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Evaluation of the Effects of Methanol and Ethanol Additions on Performance and Emissions in a Spark Plug Ignition Engine Fueled with Gasoline

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Abstract

The aim of this experimental study was to investigate the effect of addition of methanol and ethanol (5% - 10% and 15%) as a fuel at low rates to gasoline fuel against performance, and emissions characteristics. The experiments were carried out in a single cylinder, four-stroke, air-cooled spark plug ignition engine at various engine loads (2 - 2.5 - 3 - 3.5 and 4 Nm) and constant engine speed (2500 rpm). Performance, and emission characteristics of gasoline, methanol-gasoline and ethanol-gasoline blends were evaluated. When the results are examined, with the addition of ethanol and methanol, the specific fuel consumption and specific energy consumption increased, while the brake thermal efficiency decreased. Apart from that, CO and HC emissions have improved. The lowest CO and HC emissions were obtained in G85M15 and G85E15 fuels, respectively. Compared to gasoline, a reduction in CO and HC emissions of over 50% was observed.

Keywords: Ethanol, Engine performance, Exhaust emissions, Methanol

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1. Introduction

Increasing industrialization and growing transportation and agriculture sectors around the world increase the demand for energy. Energy needs in transportation, agriculture, industry and etc. are mostly met from fossil fuels. It has been reported that the transportation sector is one of the areas with the highest energy consumption in the world [1, 2]. However, the increment in the use of petrol fuels causes concerns about the depletion of reserves. In addition, the formation of exhaust emissions caused using petrol fuels has increased environmental concerns [3-7]. The use of these fuels causes negative effects on both human health and the environment. For example, the spread of exhaust emissions from vehicles can cause acid rain, depletion of the ozone layer and climate changes. [3, 4, 8, 9]. Researchers have been working for a long time to impair the use of petrol fuels, which can be an alternative to petrol fuels with limited reserves. Nowadays, gaseous fuels such as LPG, CNG and alcohols such as methanol, ethanol and bioethanol are used as alternative fuels in spark ignition engines. The fact that alcohols such as methanol, ethanol and bioethanol can be produced from renewable, sustainable biomass sources and waste materials puts them in a strong position among alternative fuels. In addition, it can be said that these alcohols have a high potential for use IC engines due to the cheapness of raw materials and their physical properties similar to gasoline and diesel [10, 11]. Alcohols can have lower emission levels and better combustion performance thanks to the existence of oxygen in their molecular structure and high-octane number (~ 108). Alcohols have a high latent heat of vaporization. This makes the charge blends (alcohol-air) in the intake manifold cooler than the gasoline-air blends. Compared to the spark-ignition engine, the colder charge (alcohol-air blends) taken into the cylinder causes a decrease in NO_x emissions resulting from combustion [12, 13].

Methanol is one of the most popular alternative alcohol fuel. Moreover, according to many authorities and companies reported that methanol and other alcohol fuels will be the fuel of the future in the USA and around the world [14]. Methanol is a simple hydrocarbon with oxygen and hydrogen in its chemical structure, which can be easily obtained from lignite, coal, natural gas, and biomass sources such as waste biomass, agricultural biomass, wood waste [5, 6, 15-17]. In recent years, tons of methanol have been used as fuel and fuel blends in the field of energy applications, and this number is increasing every year [18, 19]. Methanol, which has a higher-octane number than gasoline, limits the operation of engine, allowing it to operate at high compression rates without knocking. It has a low boiling temperature, which provides the advantage for better fuel evaporation in cold engine operation, and has the highest hydrogen/carbon ratio, which ensures a lower carbon density of the fuel [20]. Although it is difficult to start the engine running with methanol added fuels when the engine is cold, the high evaporation temperature of methanol has a affirmative efficacy on increasing the volumetric efficiency of the engine. The high evaporation temperature feature of methanol also affects the combustion chemistry. A slight decrease occurs in the maximum in-cylinder pressure and temperature values. This ensures that exhaust emissions are reduced. Ethanol can be procured by fermentation process from agricultural products considered as biomass such as potatoes and sugar cane. Because it can be produced from biomass, it is considered a renewable, sustainable, and clean fuel. Its chemical structure consists of hydroxyl and ethyl groups attached to the carbon atom [21]. A high oxygen content can result in improved in-cylinder combustion and reduced CO-HC emissions [22]. Today, it is used at low rates as a fuel additive to gasoline in order to improve exhaust emissions [23]. With these properties, methanol, ethanol and other alcohol fuels have been the subject of many studies. Some of the experimental studies on spark-ignition engines operating with gasoline-methanol and gasoline-ethanol blends are summarized below.

Studies have been carried out all over the world for the use of gasoline, methanol, ethanol and blends in SI engines. Yanju et al. [5] deduced that the gasoline-methanol mixture markedly enhances the thermal efficiency of the engine. Sapre [24] reported similar results with the addition of methanol 30%, 50% and 70% by volume to gasoline. Shayan et al. [25] reported that engine performance (brake torque, brake power, thermal efficiency and volumetric efficiency) considerably improves with increasing methanol addition (contains 5 - 7.5 - 10 - 12.5 and 15% methanol). In contrast, Bardaie and Janius [26] reported a power loss of by 5% when the spark-ignition engine was run with 100% methanol. Bilgin and Sezer [27] examined the effect of leaded and unleaded methanol-gasoline blends on the performance characteristics. They reported that the augmentation of methanol enhanced the performance and the maximum brake mean effective pressure (BMEP) was achieved using M5 fuel. Zaid et al. [28] stated that the addition of methanol to gasoline can be used in engines with high compression ratios, since it increases the octane number. Balki et al. [29] have compared the effect of alcohol blends. They reported that the use of alcoholic fuel increases engine torque, brake specific fuel consumption, thermal efficiency. Al-Hasan [30] researched the effects of ethanol-gasoline blends on the performance of a four-cylinder spark-ignition engine at variable engine speeds (1000-4000 rpm) and loads. Experiment findings showed that the use of ethanol increased the volumetric efficiency, thermal efficiency, braking torque and power, and decreased the equivalent air-fuel ratio and specific fuel consumption. Kamil and Nazzal [31] examine the performance parameters of three different gasoline-alcohol blends (88% gasoline - 12% methanol, 88% gasoline - 12% ethanol and 88% gasoline - 6% methanol-6% ethanol) in a single-cylinder spark-ignition engine running under different engine operating conditions. They stated that BTE and BSFC increased, and exhaust gas temperature decreased in fuel blends compared to gasoline fuel. Koc et al. [32] resourced the influences of ethanol-gasoline mixtures at 0%, 5% and 85% volumetric ratios on performance. When the performance results were examined, it was observed that the engine torque, power, and fuel consumption increased. Similarly, Costa and Sodre [33] and Kumbhar et al. [34] observed improvements in engine torque and power in their experiments with low proportions of ethanol-gasoline mixtures. Chen et al. [35] reported that the adjunct of methanol induce an development in the BTE fueled with natural gas/methanol.

Most of the researchers examining the exhaust emissions on the methanol-gasoline and ethanol-gasoline mixture reported that while they observed that the CO and HC emissions improved, they could not observe a clear trend on the NO_x emissions [36, 37]. Shayan et al. [25] stated that the adjunct of methanol to gasoline significantly improved CO and HC emissions, while CO_2 and NO_x emissions worsened. Hseih et al. [38] studied the effects of ethanol-gasoline mixtures on emissions at variable engine speeds and throttle openings. In the study, ethanol was added to gasoline at a rate of 0%, 5%, 10%, 20% and 30% by volume. When the test findings were analyzed, it was observed that HC and CO emissions decreased with the addition of ethanol. Similar results for HC and CO emissions were obtained by Al-Hasan [30] and Lodice et al. [22]. Cetinkaya and Celik [39] stated that significant reduction in NO_x and carbon monoxide (CO) emissions for methanol-gasoline fueled engines however slight increase in hydrocarbon (HC) emissions. Yanju et al. [5] observed that a high addition of methanol (M85) improved CO and NO_x emissions by 23% and 80%, respectively. Kamil and Nazzal [31] reported that alcohol blended fuels can be recommended to reduce emissions. Elfasakhany [4] reported that CO and HC (hydrocarbons) emissions significantly reduced compared to gasoline using ethanol-methanol-gasoline blends in a SI engine. He also stated that Methanol-gasoline blends have taken the lowest CO and UHC emissions among all test fuels. Balki et al. [29] indicated that the use of alcoholic fuel decreases HC, CO and NO_x emissions. Chen et al. [35] indicated that the addition of methanol increase the NO_x emissions, and improve in the total HC emission fueled with natural gas/methanol.

In this experimental study, the effect of methanol and ethanol addition to gasoline at low rates in the way of engine performance and exhaust emissions was examined. Experiments were performed using pure gasoline as reference and some methanol-gasoline and ethanol-gasoline blends such as M5 (5% methanol - 95% gasoline), M10 (10% methanol - 90% gasoline) and M15 (15% methanol - 85% gasoline); E5 (5% ethanol - 95% gasoline), E10 (10% ethanol - 90% gasoline) and E15 (15% ethanol - 85% gasoline). The tests were implemented at constant engine speed and different engine loads on a single-cylinder, air-cooled, carbureted, small SI engine.

2. Experimental Methods

2.1 Experiment engine, conditions, and procedure

The experimental study was implemented in the Automotive Laboratory of the Mechanical Engineering Department at Selcuk University. In the tests, a four-stroke, air-cooled, carburetor fuel system spark-ignition engine was used. The technical properties of the test engine used in the experimental study are given in Table 1 [40].

Table 1. Engine specifications

No. of Cylinder	1
Swept volume	0.148 L
Bore x stroke	65.1 mm x 44.4 mm
Compression ratio	7:1
Engine speed interval	2000-3000 rpm
Maximum engine power	1.2 kW
Maximum engine torque	4.5 Nm
Ignition timing	25° bTDC

Nowadays, it can be said that carburetor engine technology is not up to date, but studies are still ongoing for the development of carburetor engines, see e.g., [4, 40-45].

To load the test engine under different load conditions, the engine is connected to a drive and brake unit. GUNT brake and drive unit is shown in Figure 1. The drive and brake unit consists of a 2.2 kW three-phase asynchronous motor. The asynchronous motor is controlled by a frequency converter. The motor torque was read and adjusted from the digital display on the modular test setup. Fuel consumption was calculated from the measuring tube on the modular test stand with a stopwatch. The modular test stand can display parameters such as air flow, air temperature, fuel temperature, oil temperature and exhaust gas temperature on the digital screen. O_2, CO_2, CO and HC emissions were measured with Mobydic 5000 brand exhaust emission device. The measurement ranges and accuracies of the exhaust gas analyzer used to gauge the exhaust emissions are presented in Table 2.

Table 2. Features of exhaust gas analyzer

Measurements	Ranges	Accuracies
CO (vol.%)	0-10	0.01
HC (ppm)	0-2000	1
NO_x (vol.%)	0-5000	1
Lambda	0.5-2.0	0.001

The experiments were carried out after the engine reached operating temperature. The engine speed is set at 2500 rpm, the ignition advance is 25° bTDC and the compression ratio is 7: 1. The tests were carried out with G100 followed by M5, M10, M15 and E5, E10, E15 fuel blends at various engine loads (2 Nm, 2.5 Nm, 3 Nm, 3.5 Nm and 4 Nm).

Fig. 1. GUNT drive and brake test unit

2.2 Test fuels

In the experimental, gasoline was procured from a local petrol station as the main fuel. The methanol was supplied from a local firm that sells chemical products. Fuel mixing ratios were adjusted in graduated measuring cups at room temperature conditions. Some physical characteristics of each test fuels used in the experimental study are presented in Table 3.

Table 3. Some physical characteristics of test fuels [46, 47].

Test Fuels	Lower heating value (MJ/kg)	Density (15°C kg/m^3)	Viscosity (40 °C mm^2/s)
G100	42.582	841.5	0.565
Ethanol	26.751	788.4	1.196
Methanol	23.114	792.4	0.711
G95E5	41.815	735.52	0.593
G90E10	40.901	738.09	0.618
G85E15	40.062	739.85	0.628
G95M5	41.415	735.17	0.587
G90M10	40.317	736.23	0.613
G85M15	39.136	739.52	0.689

3. Results

3.1. Engine performance

The BSFC values calculated for different test fuels in the case of running engine at five particular engine loads and 2500 rpm engine speed, which is maximum torque speed, are shown in fig. 2. As a consequence of the experimental study, the lowest BSFC values for all test fuels were acquired at 2.5 Nm engine load. Fuel with the lowest BSFC value is gasoline with the value of 525.59 g/kWh.

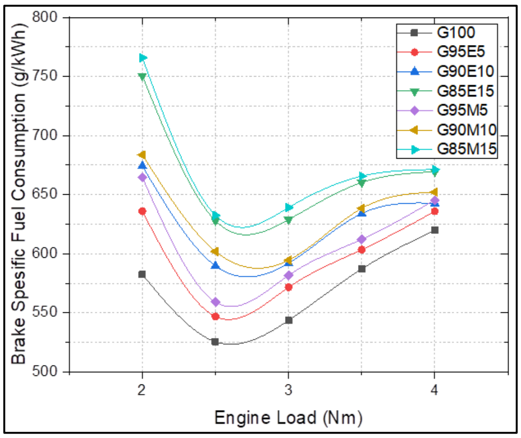

Fig. 2. Break specific fuel consumption (BSFC) variation for all test fuels at different engine loads

BSFC changes compared to gasoline for all fuels used in the experiments are shown in Figure 3. It is seen that methanol and ethanol additives to gasoline cause an increase in specific fuel consumption. It was marked that the highest specific fuel consumption for all load conditions occurred in G85E15 and G85E15 mixtures with high alcohol content. The low calorific value of the methanol and ethanol used in the experiments also reduces the calorific value of the blended fuels. When the literature is examined, there are studies showing that this situation causes an augmentation in specific fuel consumption [10, 11, 47].

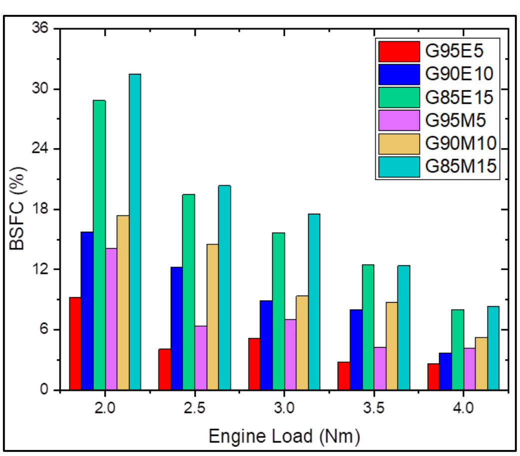

Fig. 3. BSFC variations of all blended fuels compared to gasoline for different load conditions

Brake specific energy consumption (BSEC) values calculated for all test fuels in relation to the measured fuel consumption, lower heating values and power are shown in Figure 4. When the data procured for five different engine loads were examined, the lowest BSEC was found to be 22.38 MJ/kWh at 2.5 Nm with gasoline. It was observed that the BSEC value tended to raise with the augmentation in the ratio alcohol. BSEC changes compared to gasoline for all blended fuels used in the experiments are shown in Figure 5. Methanol and ethanol have an increasing effect on BSEC because of the lower heating value compared to gasoline and consequently the amount of fuel consumed increases. Agarwal et al. [10] showed that owing to the lower heating value there was a decreasing trend in the quantity of heat energy released after combustion in the cylinder with the use of methanol, and consequently an increase is detected both fuel consumption and BSEC.

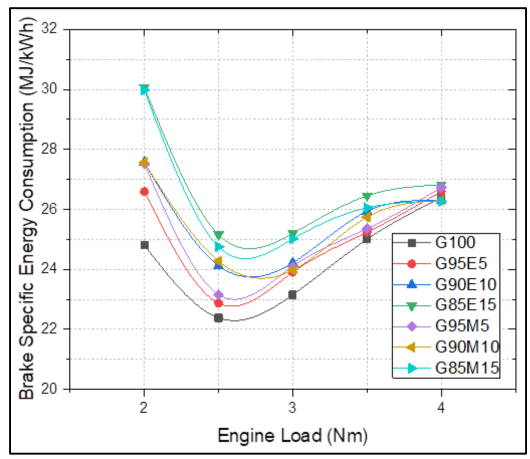

Fig. 4. Brake specific energy consumption (BSEC) variation for all test fuels at different engine loads

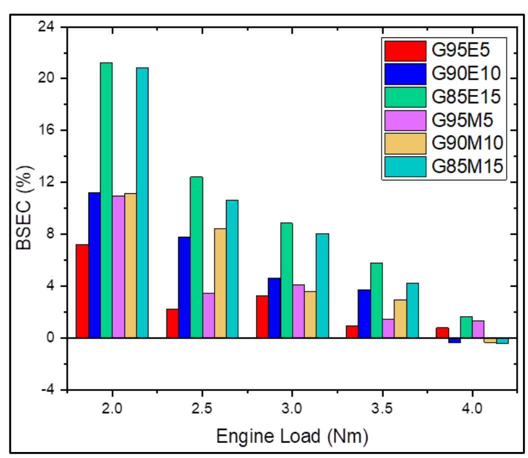

Fig. 5. BSEC variations of all blended fuels compared to gasoline for different load conditions

The variation in brake thermal efficiency (BTE) values of all test fuels depending on engine load are given in Figure 6. When the data procured for five different engine loads were analyzed, the highest BTE value was found to be 16.08% at 2.5 Nm with gasoline. It is seen that with the augmentation in the ratio of alcohol BTE values showed that tent to decrease. BTE changes compared to gasoline for all blended fuels used in the experiments are shown in Figure 7.

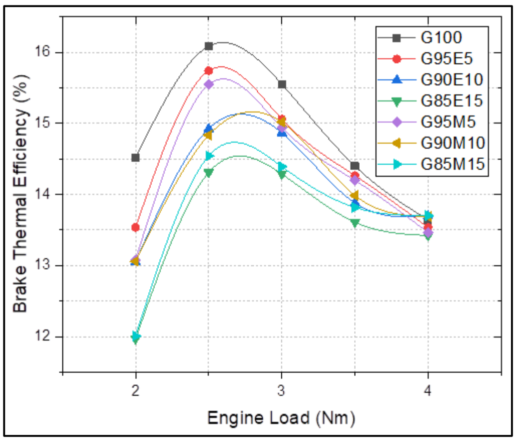

Fig. 6. Brake thermal efficiency (BTE) variation for all test fuels at different engine loads

The lower thermal value of the methanol causes the engine to consume more fuel per unit time in order to acquire an equivalent quantity of power under the same working provisions with gasoline. Since the quantity of fuel taken into the combustion chamber in a cycle is nearly the same for all test fuels and the mixture fuels have a lower sub-thermal value than gasoline, the quantity of energy generated in the end-combustion cylinder diminishes, so the engine output power decreases. Since this diminishing engine output power was procured with the same quantity of fuel, the BTE values of the engine were also diminish in the calculations. When the literature is examined, some researchers have stated the results that BTE decreases with the use of methanol and ethanol [10, 47].

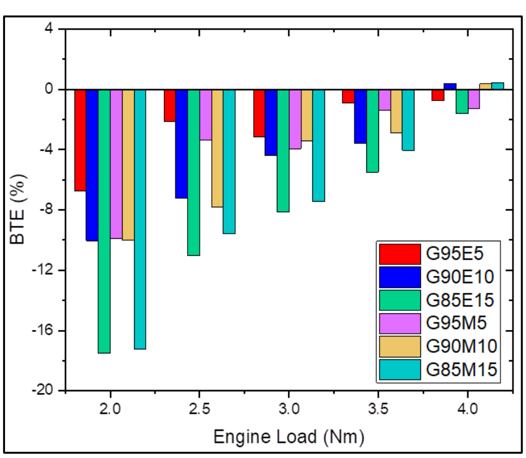

Fig. 7. BTE variations of all blended fuels compared to gasoline for different load conditions

The engine load-dependent exhaust gas temperature values are shown in Figure 8. In the experiments, the exhaust gas temperature is an substantial parameter to determine the combustion quality of the fuels taken into the cylinders and the exhaust emissions of them. The highest EGT value was found to be 489.7 ° C at 2.5 Nm with methanol. Such an augmentation in the exhaust gas temperature is a result of increasing the combustion efficiency by increasing the oxygen content of methanol in a positive way. EGT changes compared to gasoline for all blended fuels used in the experiments are shown in Figure 9. Depending on the augmentation in engine load, more fuel should be sent to the cylinders at the same speed. This is not enough time for the combustion to be sent to the cylinders. Therefore, due to lack of time, fuel is not complete burned and exhaust gas temperature decreases.

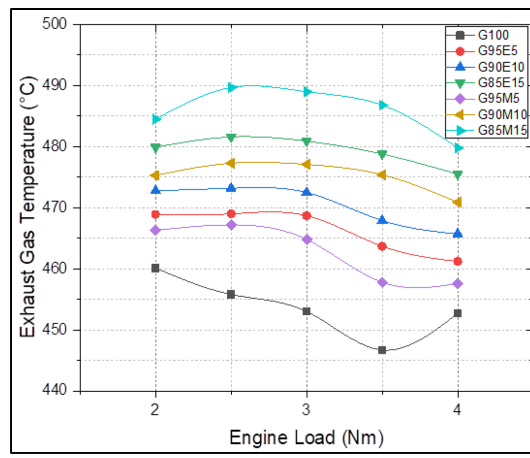

Fig. 8. Exhaust gas temperature (EGT) variation for all test fuels at different engine loads

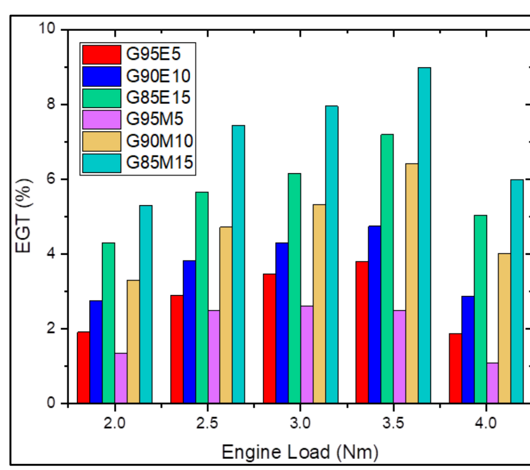

Fig. 9. EGT variations of all blended fuels compared to gasoline for different load conditions

3.2. Exhaust emissions

The amount of oxygen released as a consequence of combustion is affected by both the chemical content of the fuel and the quantity of air taken into combustion chamber. The higher the quantity of oxygen in the chemical content of the fuel used, the higher the amount of oxygen released. In addition, the high oxygen content of alcoholic fuels directly affects the stoichiometric ratio. In Figure 10, the O_2 emission changes for different engine loads in experiments with gasoline, methanol and ethanol fuels are presented. Owing to the high oxygen ingredient of methanol and ethanol, the highest O_2 emissions were obtained in these two fuels compared to gasoline. Similar results were obtained by Yelbey and Ciniviz [47]. O_2 emissions change compared to gasoline for all blended fuels used in the experiments are shown in Figure 11.

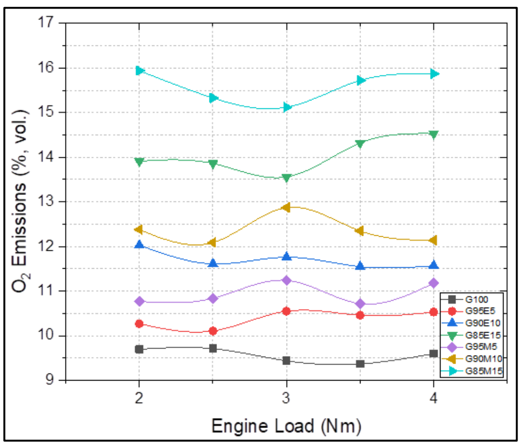

Fig. 10. O2 variation for all test fuels at different engine loads

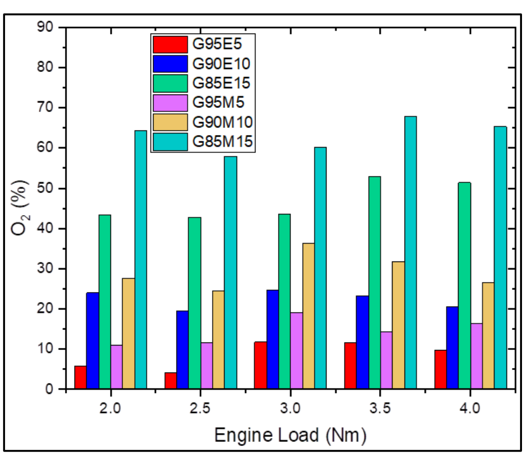

Fig. 11. O_2 variations of all blended fuels compared to gasoline for different load conditions

In Figure 12, CO_2 emission changes are presented for different engine loads in experiments with gasoline, methanol and ethanol fuels. CO_2 emission can give us information about combustion efficiency. The fact that CO_2 emissions are high gives an idea that the combustion is close to complete. The highest CO_2 value was obtained with G85M15 blended fuel at 4 Nm. The lowest CO_2 value was obtained with G100 fuel at 3 Nm. CO_2 emissions change compared to gasoline for all blended fuels used in the experiments are shown in Figure 13.

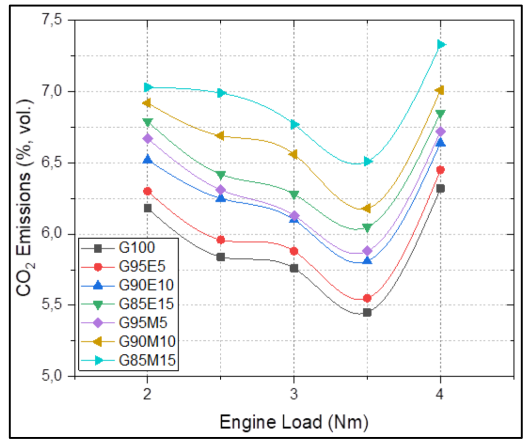

Fig. 12. CO_2 variation for all test fuels at different engine loads

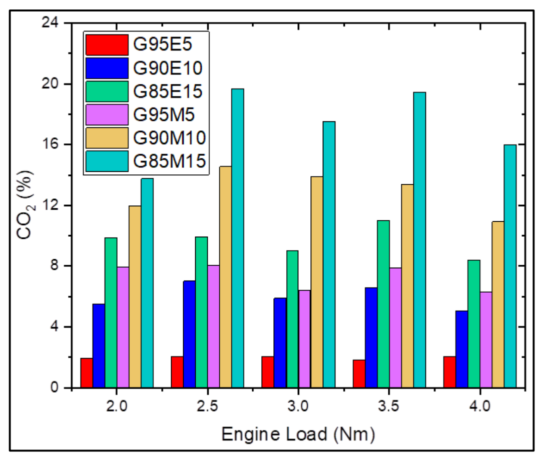

Fig. 13. CO_2 variations of all blended fuels compared to gasoline for different load conditions

The CO emission values associated with engine load are shown in Figure 14. When the engine being worked with gasoline, the lack of oxygen in the chemical structure of the fuel prevents complete combustion and CO emissions are emitted instead of CO_2 as exhaust emissions. It requires more fuel to burn during the same time period owing to engine load increase. The greater quantity of fuel in the combustion chamber cannot burn quickly due to lack of time in the cycle. This increases CO emissions due to increased engine load. Higher CO values were obtained for G100 fuel under all load conditions. Since methanol and ethanol have oxygen in its chemical structure, it provides the missing oxygen during the combustion event and causes decrease in CO emissions. The lowest CO values were achieved with G85M15 fuel. CO emissions change compared to gasoline for all blended fuels used in the experiments are shown in Figure 15.

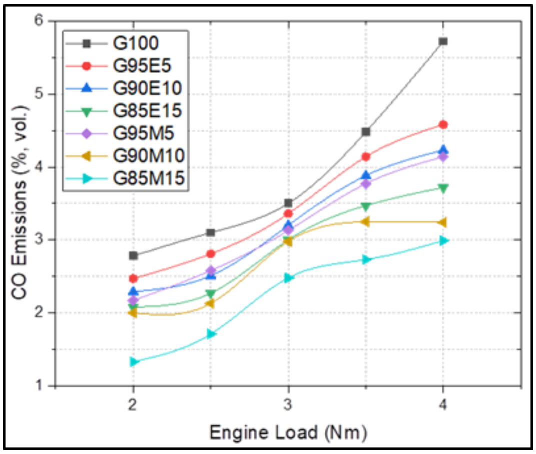

Fig. 14. CO variation for all test fuels at different engine loads

Researchers have also stated that methanol and ethanol are burned close to complete combustion owing to the oxygen ingredient in its chemical structure and thus a reduction occurs in CO emissions [47-49].

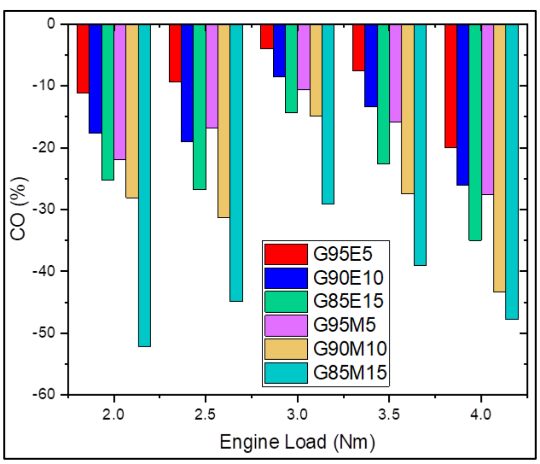

Fig. 15. CO variations of all blended fuels compared to gasoline for different load conditions

In Figure 16, HC emission values related to engine load are given. When gasoline fuel is used, when adequate oxygen is not received into the cylinder, the hydrogen atom cannot find enough oxygen atoms to react. Consequently, since combustion will not be complete, HC emission will occur. Methanol and methanol break off hydrogen atoms from carbon atoms during combustion and reacts with oxygen atoms to cause combustion. Thus, the combustion approaches to completion. When Figure 16 is examined, the highest HC emissions were obtained with the G100 under all load conditions. The lowest HC emissions were obtained with the G85E15 mixture at 2.5 Nm. The oxygen content of alcohol fuels reduced HC emissions. HC emissions change compared to gasoline for all blended fuels used in the experiments are shown in Figure 17. When Figure 17 is examined, it is seen that there is an improvement of over 50% in HC emissions. When the literature is examined, results showing that methanol reduces HC emissions have been reported [11, 29, 47].

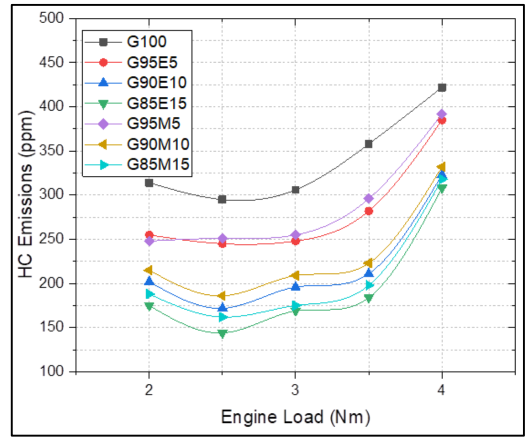

Fig. 16. HC variation for all test fuels at different engine loads

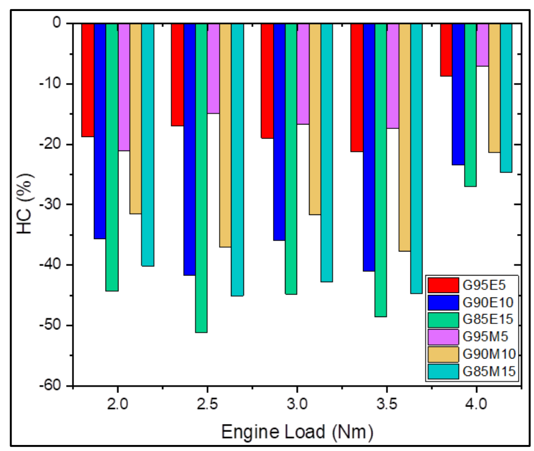

Fig. 17. HC variations of all blended fuels compared to gasoline for different load conditions

4. Conclusion

In this study, the effects of gasoline, gasoline-methanol and gasoline-ethanol blends on engine performance and exhaust emissions are examined and the results are listed below.

- Although methanol, ethanol and gasoline have similar specialties, the lower thermal value of their is the most important parameter that adversely affects engine performance.
- BSFC and BSEC increased with the addition of methanol and ethanol. The highest increase for BSFC was over 30% at 2 Nm engine load with G85M15 fuel. The highest increase for BSEC was over 20% with G85E15 fuel at 2 Nm.
- BTE value tended to decrease at 2, 2.5, 3, 3.5 Nm engine loads with alcohol fuel (methanol and ethanol) use. The lowest BTE value was above 16% at 2 Nm with G85E15 and G85M15 fuels.

- Methanol and ethanol, contains oxygen in its chemical structure, resulting in a cleaner combustion than gasoline, reduce pollutant exhaust emissions. The lowest CO emissions were above 50% at 2 Nm with the G85M15. The lowest HC emissions were above 50% with the G85E15 at 2.5 Nm.

As a result, it can be said that the specific fuel consumption, specific energy consumption, HC and CO emission results of 10% addition of methanol and ethanol by volume are close to each other. The performance of 10% addition of ethanol was slightly better than the same amount of methanol. Addition of more than 10% alcohol by volume improves emissions but worsens engine performance. Therefore, adding 10% ethanol or methanol by volume is considered as the optimum ratio.

Today, it is used in many countries, especially by mixing ethanol with gasoline in small proportions. The use of ethanol and methanol by mixing with gasoline at higher rates or as the sole fuel can be investigated. In this way, testing of fuels with high alcohol blends will increase the ethanol and methanol ratios used in gasoline vehicles.

Abbreviations

BSEC	: Break specific energy consumption
BSFC	: Break specific fuel consumption
BTE	: Break thermal efficiency
CO	: Carbon monoxide
CO_2	: Carbon dioxide
G95E5	: Gasoline 95%+Ethanol 5%
G90E10	: Gasoline 90%+Ethanol 10%
G85E15	: Gasoline 85%+Ethanol 15%
EGT	: Exhaust gas temperature
G100	: Gasoline 100%
HC	: Hydrocarbon
G95M5	: Gasoline 95%+Methanol 5%
G90M10	: Gasoline 90%+Methanol 10%
G85M15	: Gasoline 85%+Methanol 15%
O_2	: Oxygen
SI	: Spark ignition

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the present paper.

CRediT Author Statement

İlker Örs: Conceptualization, Supervision, Validation, Editing,
Halil Erdi Gülcan: Conceptualization, Writing-original draft, Data curation, Formal analysis,
Bahar Sayın Kul: Data curation, Formal analysis,
Savaş Yelbey: Writing-original draft, Data curation, Formal analysis,
Murat Ciniviz: Project coordinator.

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