performance of methanol-gasoline fuel mixtures was not as good as those of ethanol-gasoline fuel mixtures because of the effects of changes in their combustion properties. Using fuel mixtures with high amounts of ethanol and methanol, at 1,500, 2,000, 2,500, and 3,000 RPM, showed significant effects in terms of the reduction of flue gases, particularly with regard to CO, CO_2, and HC concentrations. Based on these results, ethanol-gasoline blended fuels with 10% ethanol are recommended for future use to improve the combustion characteristics and thermal performance of IC engines.

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