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The investigation of performance and emission of a gasoline engine using novel gasoline and bio-alcohols fuel blends

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ABSTRACT

Due to the increase in pollution caused by fossil fuels in internal combustion engines, the demand for renewable fuels such as bio-alcohols has increased, so in this study, the focus is on increasing the percentage of pentanol with a combination of other alcohols used in this experiment. Because so far, little study has been done on pentanol. This study was carried out on a water-cooled four-cylinder gasoline engine with different percentages of pentanol, propanol, butanol, and ethanol alcohol combined with gasoline. Fuel compounds in different volume percentages were added to gasoline at 1000, 1500, and 2000 rpm, and the number of pollutants and engine performance were evaluated at each speed. Due to the presence of excess oxygen in the structure of Pentanol, the engine power increases by 61.5 KW. Engine torque increases due to the high latent heat of Butanol and propanol, in the fuel. BSFC improved by 294 N.M compared to pure gasoline due to the high calorific value of alcohols. The pressure of the gases inside the cylinder during combustion and high temperature leads to the production of NO_X in the combustion chamber. The lower the amount of Butanol and Propanol in the fuel, the less HC is produced, which can be due to improved combustion quality. The highest amount of HC in the fuel blend No. 2 at 1500 rpm is 2476 ppm. Increasing the combustion temperature due to the presence of alcohols can cause changes in CO. The CO emission also depended on the amount of Propanol and Butanol, which produce more CO in combinations with 10% Butanol and Propanol. The highest average CO2 change compared to pure gasoline is related to the fuel blend No. 1 by 17.37%.

Keywords: Renewable Energy, Environmental Pollutants, Gasoline Engine, Engine Performance, Bio-Alcohols.

1. Introduction

Given that energy is the main input of industry and technology [1]. Therefore, changing lifestyles and increasing population has caused an increase in energy in the world. Most of the energy used by humans is currently supplied by oil-based fossil fuels, while their resources are limited and running low. Demand for energy consumption increased in the 20th century due to population growth, and governments used fossil fuels such as crude oil, coal, and natural gas refineries to meet energy demand [2]. But in the 21st century, due to the excessive consumption of energy in the last century, greenhouse gas emissions increased sharply, the reduction of oil reserves and the increase of environmental pollution became

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more noticeable, and energy security was endangered. The combustion of fossil fuels releases a significant amount of CO_2 into the atmosphere, which has a direct effect on global warming. Annually, about 25 million tons of CO2 are produced by human activities [3]. One way to eliminate CO_2 and other greenhouse gases produced when using fossil fuels is to use bio-alcohols and blend them with fossil fuels such as gasoline, which aims to maximize fuel efficiency and significantly reduce Attention paid to the emission and concentration of exhaust gases from the engine through which global warming can be reduced [4-5]. Internal combustion engines are the main source of air pollution but are still widely used around the world [6]. Adding alcohols to hydrocarbon fuels used in Spark Ignition engines increases the octane number of the fuel, thereby increasing engine performance and reducing environmental pollutants such as CO_2, NO_X, and HC [7-8]. The increasing use of automobiles in cities is causing environmental problems and producing large amounts of pollutants, especially in densely populated cities. These pollutants, directly and indirectly, harm human health and the environment. Over the years, researchers have paid special attention to alternative fuels to improve the fuel quality of internal combustion engines and reduce pollutants [9]. The use of renewable energy, especially the bio-alcohol and gasoline fuel blends, has recently been considered by researchers because due to the high octane number in alcohols, environmental pollutants are reduced and engine performance is increased. In addition, bio-alcohols are clean energy sources, and low carbon such as ethanol, butanol, propanol, and pentanol can be used in combination with gasoline [10]. Because alcohols emit fewer pollutants during combustion in the engine than pure gasoline, it is possible to blend gasoline fuel with any type of alcohol (such as ethanol, propanol, butanol, and pentanol), which generally improves engine performance and reduces emissions of pollutants can be used [11].

There are several types of alternative fuels for conventional gasoline engines, including biofuels, which are suitable fuels to reduce environmental pollutants. Ethanol is a first-generation biofuel that is mainly produced from agricultural products such as sugarcane and corn [12]. Ethanol is the most common alternative fuel used in SI engines [13]. Butanol is prepared as one of the second-generation biofuels from non-edible plants and due to its physical properties similar to gasoline, it can be used as a fuel in internal combustion engines [14-15]. Compared to ethanol, butanol has a higher density, less corrosion, and less exposure to water contamination [16]. Propanol is a renewable fuel that can be even better than bioethanol because it has a higher energy density and lower moisture absorption [17]. Also, pentanol, like other bio-alcohols, reduces the emission of environmental pollutants and increases engine performance due to the presence of excess OH in its structure [18]. Pollution emissions from a four-stroke engine were investigated using ethanol-gasoline and propanol-gasoline fuel blends. Ethanol and propanol with volume percentages of 4, 8, 12 and 16, and 20% were added to unleaded gasoline. CO and HC emissions were reduced by 65.56 and 33.92% with ethanol-gasoline and propanol-gasoline fuel blends, respectively. Emissions of NO and CO_2 with combined fuels showed an increasing trend [19]. In another study, the effects of ethanol-gasoline (E5, E10) and methanol-gasoline (M5, M10) fuel blends on the performance and combustion characteristics of a SI engine were investigated. The results showed that the use of alcohol-gasoline fuel blends increased brake-specific fuel consumption. In almost all test conditions, pollutant emissions were lower than in pure gasoline [20]. Another study using gasoline and ethanol fuel, which was performed on several turbocharged engines, showed that the addition of ethanol to gasoline increases the octane number, thus reducing CO2 emissions, fuel consumption, and energy consumption in the engine [21]. In another study, the pollutants of a gasoline engine were investigated using a combination of normal butanol fuel with gasoline. Alcohols were blended with gasoline fuel in a ratio of (0, 5, 10, 15, and 20) by volume. By increasing the percentage of normal butanol in fuel to 20%, the emission of CO, CO2, and UHC pollutants in the engine decreased. Also, increasing engine speed reduced UHC and CO pollutants and increased CO2 and NOX pollutants [22]. In a study, the combination of ethanol, butanol, methanol, and gasoline on a four-cylinder gasoline engine was studied in different volume percentages The results showed that the engine performance is higher in fuel combinations with lower methanol content, and engine performance decreases in fuel combinations with less ethanol [23]. In research that was conducted on a turbocharged engine using an ethanol-gasoline fuel combination. The results showed that adding ethanol to gasoline can reduce greenhouse gas emissions by 35% [24]. In a study, engine performance and pollutant emissions of a spark ignition engine were investigated in a gasoline and ethanol fuel mixture.The results showed that with the increase in engine speed, engine efficiency and exhaust gas emissions decreased significantly [25]. In a study on a gasoline engine with a combination of ethanol and gasoline, it was shown that adding ethanol to gasoline increases the efficiency of the engine by 25% [26]. In research, the emission of engine pollutants with the combination of gasoline and methanol fuel was investigated. The results showed that with the addition of methanol, the number of emissions of pollutants decreases [27]. The performance and emissions of a gasoline engine with a combination of gasoline and n-butanol fuel were investigated in a study.The results showed that adding n-butanol to gasoline reduces engine torque and power. It also reduces the amount of CO, CO2, and UHC pollutants [28]. In a study on a gasoline engine with a combination of gasoline and alcohol, the results showed that by increasing the percentage of ethanol in gasoline, the octane number increases, thus reducing CO2 [29]. In research, the combination of ethanol, methanol, butanol, and gasoline alcohols was studied on a gasoline engine.The results showed that adding alcoholic fuels to gasoline increases power, torque, and BSFC, and the amount of CO and NOx pollutants decreases [30]. The results of the study conducted by Gu et al. on a three-cylinder gasoline engine showed that adding n-butanol reduces greenhouse gas emissions by 20% [31]. Singh et al. conducted a study on a four-cylinder gasoline engine with the combination of n-butanol fuel with gasoline, and the results showed that the specific fuel consumption increases in fuel combinations that have a higher amount of n-butanol [32]. In a study that was conducted on a gasoline engine with a combination of gasoline and butanol, the results showed that increasing the amount of butanol reduces the emission of CO, NOx, and HC [33].

Due to the increasing consumption of fossil fuels and the end of these fuels, the demand for renewable alcoholic fuels has increased. Therefore, in this research, the performance and pollutant emissions of a four-cylinder gasoline engine coupled to a dynamometer were investigated in different volume percentages of pentanol, propanol, butanol, and ethanol fuel combinations with gasoline. Volume percentages used in this research are G60Pe10E10Bu10Pr10, G40Pe10E10Bu20Pr20, G55Pe15E10Bu10Pr10, G35Pe15E10Bu20Pr20, G50Pe20E10Bu10Pr10, G30Pe30E10Bu20Pr20. On the other hand, because pentanol is one of the best biofuels, it has a significant amount of OH in its structure. Therefore, it causes the complete combustion of fuel in the combustion chamber of the engine and since few studies have been done on pentanol, the purpose of this study is to investigate the performance and pollutants of the gasoline engine with different volume percentages of pentanol and other alcohols with gasoline, which improves the performance of the engine and reduces its emissions.

2. Materials and Methods

In this section, how to conduct the experiment and the experiment equipment are explained to the training.

2.1 Preparation of fuel

The gasoline used in this experiment was prepared from a conventional fuel station in Hamedan. Also, ethanol, butanol, propanol, and pentanol alcohols were prepared with 99.6% purity. Gasoline-alcohol fuel blends were prepared with different volume percentages using a graduated container according to Table 1. (The letter E stands for ethanol, B stands for butanol, Pr stands for propanol, Pe stands for pentanol, and G stands for gasoline. Subtitle numbers indicate the volume percentage of each fuel). The selection of volumetric percentages of fuel composition of the present study is based on previous research in which engine performance is optimal in these percentages.

2.2 Engine Set Up

The equipment used in the test includes a four-cylinder gasoline engine mated to a Ford factory PLINT dynamometer. The specifications of this engine are given in Table 2. Also, the AIRREX HG-550 gas analyzer made in Korea was used to investigate and measure the emissions (Table 3).

Table 1. Fuel compositions

Type fuel	Pentanol%	Ethanol%	Butanol%	Propanol%	Gasoline%
$G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$	10	10	10	10	60
$G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$	10	10	20	20	40
$G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$	15	10	10	10	55
$G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$	15	10	20	20	35
$G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$	20	10	10	10	50
$G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$	20	10	20	20	30

Table 2. Test engine specifications

type	GB132L26BF
Power(kW)	65.5
Max Speed(rpm)	6000
Min Speed(rpm)	3680
Number of cylinders	4

Table 3. Gas analyzer- AIRREX- HG-550

Parameters	Accuracy
CO	0-9.99 (V%)
NO_X	0-5000 (ppm)
HC	0-10000 (ppm)
CO_2	0.01-20 (V%)
O_2	0.01-25(V%)

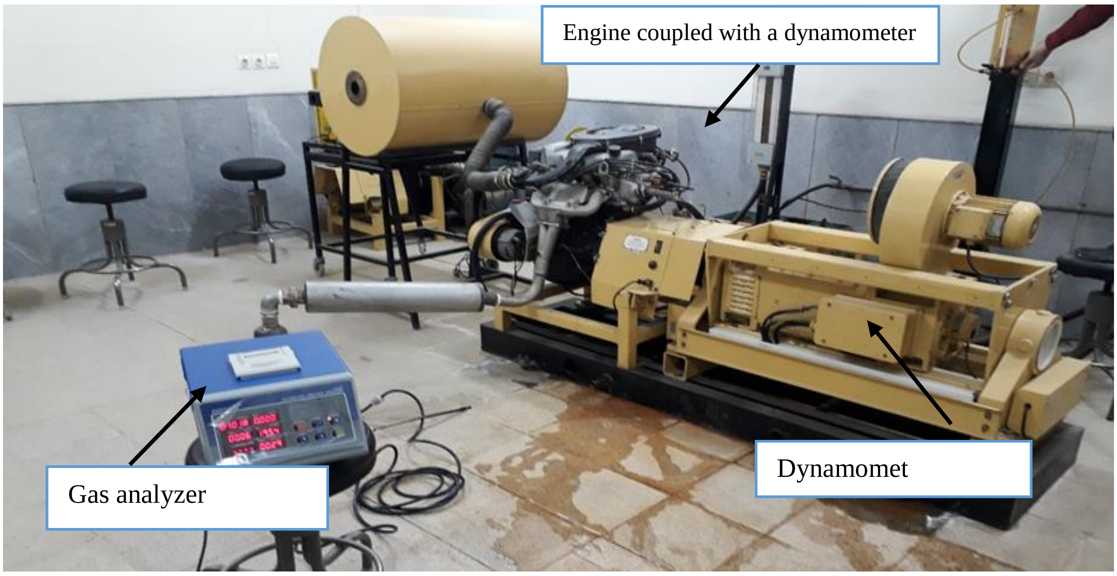

Fig 1. Engine Set up

The experiments were performed in the laboratory of the Bu-Ali Sina University of Hamadan (according to Fig. 1), to perform the experiments, the mixture of gasoline and alcohol fuel was first mixed in 1-liter bottles according to Table 1. Then pure gasoline was filled into the engine fuel tank and the engine was run for 15 minutes to stabilize the engine conditions. Emissions data were measured by a gas analyzer. Also, by dynamometer, data related to engine performance including power, torque, and fuel consumption were measured at three different speeds (2000, 1500, and 1000 rpm).

After the experiment, the experimental data were analyzed by SPSS 26 software and the average data of the experiment were analyzed by the General linear model by the single variable analysis of variance method. The type of experimental design was factorial in the form of a completely random design.

3. Results and discussion

3.1 Analysis of experimental data with SPSS software.

The average experimental data with SPSS software was in the form of a completely randomized factorial design with six factors of Power, Torque, Brake specific fuel consumption, Hydrocarbon pollutants (HC), Carbon Monoxide (CO), and Nitrogen Oxides (NOX). The results of the variance analysis of test data are shown in Tables 4, 5, 6, and 7.

Table 4. Analysis of variance results for factors power and torque.

Source	df	Mean square	
		Power (KW)	Torque (N.m)
Fuel	6	20.568**	575.30**
Speed	2	4626.445**	13.26/549**
Fuel × Speed	12	2.66**	92.62**
Error	21	0.765	68.881

** Significance at the 0.01 level

Table 5. Analysis of variance results for factors BSFC and HC.

Source	df	Mean square	
		BSFC (L/KW.H)	HC (ppm)
Fuel	6	0.16**	132244.151**
Speed	2	3.104**	73373.643**
Fuel × Speed	12	0.004ns	10738.532**
Error	21	0.004	732.5

** Significance at the 0.01 level

ns It has no significant effect

Table 6. Analysis of variance results for factors CO and NO_X.

Source	df	Mean square	
		CO (V%)	NO_X (ppm)
Fuel	6	0.320**	172.111**
Speed	2	0.304**	1447.167**
Fuel × Speed	12	0.073**	32.444**
Error	21	0.01	2.071

** Significance at the 0.01 level

Table 7. Analysis of variance results for factor CO_2

Source	df	Mean square
		CO_2 (V%)
Fuel	6	0.129**
Speed	2	0.013**
Fuel × Speed	12	0.071**
Error	21	0.012

** Significance at the 0.01 level

According to the results that can be seen in the variance analysis tables(tables of 4,5,6 and 7), the main effect of fuel mixture and the main effect of engine speed are significant in the factors of power, torque, and specific fuel consumption, CO, CO_2, NO_X and UHC. Also, the effect of fuel mixture × engine speed is significant for all the mentioned factors except for special fuel consumption. Since most of the treatments were significant, therefore, the comparison of the average fuel mixture × engine speed was done for all factors except special fuel consumption; because the interaction effect of fuel mixture × engine speed was not significant.

3.2 Average comparison

The results of comparing the average fuel mixture × speed for Power showed (According to Table 4) that $G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$ fuel mixture has the highest Power the amount 42.10 kW at 2000 rpm. And after this fuel combination, fuel combinations $G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$, $G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$, pure gasoline, $G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$, $G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$, and $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$ have the highest power. It can also be seen that the $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$ fuel mixture has the lowest average power the amount 36.91 kW at 1000 rpm compared to other fuel mixtures. The reason for this can be related to the low quality of pure gasoline fuel and the significant amount of excess oxygen in alcohols.

The results of the comparison of the average fuel mixture × speed for Torque showed (According to Table 4) that the $G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$ fuel mixture has the highest torque the amount 297 N.M at 2000 rpm. And after that, the fuel combinations $G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$, $G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$, pure gasoline, $G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$, $G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$ and $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$ have the highest torque. The lowest average torque is related to $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$ compound fuel the amount of 258 N.M at 1000 rpm.

The results of the comparison of average fuel mixture x speed for HC pollutant showed (According to table 5) that $G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$ fuel mixture has more HC in the amount of 2395 ppm at 1500 rpm speed. And after this composition, in the order of pure gasoline, $G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$, $G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$, $G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$, $G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$ and $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$ have the highest amount of HC. The lowest average HC corresponds to $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$ the amount of 1998 ppm at 1500rpm.

The results of the comparison of average fuel mixture x speed for CO pollutants showed (According to Table 6) that pure gasoline has the highest amount of CO the amount 2.46 (V%) at 1500 rpm. And after that, the average fuel combinations of $G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$, $G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$, $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$, $G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$, $G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$ and $G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$ have the highest average of CO pollutants. The lowest average amount of CO related to fuel 2 the amount 1.77 (V %) at 1500 rpm.

The results of comparing the average fuel mixture × speed for NO_X pollutants showed (According to table 6) that the fuel mixture $G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$ has the highest amount of NO_X the amount 48 ppm at 2000 rpm. After that, pure gasoline and fuel blends $G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$, $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$, $G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$, $G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$ and $G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$ have the highest amount of NO_X. The lowest amount of NO_X corresponds to fuel 5 the amount 32 ppm 1500 rpm.

The results of comparing the average fuel mixture × speed for CO_2 pollutants showed (According to table 7) The results of the comparison of the average fuel blend × speed for the CO_2 pollutant showed, that the fuel blends $G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$ has the highest amount of CO_2 pollutant the amount 2.75 (V%) at the speed of 1500 rpm, and then $G_{60}Pe_{10}E_{10}Bu_{10}Pr_{10}$, $G_{35}Pe_{15}E_{10}Bu_{20}Pr_{20}$, $G_{55}Pe_{15}E_{10}Bu_{10}Pr_{10}$, $G_{50}Pe_{20}E_{10}Bu_{10}Pr_{10}$, $G_{30}Pe_{20}E_{10}Bu_{20}Pr_{20}$ and gasoline have the highest average amount of CO_2 pollutant. In terms of average comparison, there is no significant difference between fuel blends No. 6, 5, 3, and 4. Similarly, fuel blends No. 3, 4, 2 and are also in the same range and there is no significant difference between the mentioned blends. But fuel blend 1 has a significant difference of 0.01 level with all the compounds in the test. The lowest average amount is related to pure gasoline the amount of 2.36 (V %) at 1000 rpm.

3.3 Engine Performance

3.3.1 Engine power

According to Fig. 2a, the engine output power of pure gasoline and its comparison 2000 engine power has increased. Therefore, adding alcohol in different volume percentages to gasoline has increased engine power. Engine power production with each fuel is close to each other and close to pure gasoline. Previous researchers in similar experiments examined the power of the engine using alcohol at different speeds [35]. This showed that the use of bio-alcohols in the engine increases the engine power due to the high calorific value of alcohols compared to gasoline fuel, which increases the combustion efficiency inside the engine combustion chamber [36]. Combustion behavior in the combustion chamber is influenced by several factors including the calorific value of the fuel composition, the degree of mixing and the homogeneity of the charge (air and fuel) in the combustion chamber as well as the A/F ratio and boiling points or evaporation of the fuel blend. All of these factors may affect the combustion process [37]. As you can see in Fig. 3a, the highest power for fuel No. 6 at 2000 rpm is 61.5 KW, which has the highest percentage of alcohol, and the lowest power for pure gasoline is 20.85 KW at 1000 rpm.

Figure 2b shows the average power change at all speeds relative to pure gasoline. As shown in the figure, the highest percentage of average power was related to the fuel blend No. 6 it 13.62%. The lowest power for fuel No. 5 is 1.29%. According to Fig. 3b, the average power changes in fuel blend No. 6 has 20% propanol and butanol and in fuel blend No. 5 it is 10% butanol and propanol. Due to the amount of pentanol that is constant in both fuel combinations. Changes related to power depend on the amount of butanol and propanol present in fuel compositions; That is, with the increase in the percentage of butanol and propanol, the average power changes compared to pure gasoline in the fuel blend No. 6 increased [35]. The improvement in power obtained for fuels can be attributed to the presence of excess oxygen molecules in propanol and butanol, which cause complete combustion of the fuel inside the cylinder. Also, the reduced viscosity of the fuel blends shows better spray properties and improved fuel. Atomization leads to faster combustion, which improves engine performance. The presence of the OH group in propanol and butanol in the mixture weakens the carbon bond during combustion at higher temperatures and leads to faster combustion, which leads to an increase in power [38].

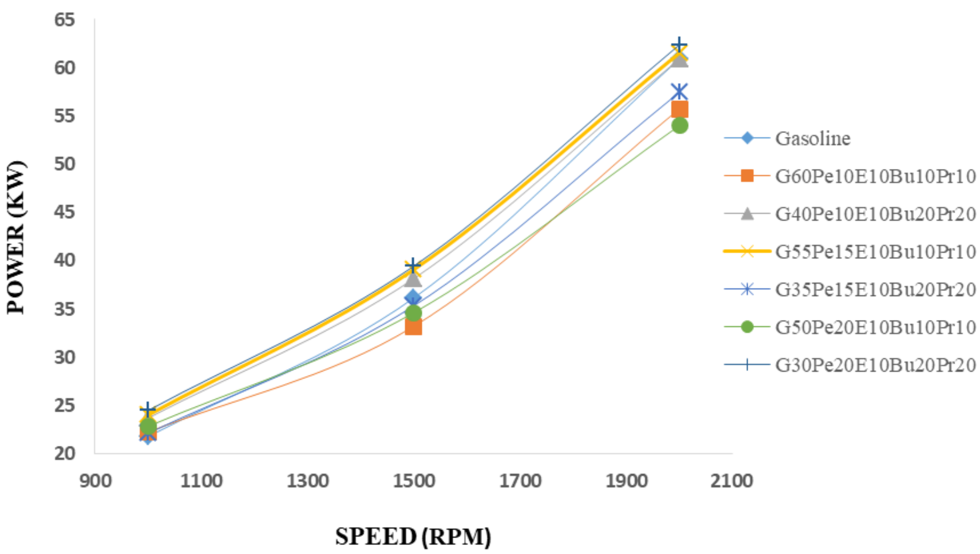

Fig 2a. Engine power

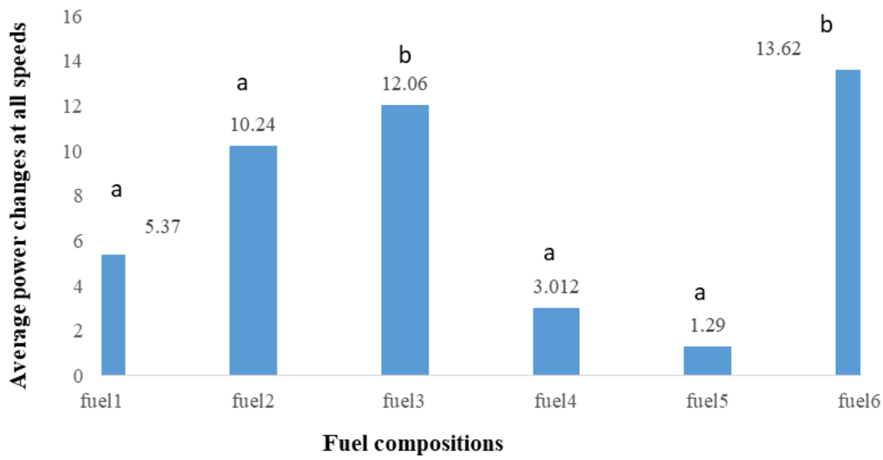

Fig 2b. Average power changes at all speeds compared to pure gasoline

3.3.2 Torque

Torque is the rotational force produced by the pressure from the piston crankshaft. Engine torque depends on engine length, charge status, and average effective cylinder pressure [38]. According to Fig. 3a, with increasing engine speed, the torque increased. In all fuel blends, with increasing speed from 1000 to 1500 rpm, the torque increases. This trend is similar and close to each other, which in base fuel is the same trend with other fuels. The highest torque related to the fuel blend No. 3 at the speed of 2000 rpm is 294 N.M. Previous studies have found that increasing the amount of alcohol increases engine torque by 3.6% due to the presence of hydrogen, in which the calorific value of hydrogen is 120MJ / KW, which is a significant amount and helps increase torque [39-40].

According to Fig. 3b, the lowest torque is related to the fuel blend No. 1 with –6.9%. And the highest torque for fuel blend No. 6 is 7.14% compared to pure gasoline. That is, fuel blend No. 1 torque has decreased by -6.9% compared to pure gasoline. According to fuel composition No. 1 and fuel blend No. 6, the amount of propanol and butanol in these two fuel combinations is variable and with increasing the amount of propanol and butanol, the engine torque has increased. Therefore, previous studies have found that by adding higher percentages of butanol to gasoline, engine torque can be increased by 4.6%. Because as an oxygenated fuel, the addition of butanol to gasoline improves the quality of combustion. Butanol also has a higher latent heat than pure gasoline, which reduces the inlet manifold temperature and increases volumetric efficiency [41]. Under the influence of constant engine conditions at different speeds, the torque properties of the fuel increase with increasing speed and the percentage of propanol in the fuel. The increase in torque may be due to the high latent heat of evaporation of propanol and butanol [42].

3.3.3 Brake-specific fuel consumption

BSFC value is a measure of how much fuel the engine uses and therefore less BSFC is always desirable [38]. From Fig. 4a, it can be seen that among all the fuels tested, the fuel blend No. 6 shows the lowest BSFC value at different speeds. According to Fig. 4a, the addition of alcohols used to gasoline reduces the brake-specific fuel consumption of the engine by increasing the speed from 1000 to 2000rpm and reaching its lowest value in the fuel blend No. 6 to 1.137 L/Kw.h. Also, the highest amount of brake special fuel consumption is related to the fuel blend No. 4 at 2.25 L / Kw.h. Improving the brake-specific fuel consumption of the engine during the use of different fuel blends is due to the high calorific value of alcohols compared to gasoline fuel, which generally increases the combustion efficiency inside the engine combustion chamber [35]. Previous studies have found that a higher percentage of pentanol in the fuel blends leads to a lower engine BSFC [43].

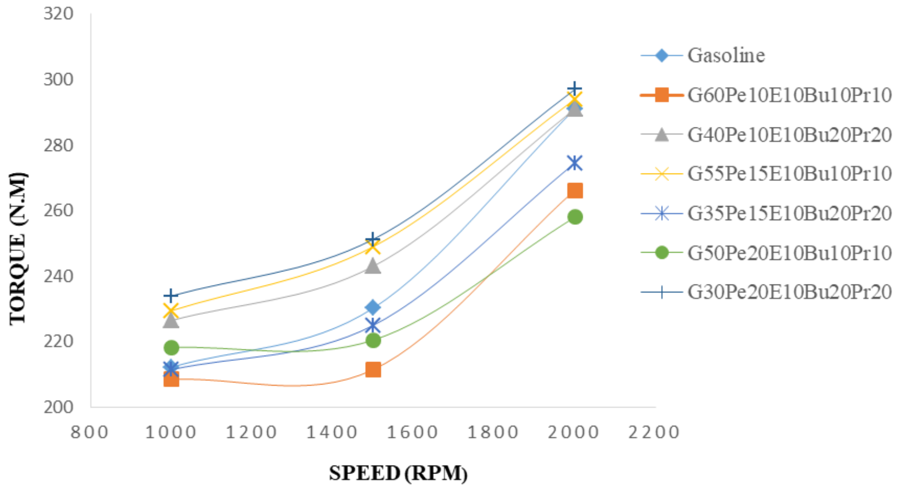

Fig 3a. Engine torque

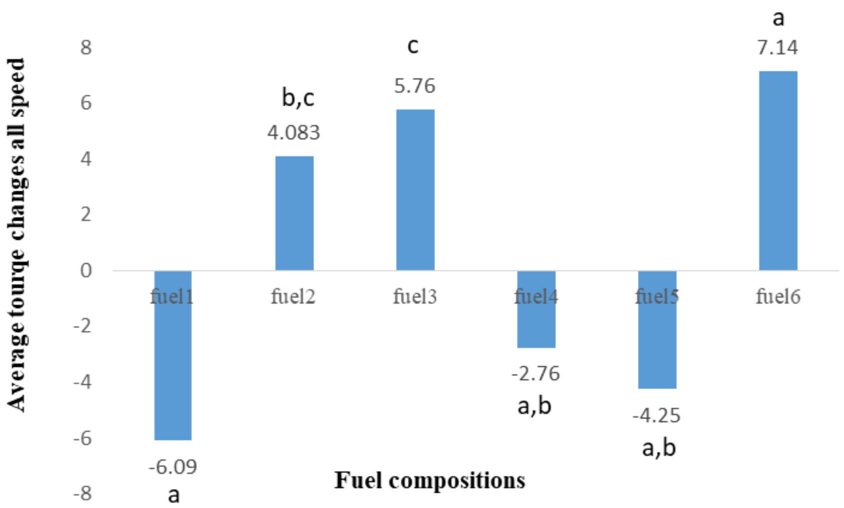

Fig 3b. Average Torque changes at all speeds compared to pure gasoline

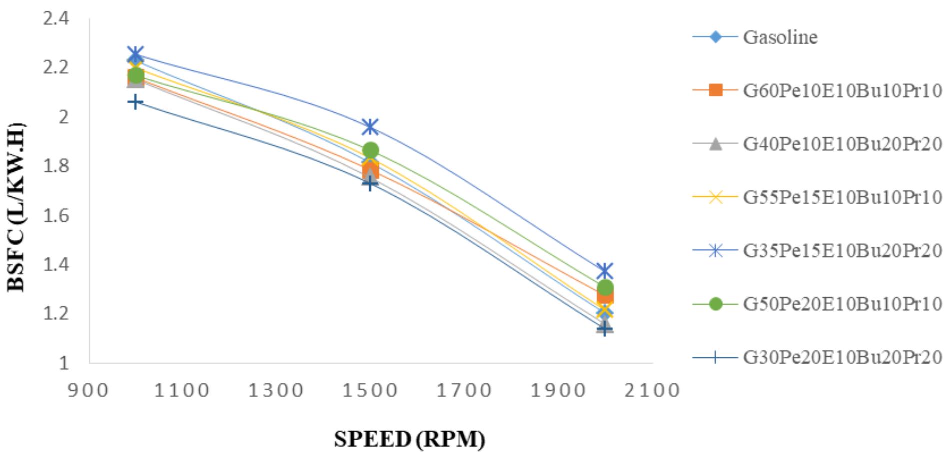

Fig 4a. Engine brake-specific fuel consumption

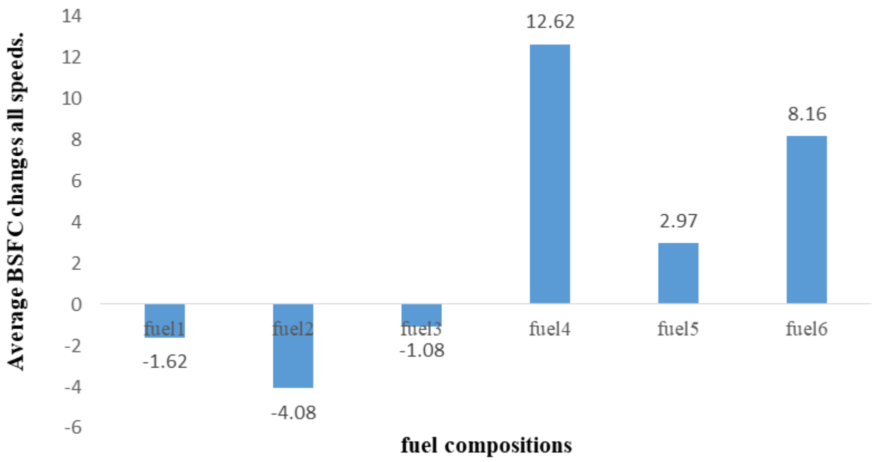

Fig 4b. Average BSFC changes at all speeds compared to pure gasoline

As can be seen in Fig. 4b, the highest average BSFC is related to fuel blend No. 4 at 12.62%, and the lowest average BSFC is related to the fuel blend No.2 at -4.08%. Because pentanol has a high latent heat of vaporization and in the evaporation stage absorbs more heat from the combustion chamber and thus causes a cooling effect that leads to a reduction in combustion efficiency [44]. In the case of fuel blends with a small amount of pentanol, such as fuel blend No. 4, the improvement obtained in the BSFC can be attributed to an increase in the combustion process. The increase in combustion is due to the presence of excess oxygen molecules, lower viscosity and lower density of the fuel composition [42].

3.4 Engine Emissions

3.4.1 NO_X

The formation of NOx inside the combustion chamber of an engine takes place mainly through the rapid thermal mechanisms of the fuel. Figure 5a shows the change in NOx concerning the engine load for pure gasoline and fuel blends. The oxygen content of fuel blends is higher than that of pure gasoline, allowing carbon and oxygen the opportunity to complete the chemical interaction, thus increasing the combustion temperature in the engine [46]. For all fuel blends, it has been found that NOx gradually increases with engine load because more fuel input increases the temperature in the combustion chamber. According to Fig. 5a, for base fuel, NOx increases slowly from 1000 to 1500 rpm, and from 1500 to 2000 NOx increases sharply, reaching its highest level for base fuel at 6200 rpm at 62 ppm. In fuel blends No. 2, 4 and 6, where the amount of butanol and propanol is 20%, the amount of NOx is similar to the base fuel. In fuels with 10% butanol and propanol, the NOx process is similar in that the NOx decreases with increasing speed from 1000 to 1500 rpm and the NOx increase from 1500 to 2000 rpm. Also, the lowest NOx is related to fuel blend No. 5 at 1500 rpm. The temperature of the combustion chamber increases due to the increase of NO_X. High-pressure gases inside the cylinder during combustion, high temperature or both lead to the formation of nitrogen oxides in the combustion chamber. The amount of oxygen in pentanol may increase the oxygen inside the engine cylinder, which causes the formation of the NOx. In addition, lower cetane numbers, higher viscosity, density and volatility of pentanol cause more delay in combustion and greater fuel accumulation. Previous researchers have reported that NOx formation is mainly influenced by temperature, oxygen concentration and retention time and have similar results to the above experiment [47]. Also, another reason for the increase in NO_X can be related to engine load. As the engine load increases, the temperature inside the cylinder also increases, and as a result, NOx increase relative to higher engine loads [48].

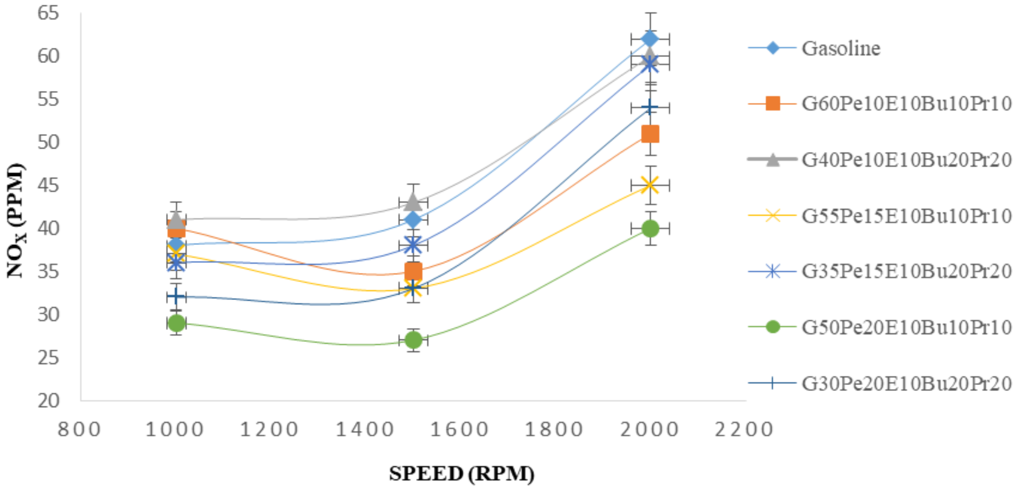

Fig 5a. NO_x emission

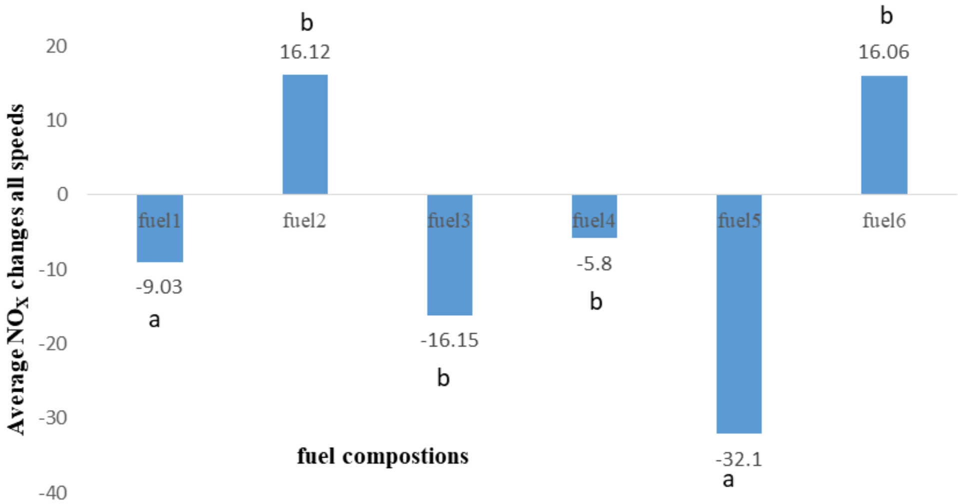

Fig 5b. Average NO_x changes at all speeds compared to pure gasoline.

Figure 5b shows the average value of NO_x changes compared to pure gasoline. The highest level of NO_x emissions is related to the fuel blend No. 2 with 16.12%. The lowest percentage change of NO_x compared to pure gasoline related to the fuel blend No.5 at 32.1%. In fuel blend No. 5 ($G_{50}Pe20E_{10}Bu_{10}Pr_{10}$) the amount of pentanol is higher than in fuel blend No.2 ($G_{40}Pe_{10}E_{10}Bu_{20}Pr_{20}$), which increases the combustion quality of mixtures. Therefore high latent heat of vaporization, oxygen content, lower calorific value and lower cetane number are the main features that reduce NOx emissions for pentanol blends [47]. The concentration of butanol in fuel blends also plays an important role in determining NOx emission levels. Increasing the concentration of butanol in the fuel blends leads to an increase in the total amount of pollutants emitted [42].

3.4.2 Unburned Hydrocarbon (UHC)

The release of hydrocarbons in the engine is an indicator of the quality of combustion. Fuel properties, fuel-to-air ratio, fuel injection characteristics and operating conditions are the factors that determine the formation of unburned hydrocarbons [49]. The change in UHC emission for fuel blends with different engine speeds is shown in Fig. 6a. UHC emissions are also affected by engine speed, compression ratio and alcohol concentrations in blends. As can be seen in Fig. 6a, the amount of UHC for the base fuel is decreasing and reaches its lowest level at 1500 rpm. Fuel blends 1, 3 and 5, which contain 10% propanol and butanol, respectively increased percentage of pentanol (10%, 15% and 20%) UHC emissions are reduced and are almost identical to base fuels. Also, fuel blends 2, 4 and 6 with 20% propanol and butanol, as the percentage of pentanol increases, the UHC emission rate UHC emission is increasing from 1000 to 1500 rpm and decreasing sharply from 1500 to 2000 rpm. Previous researchers have reported that lower percentages of butanol have a similar emission to pure gasoline and increase UHC emission levels by up to 18% as the amount of butanol increases [50-51]. Low HC emissions indicate that propanol-containing fuels burn well in the cylinder compared to unleaded gasoline, possibly due to the cooling effect of alcohols on the surface of the combustion chamber [52]. These results are similar to the results of previous researchers [53].

Figure 6b shows the lowest average UHC changes related to the fuel blend No. 1 at -14.89% compared to pure gasoline. Also, the highest average UHC changes are related to the fuel blend No. 2 at -6.15%.

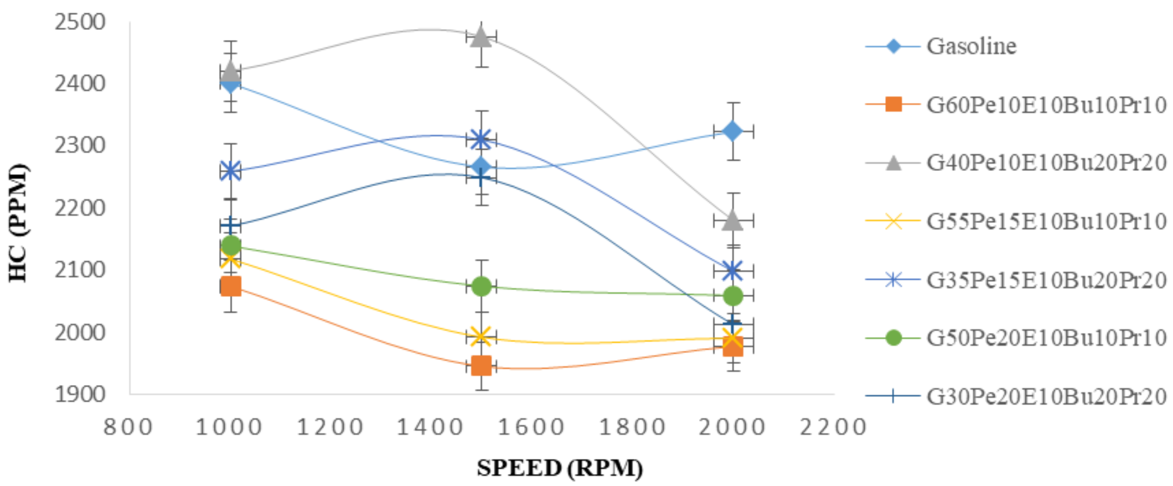

Fig 6a. HC emission

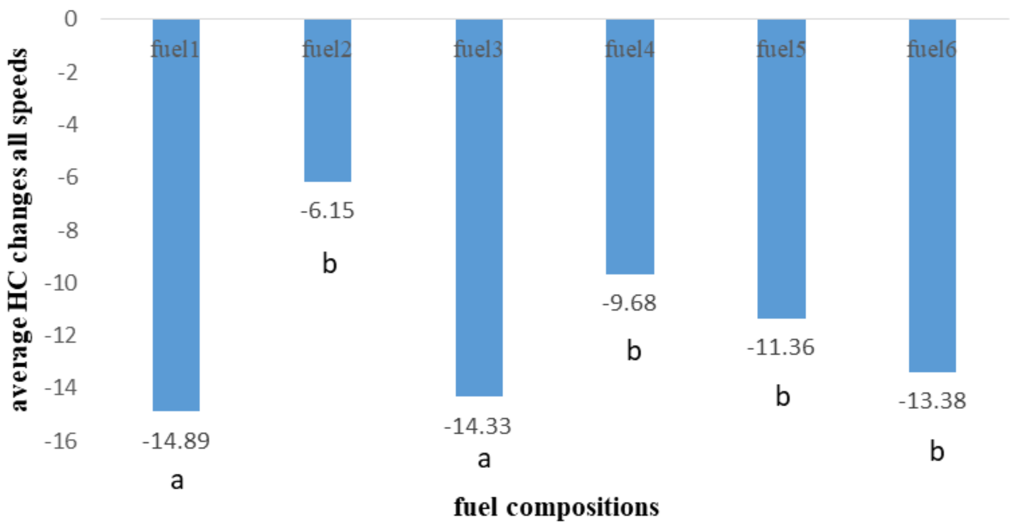

Fig 6b. Average HC changes at all speeds compared to pure gasoline

3.4.3 CO

According to Fig. 7a, the amount of CO produced from pure gasoline is relatively increasing from 1000 to 1500, and from 1500 to 2000 CO is reduced. In other fuel compounds in which butanol and propanol are used at a rate of 10%, considering the increase in the percentage of pentanol from 10% to 20%, the amount of CO pollutant increases. But in fuels that use 20% butanol and propanol, respectively, increasing the percentage of pentanol, the amount of CO pollutants decreases from 1000 to 1500 rpm. From 1500 to 2000 rpm, CO production is increasing. In similar experiments, the researchers found that increasing the percentage of butanol reduced CO emissions, which in general, insufficient oxidizing conditions or low combustion temperatures could lead to higher CO emissions [51]. Carbon monoxide is produced by incomplete combustion and when the oxidation process is not complete, the product is converted to carbon monoxide instead of carbon dioxide [56]. At low percentages of butanol, the amount of CO produced is less than that of pure gasoline. This low CO emission in fuel blends with a low percentage of butanol may be because if hydrocarbons can begin to oxidize, there is too much oxygen to continue the oxidation process [52]. Also, in the study of propanol content in previous studies, they found that in compounds that have less propanol content and at lower speeds, the amount of CO pollutants is low and with increasing speed, adding more propanol to the fuel increases the amount of CO [55]. The lowest amount of CO production related to fuel blend number 2 at 1500 rpm is 1.346.

Figure 7b shows that the highest average change in CO is related to the fuel blend No. 2 with 27.67%. Also, the lowest average change of CO compared to pure gasoline related to the fuel blend No. 5, at -9.21 Previous. Studies have shown that the higher the volume percentage of butanol added to gasoline, the higher the CO emission compared to gasoline [56]. They also showed that lack of oxygen should not increase CO emissions. Even if the high oxygen content of alcohol-containing fuels provides a higher combustion quality, more combustion products are produced in terms of heat capacity. It increases the combustion temperature and slows down the oxidation process of CO. In addition, butanol gasoline mixtures had a shorter combustion time. Therefore, insufficient oxidation of CO increased CO emissions [54].

3.4.4 CO_2

The curve of carbon dioxide changes in gasoline and alcohol fuel blends, about engine speed, is shown in Fig. 8a. The amount of CO_2 produced was measured in terms of volume percentage (V%) using a gas analyzer. CO_2 is a greenhouse gas that causes global warming and is produced from the complete combustion of hydrocarbon fuel. Its formation is influenced by the ratio of carbon to hydrogen in the fuel [54]. Fig. 8a shows that gasoline and alcohol fuel compositions show different behavior. The curve of fuel blends No. 1, 3 and 5 generally have lower CO_2 emissions than fuel blends No. 2, 4 and 6 because fuel blends No. 2, 4 and 6 have more butanol and propanol. And as was mentioned, the increase of oxygen in the fuel causes the increase in CO_2 emission, and from there the graphs of CO and CO_2 are opposite to each other, so the above results show the correctness of the work [54].

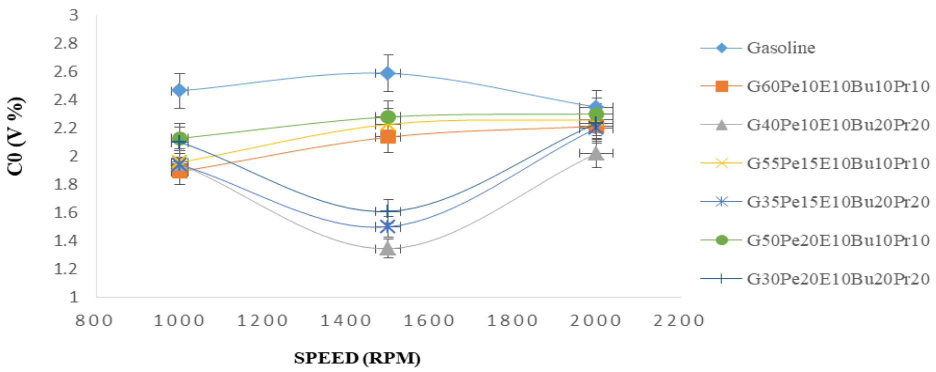

Fig 7a. CO emission

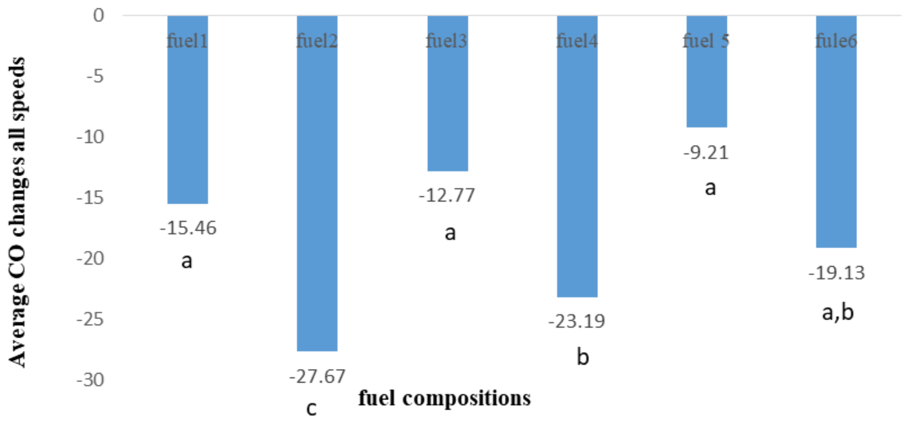

Fig 7b. Average CO changes at all speeds compared to pure gasoline.

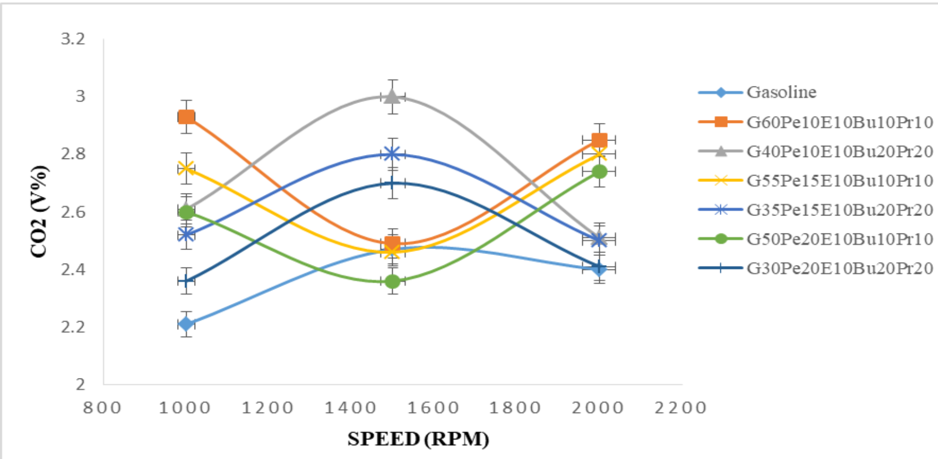

Fig 8a. CO_2 emission

The presence of excess oxygen in fuel compounds caused the complete combustion of the engine and reduced the amount of carbon dioxide. Therefore, with the increase in the concentration of existing alcohols, the amount of CO_2 in the exhaust has increased. Researchers found similar results regarding CO_2 increases using gasoline and alcohol fuel blends in spark ignition engines, which they attributed to complete fuel combustion [30].

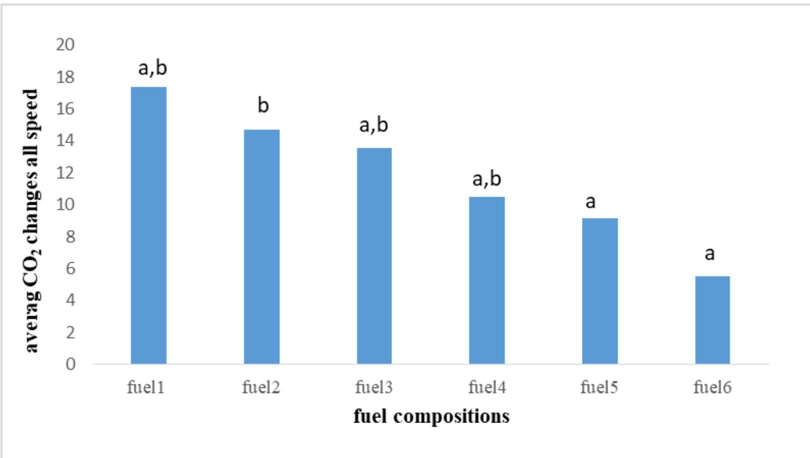

Fig 8b. Average CO_2 changes at all speeds compared to pure gasoline.

4. Conclusion

In this study, the performance and emissions of the gasoline engine with gasoline-alcohols including ethanol, propanol, pentanol and butanol fuel blend at different speeds were investigated. The following results were obtained from this study:

1. Engine power is increased by using the fuel compounds tested in this study and the lowest power is related to pure gasoline. The improvement in power obtained for fuels can be attributed to the presence of excess oxygen molecules in pentanol, which causes the complete combustion of the fuel inside the cylinder. The results of the average comparison with SPSS software showed that engine power in fuels with the highest percentage of alcohol has the highest average compared to other fuels.
2. The brake-specific fuel consumption of the engine is reduced by increasing the speed by using the gasoline-alcohol fuel blends. This is because the improvement in specific fuel consumption of the engine during the use of different fuel blends is due to the high calorific value of alcohols compared to gasoline fuel, which increases the overall combustion efficiency inside the engine combustion chamber.
3. Engine torque increases with increasing engine speed in fuel blends. The increase in torque is due to the presence of excess hydrogen in the structure of the alcohols used, as well as the high calorific value of alcohols compared to pure gasoline. The results of the average comparison with SPSS software showed that torque in fuels with the highest percentage of alcohol has the highest average compared to other fuels.
4. NOX emissions increase with increasing speed engine. Due to the increase in engine speed, the temperature in the combustion chamber increases and causes more nitrogen oxides to be produced The results of the average comparison with SPSS software showed that NO_X pollutants have the highest average in fuel blend No. 2.
5. In the UHC emission, the content of alcohol and the speed of the engine cause different behavior in the combustion chamber. Therefore, in fuel blends with low alcohol content, the amount of UHC decreases with increasing engine speed. Also, the amount of UHC for fuel compounds with low alcohol content is different at different speeds. The results of the average comparison with SPSS software showed that NO_X pollutants have the highest average in the fuel blend No. 2.
6. The amount of CO produced from gasoline-alcohol fuel blends shows that in blends containing Butanol and propanol 10%, it increases with increasing speed and the highest amount of CO is related to pure gasoline. Also, in fuel blends with 20% of Butanol and Propanol, the amount of CO is sharply reduced from 1000 to 1500 rpm and from 1500 to 2000 rpm is increased. The results of the average comparison with SPSS software showed that CO pollutants have the highest average amount of CO in pure gasoline.
7. The release of CO_2 pollutants in the tested fuel blends is different because there is less alcohol in fuel blends No.1, 3, and 5 than in fuel blends No. 2, 4, and 6. Therefore, increasing the amount of alcohol causes the presence of additional oxygen in the combustion fuel and more completely.

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