e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage:

https://dergipark.org.tr/en/pub/ijaet

Original Research Article

Experimental evaluation of gasoline-hexane fuel blends usage in a spark ignition engine

Tolga Kocakulak[1], Nurettin Mert Boyacıoğlu[2], Yusuf Dağoğlu[3], Ahmet Uyumaz[4, *], Fatih Aksoy[5], Emre Arabacı[6]

[1]Burdur Mehmet Akif Ersoy University, Technical Sciences of High Vocational School, Hybrid and Electric Vehicles Program, Burdur, Türkiye.
[2] Burdur Mehmet Akif Ersoy University, Graduate School of Natural and Applied Sciences, Department of Mechanical Engineering, Burdur, Türkiye.
[3, 4 *] Burdur Mehmet Akif Ersoy University, Engineering Architecture Faculty, Department of Mechanical Engineering, Burdur, Türkiye.
[5]Afyon Kocatepe University, Faculty of Technology, Department of Automotive Engineering, Afyonkarahisar, Türkiye.
[6]Pamukkale University, Technology Faculty, Department of Automotive Engineering, Denizli, Türkiye.

ARTICLE INFO

Orcid Numbers

1. 0000-0002-1269-6370
2. 0009-0002-8337-451X
3. 0009-0007-1555-8751
4. 0000-0003-3519-0935
5. 0000-0003-0877-9373
6. 0000-0002-6219-7246

Doi: 10.18245/ijaet.1382927

* Corresponding author
auyumaz@mehmetakif.edu.tr

Received: Dec 29, 2023
Accepted: Mar 14, 2024

Published: 27 Mar 2024

Published by Editorial Board Members of IJAET

ABSTRACT

In the present study, the influences of hexane addition to gasoline were researched on performance and exhaust emissions in a SI engine. It was aimed to increase engine performance and thermal efficiency of spark ignition engine. So, a single cylinder, four stroke SI engine was operated with gasoline and gasoline/hexane fuel volumetric mixtures (H10, H20, H30 and H40) at wide opening throttle (WOT) and 4000, 3600, 3200, 2800 and 2400 rpm. It was seen that engine torque and power output decreased while SFC increased with the addition of hexane in the fuel blends. Engine torque decreased by 5.69%, 7.66%, 10.80%, 14.86% with H10, H20, H30 and H40 compared to gasoline at 2800 rpm grespectively. Thermal efficiency declined by 3.27%, 7.50%, 8.95% and 11.12% using H10, H20, H30 and H40 test fuels compared to gasoline at 2800 rpm respectively. Higher CO and HC were measured with fuel blends according to gasoline for all test fuels. CO reduced by 3.77% with H40 compared to H10 at 3200 rpm. On the contrary, CO_2 increased by 16.49% with H40 compared to H10 at 3600 rpm. HC increased by about 21.26% H40 compared to H10 at 3200 rpm. Although there is no positive difference on exhaust emissions and thermal efficiency is reduced, gasoline/hexane fuel mixtures can be used without modifications in SI engines.

Keywords: Spark ignition engine, Hexane, Engine performance, Exhaust emission.

1. Introduction

The increasing urbanization, industrialization, and world population have led to an excessive increase in transportation demand. Currently, a large part of this transportation demand is met by internal combustion engines (ICE). As it is known, ICEs operate with fossil fuels such as gasoline and diesel. The rapid increase in fossil fuel consumption leads to air pollution, climate change, and a continuous increase in global carbon emissions [1]. Data from the WRI determined that the transportation sector is the second sector that causes the most greenhouse gases after electricity production [2]. It is a well-known fact that the production of electric and hybrid vehicles in the transportation sector is increasing to reduce emissions, and their use is also increasing every day. Since a large part of the hybrid vehicles used in the world contain spark ignition engines and electric motors, Spark ignition engines need to be improved due to lower exhaust emissions and better operation in cold conditions compared to diesel engines. Çelik et al. [3] observed that adding n-hexane additive to diesel, cotton methyl ester and canola methyl ester, in different proportions increased the engine torque and power in diesel and biodiesels, and at the same time reduced fuel consumption. They are claimed that n-hexane additive reduces CO, HC, and smoke emissions. However, they determined that nitrogen oxide (NO_x) emissions increase. Vural et al. [4], analyzed the influences of diesel fuels (D90W5H5 and D85W5H10) mixed with different ratios of hexane and water in ceramic-coated and uncoated diesel engines. The usage of diesel fuels mixed with hexane and water has been presented to provide improvements on emission and performance. They reported that NO_x, HC, CO, BSFC values decreased, while exhaust gas temperature (EGT) and CO_2 values increased. Kumar et al. [5] experimented the influences of blending WPF and jatropha biodiesel with diesel in view of emissions and performance. The results of adding hexane to these mixtures have also been examined. They found that hexane-added mixtures provide higher thermal efficiency, lower fuel consumption, and lower CO and NOx. However, they determined that HC emissions increase. The best performance and emission were obtained in the blend coded D65HX5WPF10JB20. Gonca et al. [6] researched the emissions and performance of the mixtures of butane, propane and liquid hydrogen, methane with gasoline, hexane, isooctane, benzene, ethanol, toluene and methanol fuels. It was seen that the rates of methane, butane, hydrogen, and propane significantly influenced the performance. Nour et al. [7] conducted studies by mixing diesel fuel and n-hexanol in different proportions. Diesel and n-hexanol fuels were mixed in five different ways: 10%, 20%, 30%, 40%, and 50% by volume, without any changes to the fuel system. It was found that n-hexanol addition to diesel fuel caused to increase ID and BTE for diesel was higher by 0.6% than diesel/n-hexanol mixtures. BSFC of the Hex50 blend was determined to be 6.4% higher than diesel at full load. They stated that smoke opacity and NOx decreased by 54% and 26%, respectively, for the Hex50 blend at full load. Aydoğan [8] examined the performance, combustion and emissions obtained using n-hexane/n- heptane mixtures, n-heptane and n-hexane in a HCCI engine. According to the results, He stated that HC emissions increase as lambda increases, while CO emissions decrease. He stated that the ignition delay and start time were delayed with n-hexane because of high octane number. SFC was reported to be higher for n-heptane than for n-hexane because of higher density of n-heptane. Yılmaz [9] investigated the influences of the air excess coefficient on performance and combustion in a HCCI engine running on hexane and n-heptane fuel mixtures. He stated that hexane fuel makes it easier to control HCCI combustion due to its higher octane number and lower combustion heat compared to n-heptane, and allows operation at lean mixture ratios. At the same time, He observed that emissions (HC and CO) decreased, while thermal efficiency first increased and then decreased. Çelik and Bayındırlı [10] studied motor performance and emission values by adding n-hexadecane and n-hexane additives at different ratios to eliminate the disadvantages of steel and reinforced biodiesel. They noted that engine torque and BP increased with the rise in additive ratio. On the other hand, specific fuel consumption has been reported to decrease. HC, smoke, and CO emissions reduced; they observed that NOx increased. Şimşek et al. [11] observed the influences of hexane addition to a gasoline-alcohol blend in a SI engine. 1-3% hexane was added to the determined fuel blend and its influence was examined. After the addition of hexane, they observed that there was an improvement on SFC. They stated that engine performance deteriorated with increasing hexane addition. They observed that with the addition of 1% hexane, there was a reduction on HC and CO compared to gasoline fuel, no significant change in NOx emissions, and a rise in CO_2. Bayındırlı et al. [12] added n-hexane to biodiesel produced by the transesterification method from cottonseed oil at volumes of 4%, 12%, and 20%, and examined engine performance and emission data. In the experiment, they observed that BP and engine torque increased with the fuels added with additives, and SFC decreased. They also stated that the heat release rate and cylinder pressure rised as the additive ratio increased. While NOx emissions increased proportionally with the additive ratio, they mentioned that HC, CO and smoke decreased. Bose et al. [13] aimed to optimize emission and performance of diesel engine at various loads with ethanol-hexane-diesel mixtures at various ratios. They found that the optimal input condition for 95% full load operation gave an absolute error of 15.3% in NOx, 1.69% in CO, 17.1% in HC, and 3.4% in BSFC prediction, with 40% ethanol mixed with diesel, 5% hexane, and 15% DEE. Gonca [14] examined the effects of various fuel types such as hexane, gasoline, benzene, isooctane, propane, toluene, methane, hydrogen, ethanol and methanol and engine design parameters. He stated that toluene provides the highest BP and hexane provides the highest BTE. He found that benzene causes the highest NO formation and hydrogen has the lowest performance and NO values. Balamurugan and Nalini [15] analyzed diesel engine performance by mixing diesel with n-hexane and n-pentane in ratios of 4%, 6%, and 8%. They observed that the hexane mixture provided higher performance and lower emissions compared to the pentane mixture. Gonca et al. [16] indicated that when mixed with hexane, hydrogen, methane, or propane, it can enhance the engine's power output, thermal efficiency, and exergy efficiency. However, they have also reported that the equivalent ratio of these mixtures and fuel temperature can have a significant negative impact on performance. Additionally, they have observed that it can contribute to the formation of polycyclic aromatic hydrocarbons during combustion, thus potentially increasing NOx emissions. Previous studies showed that the addition of hexane to diesel, biodiesel, and gasoline fuels affects emissions, but its impact on engine performance is not significant. However, the effect of hexane in spark ignition engines has remained a relatively neglected line of inquiry than in diesel engines. The primary distinction of this paper from the existing literature studies is an examination of the effect of hexane added to gasoline by volume mixing at varying ratios on engine performance and emissions in SI engines. The objective of the study was not only to contribute to the existing literature but also to investigate the positive and negative effects of gradually increasing the amount of hexane in gasoline through experimental testing in an internal combustion engine.

2. Material and Method

The tests were conducted at the Automotive Laboratory of Burdur Mehmet Akif Ersoy University, Technical Sciences of Vocational School. The schematic view of the engine test bed and test environment are given in Figure 1.

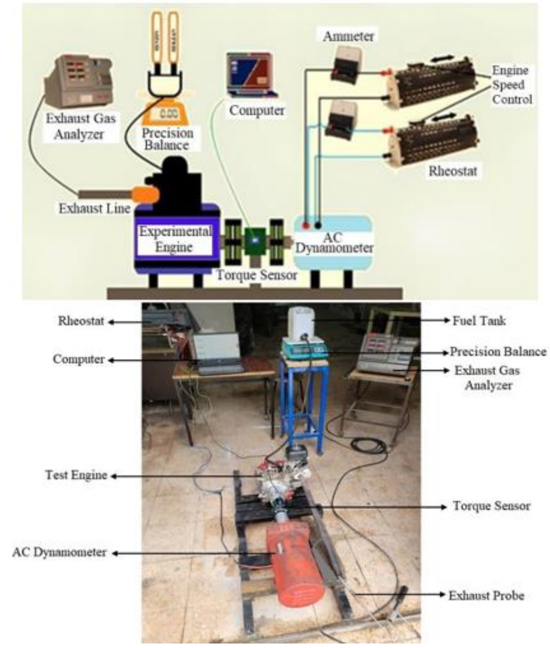

Figure 1. Schematic view of the engine test bed and test environment

To experimentally investigate the influences of gasoline and hexane fuel blends on emissions and engine performance, a single-cylinder, spark-ignited, air-cooled engine, whose features are presented in Table 1, was used.

The engine has been heated up before starting the experiments. All measurements were made while the engine was at operating temperature. Experiments were conducted at wide opening throttle, in the full load speed characteristic method, with gasoline and gasoline-hexane volumetric mixtures at 4000, 3600, 3200, 2800 and 2400 engine speeds. Engine was loaded safely at minimum 2400 rpm with the AC dynamometer and rheostat. Engine torque could be measured accurately up to 2400 rpm. All test fuels and volumetric mixture ratios are given in Table 2. Test fuels and their properties can be seen in Table 3.

Table 1. Technical properties of the test engine

Determination	Descriptions
Model	GX 160
Engine	4 Stroke - Overhead Valve - Single Cylinder
Diameter x stroke (mm)	68x45
Cylinder Displacement (cm^3)	163
Maximum Power BG@3600 rpm	5.5
Maximum Torque (Nm) @2500 rpm	10.78
Cooling system	Air Cooled

Table 2. Test fuels and mixture ratios

Gasoline	%100 Gasoline
H10	%10 Hexane + %90 Gasoline
H20	%20 Hexane + %80 Gasoline
H30	%30 Hexane + %70 Gasoline
H40	%40 Hexane + %60 Gasoline

Table 3. Properties of test fuels [6,14,16]

	Gasoline	Hexane
Density (kg/m^3)	746	659
Lower Calorific Value (kJ/kg)	43594	44750
Freezing Point (°C)	<-52	-95.35
Octane Number	96.47	36
Auto-Ignition Temperature (°C)	257	240
Boiling Point (°C)	30-225	69

In the experiments conducted at full load condition, an AC dynamometer was utilized to load the test engine. The test engine was connected to AC dynamometer and electrical power was used in order to load the test engine with receiver rheostat and resistors as shown in Figure 1. The rheostat and resistors were adjusted step by step to run the test engine at the desired speeds. A Burster 8661 brand torque sensor was used for measuring torque. Technical properties of Burster 8661 brand torque sensor are presented in Table 4. A PLT Power brand precision scale with a accuracy of 0.5 g was utilized to determine fuel consumption. CO, CO_2 and HC were measured with gas analyzer. The technical properties of the exhaust gas analysis device are given in Table 5.

Table 4. Technical properties of torque sensor

Determination	Descriptions
Nominal supply voltage range U:	10-30V DC
Output voltage at rated torque:	+10 V
Output impedance:	1 KΩ
Insulation resistance:	> 5 MΩ
Fluctuation:	<50 mV
Drive signal (K pin):	10 ... 30 V DC

Table 5. Technical properties of exhaust gas analyzer

Parameters	Measuring Range	Sensibility
HC	0- 9999 ppm	1 ppm
CO	0- 14 %	% 0.001
CO_2	0- 18 %	% 0.1
O_2	0- 25 %	% 0.01
NO_X	0- 5000 ppm	1 ppm

The full load speed characteristics of the test engine, which is operated with gasoline, gasoline- hexane mixtures, have been obtained. The change in torque, power, SFC, thermal efficiency, CO, CO_2 and HC emissions depending on the engine speed has been experimentally investigated. The engine torque was measured instantaneously, and the effective power was calculated with the following equation.

$$P = T.W \quad (T{:}Torque, W{:}Angular\ Velocity) \quad (1)$$

This equation represents the relationship between engine torque, engine speed, and effective power [16,17]. BSFC refers to the fraction of fuel consumed per unit power per unit time by the engine. It is one of the most important factors when comparing fuels on an economic basis. The fraction of fuel measured per unit time is used in the following equation to calculate it [16,17].

$$BSFC = \frac{m_f}{N_e} \quad (2)$$

m_f and N_e represent the value of fuel measured in unit time and effective power. Thermal efficiency defines to how much of the energy released from the combustion of the fuel is converted into net work. The thermal efficiency is calculated using equation 3.

$$\eta_T = \frac{W_{net}}{m_y . H_u} \quad (3)$$

In this equation, W_{net} and H_u represent the net work and the calorific energy of the fuel, respectively [16,17].

Uncertainty analysis was performed. Uncertainties of various measurements were given as below in Table 6 [18-21]. Equation 4 was used to determine the uncertainties.

$$\Delta f = \left[\left(\frac{\partial f}{\partial x_1} \Delta x_1 \right)^2 + \left(\frac{\partial f}{\partial x_2} \Delta x_2 \right)^2 + ... + \left(\frac{\partial f}{\partial x_n} \Delta x_n \right)^2 \right]^{1/2} \quad (4)$$

Table 6. Uncertainties of various measurements

	Accuracy	Uncertainty (%)
Fuel consumption [g]	± 0.5	± 0.16
Engine torque [Nm]	± 0.01	± 0.38
Engine power [kW]	± 0.01	± 0.13

Figure 2 depicts the variations of engine torque according to engine speed. It was depicted from Figure 2 that hexane addition leads to decrease engine torque. Gas leakages and heat losses increase at high engine speeds [17]. So, engine torque decreases. This situation is attributed with the lower density and octane number of hexane. Average pressure applied on the piston during a cycle decreases with the usage of hexane. The highest torque was obtained at 2800 rpm for each test fuel. Engine torque declined by 14.86% with H40 according to gasoline at 2800 rpm.

Figure 3 shows the power output according to engine speed. Similarly, obtained power decreased with hexane addition into fuel mixtures. It is thought that lower octane number and density lead to obtain lower power output. Oxidation reactions can be easily performed without sufficient compression process. These phenomena caused to decrease temperature and pressure during combustion.

It can be also attributed that torque and power output declined owing to lower density of hexane-gasoline mixtures. Charge mixture that is taken into the cylinder decreases by mass with fuel mixtures. Besides, auto-ignition tendency of fuel mixtures increases without obtaining sufficient temperature and pressure during compression stroke. Hence, lower in-cylinder pressure is obtained resulting in lower torque and power.

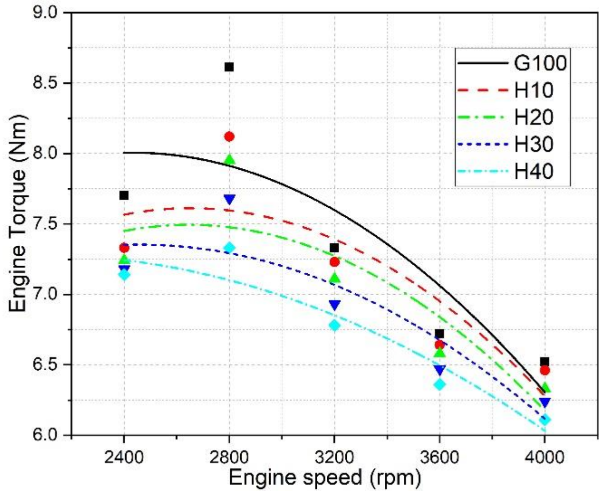

Figure 2. The variations of engine torque

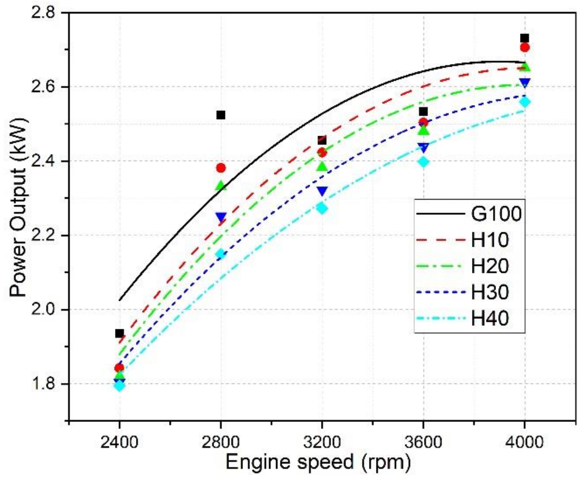

Figure 3. Power output

Fuel economy is one of the most important performance indications [17]. The influences of hexane on SFC are presented in Figure 4. It was clearly seen that SFC increased with the rise of hexane in the fuel mixtures. There is no big difference on calorific value between gasoline and hexane. In addition, the density of hexane is lower that gasoline. Lower density caused to take lower charge mixture into the cylinder during intake process by mass. So, more fuel should be consumed to generate higher power. Latent heat of vaporization of hexane is higher than gasoline. Higher heat is extracted during vaporization. It causes to take more charge into the cylinder. Nevertheless, averaged temperature in the cylinder decreases and oxidation reactions slow down. Thus, BSFC increases via using fuel mixtures. The highest SFC was determined with H40 test fuel as shown in Figure 4.

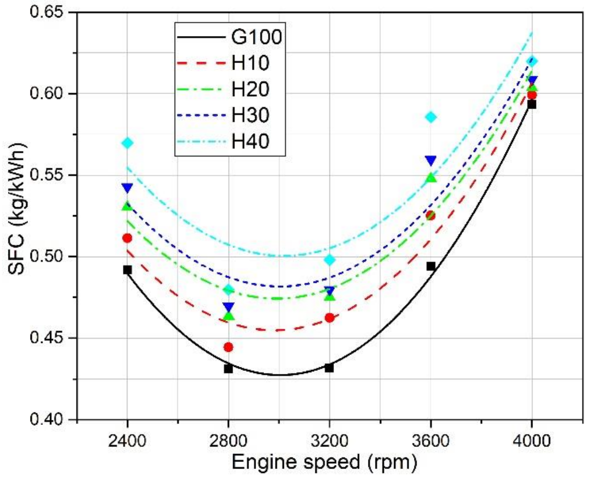

Figure 4. Changing of SFC

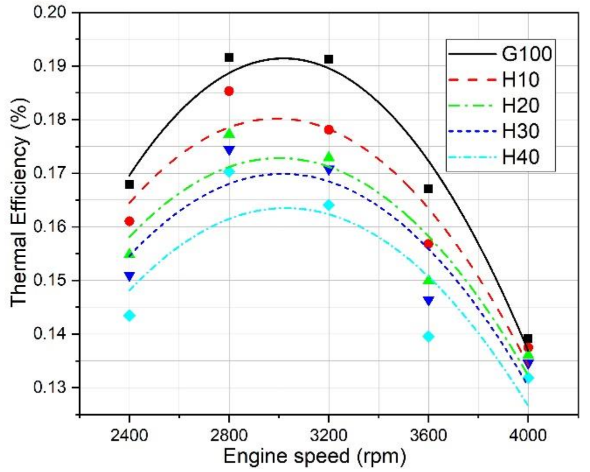

Figure 5. The variations of thermal efficiency

Thermal efficiency defines the conversion of fuel energy to net work [17]. Figure 5 illustrates thermal efficiency variations versus engine speed. As expected, thermal efficiency declined with fuel mixtures due to lower density and autoignition temperature of hexane. In addition, the heating value of hexane is almost the same as gasoline. Maximum thermal efficiency was determined at 2800 rpm with pure gasoline. CO emission is formed due to incomplete combustion. So, the evaluation of CO is valuable. The changing of CO emission is shown in Figure 6. CO is reduced with the rise of engine speed and tend to increase with the rise of engine speed. Heat losses and gas leakages decrease at medium engine speeds. Higher CO was measured with fuel blends compared to gasoline. But it can be claimed that hexane addition caused to reduce CO emissions. This effect can be explained with the lower auto ignition temperature of hexane compared to gasoline.

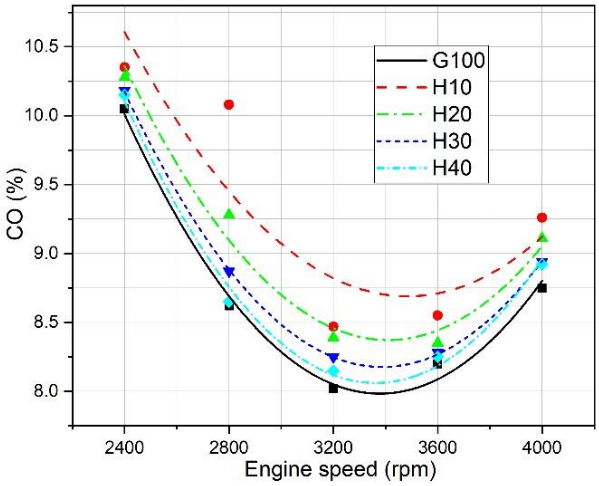

Figure 6. CO emissions

The variations of CO_2 are seen in Figure 7. The increase on CO_2 were realized with the rise of hexane addition. Incomplete combustion product reduces with the hexane addition. On the contrary, CO_2 emissions increased with the hexane addition owing to lower octane number and autoignition temperature of hexane.

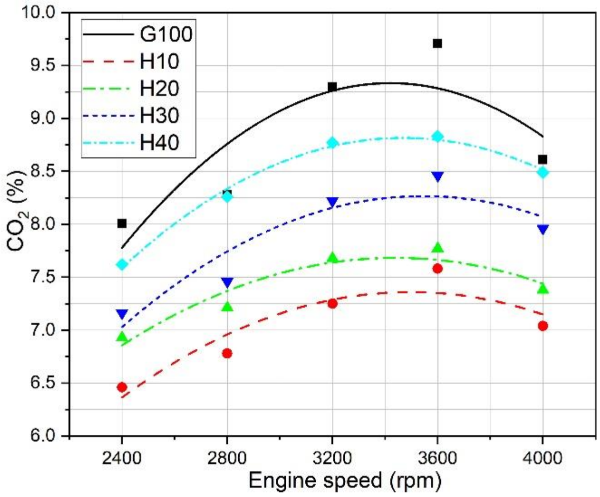

Figure 7. CO_2 emissions

Figure 8 shows the HC variations with test fuels. It can be said that HC increased with the rise of hexane fraction in the fuel blends. Homogeneity of the charge mixture is improved due to the rise of engine speed and local richer mixture zones can be prevented. So, HC formation decreases. On the other hand, sufficient oxygen cannot be delivered into the cylinder and oxidation reactions deteriorate at higher engine speed. Hence, HC formation increases again. Low autoignition temperature and octane number of hexane affect combustion conditions negatively.

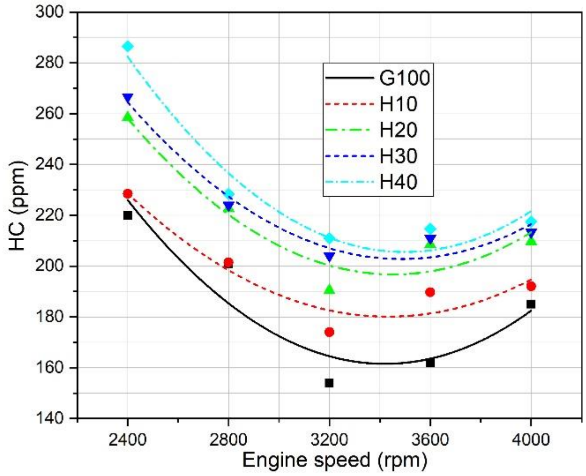

Figure 8. HC emissions

4. Conclusion

This work aims to evaluate the influences of hexane addition on performance and exhaust emissions in a SI engine. Test engine could be loaded between 2400 and 4000 rpm with gasoline-hexane fuel blends owing to test environment restrictions. The engine could not be loaded efficiently and below 2400 rpm. In addition, engine torque could not be determined accurately. But, sufficient data was collected to determine the engine performance and exhaust emissions. So it was preferred to measure performance and emissions between 2400 and 4000 rpm. In addition, combustion analysis could not be performed, because in-cylinder pressure gradient was could not be able to detect. In this respect, uncertainty analysis was performed. Engine torque and effective power declined with the addition of hexane according to gasoline. Engine torque decreased by 5.69%, 7.66%, 10.80%, 14.86% with H10, H20, H30 and H40 according to gasoline at 2800 rpm respectively. SFC also increased with the rise of hexane in the fuel mixtures. Thermal efficiency decreased by 3.27%, 7.50%, 8.95% and 11.12% using H10, H20, H30 and H40 test fuels compared that gasoline at 2800 rpm respectively. Experimental study presented that remarkable reduction was seen on CO with the addition of hexane. CO reduced by 3.77% with H40 compared to H10 at 3200 rpm. However, CO_2 increased 16.49% with H40 compared to H10 at 3600 rpm. HC emissions also increased by 37.01% with H40 compared to gasoline at 3200 rpm. In conclusion, gasoline/hexane fuel blends should be used in SI engines without changes. Although there is no positive difference on thermal efficiency, CO and HC emissions with fuel blends compared to pure gasoline, gasoline/hexane fuel mixtures can be used without modifications in SI engines.

Nomenclature

AC	Alternative Current
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DEE	Diethyl Ether
EGT	Exhaust Gas Temperature
ICE	Internal Combustion Engine
ITE	Indicated Thermal Efficiency
HC	Hydrocarbon
HCCI	Homogeneous Charged Compression Ignition
H_u	Calorific Value
ID	Ignition Delay
m_f	Fuel Consumption
M_e	Engine Torque
n	Engine Speed
N_e	Effective Power
SI	Spark Ignition
W	Angular velocity
W_{net}	Net Work
WPF	Waste Plastic Fuel
WRI	World Resources Institute
WOT	Wide Opening Throttle
η_T	Thermal Efficiency

Credit Authorship Contribution Statement

Tolga Kocakulak: Investigation Determining the Concept and/or Design Processes of the Research, Data Collection, Final Approval and Full Responsibility **Nurettin Mert Boyacıoğlu:** Writing – Review & Editing, Data Analysis and Interpretation of the Results, Investigation, Validation, Data Collection, Writing-Original Draft **Yusuf Dağoğlu:** Data Collection, Validation, Preparation of the Manuscript, Writing – Review & Editing, Final Approval and Full Responsibility **Ahmet Uyumaz:** Management of the Concept and/or Design Process of the Research, Determining of the Concept and/or Design Processes of the Research, Methodology, Writing-Original Draft, Final

Approval and Full Responsibility **Fatih Aksoy:** Preparation of the Manuscript, Methodology, Investigation, Data Analysis and Interpretation of the Results, Formal analysis **Emre Arabacı:** Methodology, Management of the Concept and/or Design Process of the Research, Critical Analysis of Intellectual Content, Data Analysis and Interpretation of the Results.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships in this study.

5. References

1. Hua Y., "Research progress of higher alcohols as alternative fuels for compression ignition engines", Fuel, 357, 129749, 2024.
2. https://www.wri.org/data/world greenhouse-gas-emissions-2019, World Resources Institute. World Greenhouse Gas Emissions. 2019.
3. Çelik M., Bayındırlı C., Recai Kuş, "Experimental Investigation of Effect of n-Hexane Addition in Diesel and Biodiesel Fuels on Performance and Emissions Characteristics", International Journal of Automotive Science and Technology, 7(2), 118-124,2023.
4. Vural E., Özer S., Özel S., Binici M., "Analyzing the effects of hexane and water blended diesel fuels on emissions and performance in a ceramic-coated diesel engine by Taguchi optimization method", Fuel, 344, 128105, 2023.
5. Kumar R., Mishra M. K., & Roy M. K., " Effects of Hexane Addition in Waste Plastic Fuel-Biodiesel-Diesel Blends on the Performance and Emission Characteristics of DI Diesel Engine", Automotive Experiences, 5(3), 416-432, 2022.
6. Gonca G., Sahin B., Hocaoglu M. F., "Influences of hydrogen and various gas fuel additions to different liquid fuels on the performance characteristics of a spark ignition engine", International Journal of Hydrogen Energy, 47(24), 12421-12431,2022.
7. Nour M., Sun Z., El-Sees A. I., Li, X., "Experimental evaluation of the performance and emissions of a direct-injection compression-ignition engine fueled with n–hexanol–diesel blend", Fuel, 302, 121144, 2021.
8. Aydoğan B., "An experimental examination of the effects of n-hexane and n-heptane fuel blends on combustion, performance, and emissions characteristics in an HCCI engine", Energy, 192, 116600, 2020.
9. Yılmaz E., "Hekzan ve N-Heptan Yakıt Karışımları ile Çalışan Homojen Dolgulu Sıkıştırma İle Ateşlemeli (HCCI) Bir Motorda Hava Fazlalık Katsayısının Yanma ve Motor Performansı Üzerindeki Etkileri", Gazi University Journal of Science Part C: Design and Technology, 8(1), 26-39, 2020.
10. Çelik M., Bayindirli C., "Enhancement performance and exhaust emissions of rapeseed methyl ester by using n-hexadecane and n-hexane fuel additives", Energy, 202, 117643, 2020.
11. Şimşek D., Oral F., Çolak N., "Tek Silindirli Buji Ateşlemeli Motorlarda Benzin-Propanol-Hekzan Yakıt Karışımlarının Motor Performans ve Emisyonlarına Etkisi", Isı Bilimi ve Tekniği Dergisi, 39(1), 81-89, 2019.
12. Bayındırlı C., Çelik M., Demiralp M., & Örs İ., "Investigation of the effect of n-hexane additives in biodiesel on combustion and exhaust emissions in diesel engines", International Journal of Automotive Engineering and Technologies, 6(3), 140-147, 2017.
13. Bose P. K., Bodkhe V. N., Barma B. D., & Banerjee R., "Response surface methodology-based multi-objective optimization of the performance-emission profile of a CI engine running on ethanol in blends with diesel", Biofuels: Technology, Challenges and Prospects, 201-228, 2017.
14. Gonca G., "Influences of different fuel kinds and engine design parameters on the performance characteristics and NO formation of a spark ignition (SI) engine", Applied Thermal Engineering, 127, 194-202, 2017.
15. Balamurugan T., Nalini R., "Experimental investigation on the effect of alkanes blending on performance, combustion and emission characteristics of four-stroke diesel engine", International Journal of Ambient Energy, 37(2), 192-200, 2016.
16. Gonca G, Sahin B, Hocaoglu MF. "The Effects of Equivalence Ratio and Temperature of Different Fuel Mixtures on the Performance

and NO Emission Characteristics of a Spark Ignition Engine", Arab J Sci Eng. 1-22, 2023.
17. Heywood JB., "Internal Combustion Engine Fundamentals", NewYork: McGrawHill Education; 1988.
18. Kumar D.S., Murugesan S., "Experimental Investigation on Impact of Diethyl Ether Additives with Cashew Nutshell Liquid Biodiesel Blends on Performance Characteristics of Engine Operating at Optimum Conditions", Emission Control Science and Technology, 9:66-75, 2023.
19. Gorski K., Smigins R., Longwic R., "Research on Physico-Chemical Properties of Diethyl Ether/Linseed Oil Blends for the Use as Fuel in Diesel Engines", Energies, 13:6564, 2020.
20. Mofat R.J., "Using uncertainty analysis in the planning of an experiment", J Fluids Eng., 107(2), 173-178, 1985.
21. Holman J.P., "Experimental Methods for Engineers", McGraw Hill eight edition, Newyork, 2001.