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The Investigation of Bioethanol as a Fuel in an SI Engine with Fuel and Ignition Systems Converted to Electronic Control

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Abstract

In this study; a four-stroke, air-cooled, spark-ignition engine was used. It's aimed to improve the performance and emissions by renewing the existing ignition and fuel system of the engine in a way that can be controlled via computer. Classical ignition system was modified with an electronic ignition system and a computer-controlled system was established by using an injector instead of the carburetor. Gasoline and bioethanol fuels were compared with the original and updated version of the engine by conducting various experiments. In these experiments, engine power and torque, specific fuel consumption, thermal efficiency, exhaust emissions and combustion analysis results were examined. When the results obtained are evaluated; with the use of electronically controlled fuel and ignition system in engine torque and power, an increase of 11.58% in maximum torque obtained from gasoline and an increase of 14.4% in average power was observed compared to the standard system. Specific fuel consumption decreased by 18.32% for gasoline and 26.95% for bioethanol at full load. At full load, thermal efficiency was 22.43% for gasoline, 36.9% for bioethanol and in-cylinder max. pressure was a 4% increase for gasoline and an 8% increase for bioethanol. In the emission values, at full load, the CO value decreased by 6.2% for gasoline, 20% for bioethanol and HC value decreased by 3.8% for gasoline and 7.5% for bioethanol. CO_2, NO_x and O_2 values increased by 4.1%, 14.9%, 0.7% for gasoline and 0.7%, 5.6%, 0.4% for bioethanol.

Keywords: Ignition advance control, gasoline, bioethanol, computer control, spraying

1. Introduction

Today, heating and energy needs are mostly met from fossil fuels, especially in the transportation sector, agriculture sector, heavy machinery industry, residences, etc. The continuous increase in the demand for fossil fuels and the harmful exhaust emissions resulting from the combustion of these fuels threaten the environment among the most important problems [1]. Researchers focus on alcohol, biofuels, and renewable biomass to reduce the use of fossil fuels and create a cleaner environment [2-4]. In addition, some studies are currently ongoing on the internal combustion engine in order to increase performance and reduce exhaust emissions and specific fuel consumption [5, 6]. Fuel injection strategy, dual fuel mode, fuel mixtures, variable valve timing, variable compression ratio, combustion chamber geometry, and alternative engine cycles (Atkinson and miller) are studies on internal combustion engines [7].

It is desired that the fuels that can be used in spark ignition engines are easy to produce, cheap, easy to store and transport, have a high calorific value, be suitable for operation at high compression ratios, and have low exhaust emission amounts. While LPG, CNG, and LNG gas fuels are used as alternatives to gasoline, hydrogen fuel is also tried as an additional fuel in studies in order to increase the thermal value of these fuels [8, 9]. The most attractive alternative fuels for spark ignition engines are alcohols such as ethanol and methanol. Alcohol-containing fuels such as methanol and ethanol can be used directly or mixed with gasoline in experiments performed on spark-ignition engines [10-13]. In particular, methanol-gasoline, ethanol-gasoline, and methanol-ethanol-gasoline mixtures are among the most frequently tested studies. The reason for this is that it reduces the use of alcohol and dependence on fossil fuels, as well as reduces polluting exhaust emissions [14]. Thanks to the studies, alcohol and gasoline-alcohol mixtures, which are considered as an alternative to fossil fuels, have reached a remarkable level of use throughout the World. Methanol and ethanol; are simple hydrocarbons with oxygen and hydrogen in their chemical structure, which can be produced from solid and gaseous fuels such as coal, lignite, natural gas, and agricultural products [15]. Methanol and ethanol fuels are of great importance in terms of our country. The fact that there are rich lignite reserves in our country, that we are an agricultural country and that we import fossil fuels can create the fact that alcohols can be an important energy source for our country.

In addition to alternative fuels, there have been many developments in internal combustion engines. From the 1900s to the present, many studies have been ongoing to improve the performance, emission and combustion characteristics of spark-ignition engines. The most obvious changing system from the history of the internal combustion engine to the present is the carburetor systems used in passenger cars before the 1970s [16].

For a long time, the idea of creating the fuel-air mixture necessary for the operation of gasoline engines outside the cylinder has been dominant. For most of the time that has passed since the invention of gasoline engines, carburetors have done the mixing task. With the development of electronic control systems, the fuel injection method to the manifold has been used. Thus, carburetor systems were replaced by injector-controlled systems after the 1970s. The historical development of fuel supply systems is shown in Fig.1. By using the injector-controlled system instead of the carburetor system, the air/fuel mixture can be around the stoichiometric ratio for almost any operating condition, resulting in better combustion. Thus, higher power, higher torque and lower exhaust emission values can be obtained with an injection engine, which has the same characteristics as a carburetor engine [15].

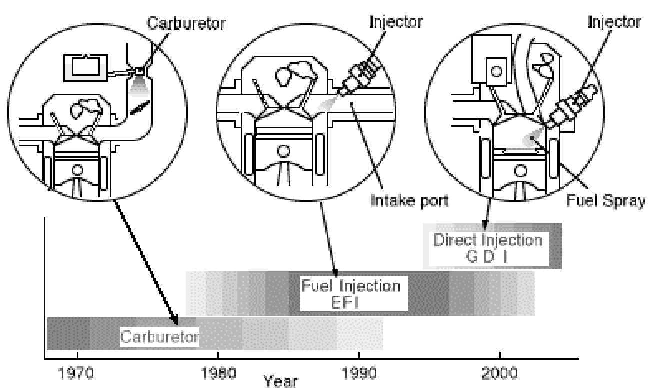


Fig. 1. Historical development of fuel supply systems

A new generation injection system such as manifold injection, port injection or direct injection are systems used after the carburetor system. Manifold injection is an injection system that allows the air-fuel mixture to form a homogeneous mixture without entering the cylinder in spark plug ignition engines. In this system, the fuel is injected into the intake manifold where the air flow is. Thus, the fuel droplets both evaporate and form a relatively homogeneous mixture until they reach the cylinder. However, due to the low volumetric efficiency at high engine speeds and the problems caused by cold starting, manifold injection has been switched to port and direct injection systems [17-19].

In this study, it is aimed to improve the engine performance and emission values of a single-cylinder spark-ignition engine with a carburetor system, by making the ignition and fuel systems controllable with an electronic control unit. A control system has been established in order to control values such as ignition and spraying times and spray amount. Necessary arrangements were made on the carburetor fuel system of the engine and it was converted to an injector system. The classical ignition system was also controlled by the control unit. Before the modifications on the engine, experiments were carried out with gasoline and bioethanol fuels at 25%, 50%, 75% and 100% loads. After the modification, the same fuel and loads were tested again, and the results were compared.

2. Material and Methods

2.1. Material

2.1.1. Test engine

The characteristics of the engine shown in Fig. 2., whose ignition and fuel system has been changed and used for experimental studies, are given in Table 1. The intake manifold on the engine has been rebuilt by opening the injector housing. By leaving the carburetor system on the engine, it is also ensured that it works with this system when necessary.

Table 1. Test engine specifications

Model	**GUNT CT152**
Engine type	Four stroke, SI engine with external carburetor
Cylinder number	1
Cooling type	Air cooling
Diameter × stroke	65.1 mm × 44.4 mm
Connecting rod length	79.55 mm
Compression ratio	7:1
Maximum engine power	1.2 kW
Maximum engine torque	4.5 Nm
Ignition timing	25° bTDC

Fig. 2. CT 152 Spark ignition engine

2.1.2. Experimental setup

All studies were carried out in Selçuk University Automotive Technologies Application and Research Center, engine performance tests were carried out in the engine test setup in this center, shown in Fig. 3.

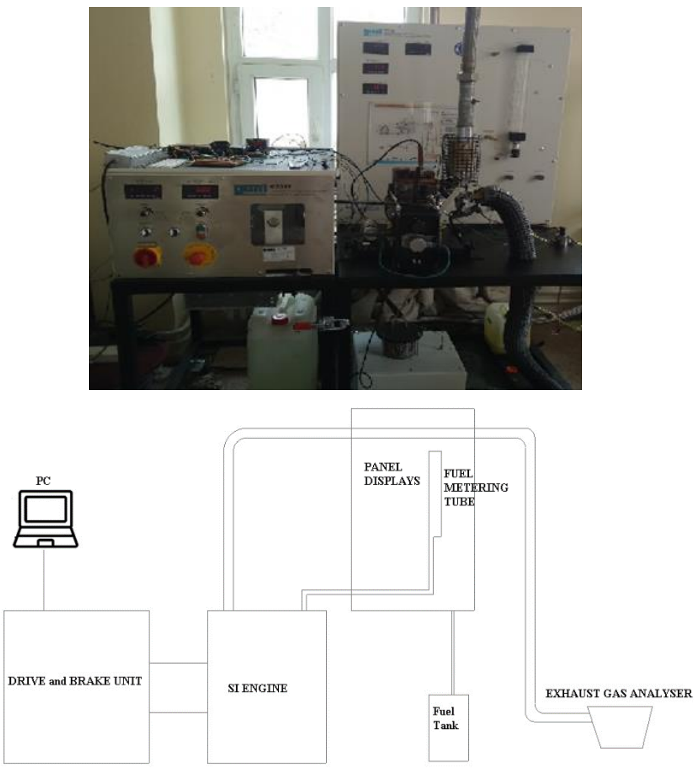
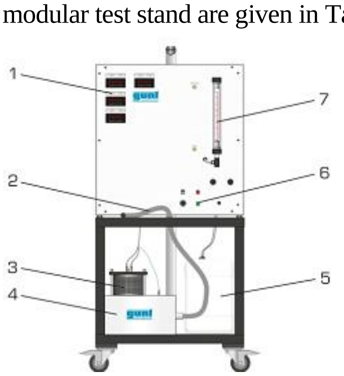


Fig. 3. Experimental setup

2.1.3. Modular test stand

The modular test stand display elements are shown in Fig. 4. With the modular test stand, connection and controls are provided with the elements given in the figure. Air temperature, exhaust temperature and fuel temperature data can be obtained from the stand. In addition, there is a fuel consumption measurement tube to calculate the fuel consumption. The measurement ranges of the modular test stand are given in Table 2.



1. Indicators
2. Air hose
3. Air filter
4. Stabilization tank
5. Fuel tank with pump
6. Connection and controls
7. Fuel consumption measuring tube

Fig. 4. Modular test stand and displays

Table 2. Measuring ranges of modular test stand components

Model	GUNT CT152
ambient temperature sensor	0- 100 ºC
fuel temperature sensor	0- 100 ºC
exhaust gas temperature sensor	0- 1000 ºC
air consumption	0 – 333 L/min
fuel pump	max. 130 L/min
fuel consumption pressure sensor	0 – 100 mbar
air consumption pressure sensor	0 – 5 mbar

2.1.4. Universal drive and brake unit

The drive and brake unit used in engine speed and torque measurements is shown in Fig. 5 and its technical specifications are given in Table 3.

Fig. 5. GUNT HM365 Universal drive and brake unit

Table 3. Universal drive and brake unit technical specifications

Model	GUNT HM365
Power source	6 kW
Engine type	Cage rotor asynchronous motor
power out	2.2 kW
Speed	~300 - 3000 rpm
Torque	Maks. 12 Nm
Efficiency	%83.2
measurement ranges	Maks 5000 rpm

2.1.5. Exhaust emission device

In the experiments, Mobydic 5000 mobile gas analyzer shown in Fig. 6. was used to obtain emission values. Technical specifications are given in Table 4. Necessary calibrations were made before the device was measured.

Fig. 6. Mobydic 5000 mobile gas analyzer

Table 4. Mobydic 5000 mobile gas analyzer technical specifications

Measuring module	Measuring Range	Accuracy
CO (% vol)	0-10	0.01
CO_2 (% vol)	0-20	0.01
HC (ppm)	0-2000	1
NO_x (ppm)	0-5000	1
Lambda	0-5	0.001

2.1.6. Cylinder pressure measuring system

The cylinder pressure measurement system consists of cylinder pressure sensor, amplifier, data acquisition card and signal conditioner and filter elements, as shown in Fig. 7.

Fig. 7. Pressure measuring system components and computer interface

Kistler brand 6018C model piezoelectric pressure sensor was used to measure the in-cylinder pressure. The slot for the in-cylinder pressure sensor on the engine cylinder head was made by the company that produced the test engine, as recommended by the manufacturer. A Kistler brand 5018A model amplifier, which is compatible with the pressure sensor, has a sensitive filtering feature and converts the voltage generated by the pressure sensor, depending on the in-cylinder pressure, into a pressure signal. Atek-ARC S 50 model encoder was used to detect the change in the pressure in the cylinder depending on the crank angle.

2.1.7. Fuel injection system

The schematic representation of the fuel injection system components, fuel pump, fuel filter and injector, is given in Fig. 8. With the electronically controlled system, the spraying time is set as 5 ms. at 100º ATDC.

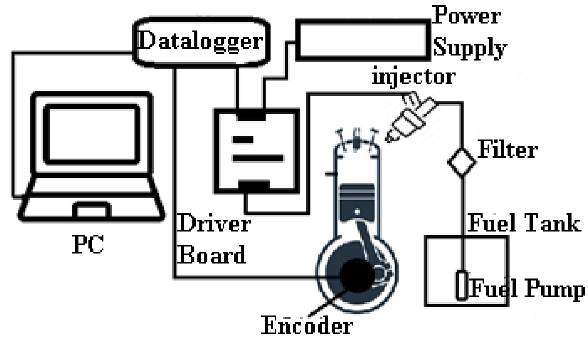


Fig. 8. Fuel system schematic

2.1.8. Ignition system

In spark-ignition engines, the air-fuel mixture in the cylinder must be ignited in a controlled manner. In order to obtain the maximum pressure, the air-fuel mixture in the cylinder should be ignited in a controlled manner towards the end of the compression stroke, as close as possible to the top dead point. This ignition process is done by creating a spark by means of a spark plug. The spark generation time and amount should be adjusted according to the variable load and speed conditions of the engine. With the electronically controlled system, the ignition degree is set as 20º BTDC. The schematic representation of the electronically controlled ignition system is given in Fig. 9.

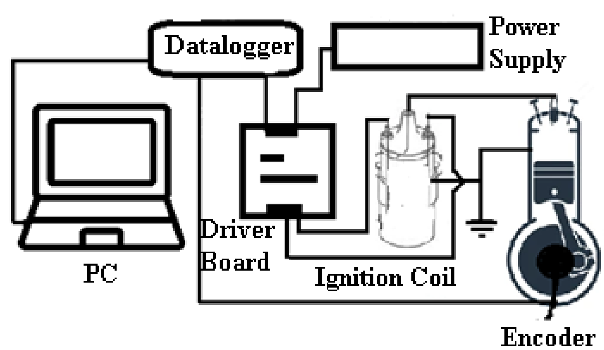


Fig. 9. Ignition system schematic

2.1.9. Electronic control system

A driver card is used to control the ignition and injector system according to the signals coming from the computer. It makes high-speed switching with the power it receives from the power source. Ignition and spraying conditions are observed with the LEDs on it. The driver board and computer interface are shown in Fig. 10.

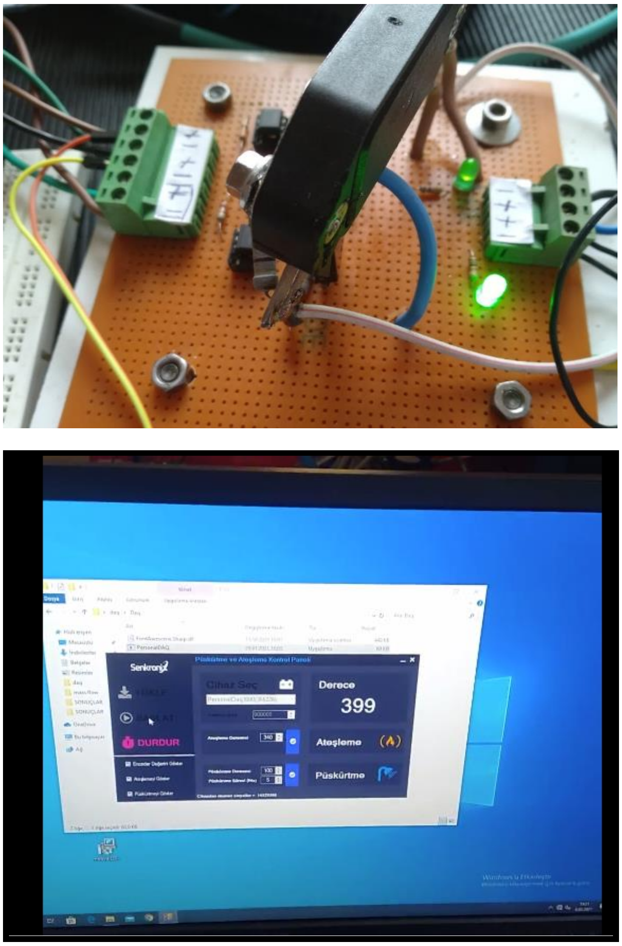


Fig. 10. Driver board and PC interface

2.1.10. Test fuels

In the experiments, were used 95 octane unleaded gasoline purchased from gas station and bioethanol supplied from Konya Sugar Factory. In Table 5, some physical properties of test fuels are given.

Table 5. Some physical properties of test fuels

Fuels	**Density (15°C-g/cm^3)**	**Lower heating value (MJ/kg)**	**Kinematic viscosity (40°C-mm^2/s)**
Bioethanol	0.78820	26.694	1.2
Gasoline	0.72926	42.582	0.566081

2.2. Method

For the full load experiments, the throttle position was first brought to full throttle and the engine was loaded slowly. The response of the Universal Brake and Drive Unit by reducing the speed was noted at 100 rpm intervals in the 2000-3200 rpm speed range. The maximum speed of the engine torque was obtained at 2500 rpm, and this speed was taken as a reference during the part load tests of the engine.

The experimental engine with the classical ignition and fuel system was converted to an electronic ignition and injection fuel system with a number of modifications. First, experiments were carried out in its current state to determine the condition of the engine in its original system. Then the new ignition and injection system was activated and the experiments were repeated. Before starting all experiments, the devices were calibrated. Before starting the experiments, the engine was brought to operating temperature. The throttle was brought to the full throttle position and the engine was slowly loaded and as a result of the reaction of the engine, it was determined that the maximum engine torque was obtained at 2500 rpm. Experiments were carried out with gasoline and bioethanol for both systems at a constant engine speed of 2500 rpm and at different engine loads (25%, 50%, 75% and 100%), and fuel consumption, surface temperature and exhaust emissions were measured. Experiments were carried out first with gasoline and then with bioethanol. With the obtained measurement results, power, brake specific fuel consumption, thermal efficiency values were calculated. The test results obtained with the current state and the modified state of the engine and the data obtained as a result of the calculations were compared.

3. Evaluation of Experiment Results

3.1. Engine Performance Results

3.1.1. Engine torque and engine power

Fig. 11. and Fig. 12. show the torque and power values obtained as a result of the full load tests. In the results obtained with the standard carburetor and classical ignition system of the engine, it was determined that the use of bioethanol reduced the maximum torque value by approximately 17.9% and the power value by approximately 21.14% on average. With the use of electronically controlled fuel and ignition system, an increase of 11.58% in the maximum torque obtained from gasoline and an increase of 14.4% in the average power value was observed compared to the standard system. The use of bioethanol with the electronic system increased the maximum torque value by 20.51% and the power value on average 27.95% compared to the standard system. In addition, using the electronically controlled system, the maximum torque and power values obtained from bioethanol are very close to the torque and power values obtained from the standard system of gasoline, as seen in the figure.

However, it was observed that the torque and average power values of the gasoline obtained with the use of the electronically controlled system were 11.32% and 11.8% higher, respectively, than the bioethanol. However, when using the classical system, the negative effects of bioethanol on maximum engine torque and average engine power compared to gasoline were improved by 36.34% and 44.18%, respectively, by using the electronically controlled system.

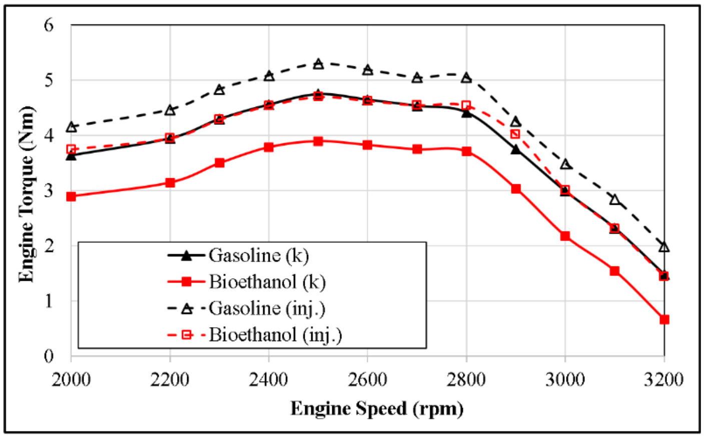


Fig. 11. Torque changes of test fuels depending on engine speed in electronically controlled and standard systems.

Bioethanol has approximately 38.01% lower calorific value than gasoline. The fact that the calorific value of bioethanol is lower than that of gasoline caused a decrease in the heat energy released in the cylinder at the end of combustion, thus reducing the torque and power values of bioethanol. Yelbey and Ciniviz [20] and Geçgel [21] stated in their studies that for the same reasons, bioethanol reduces torque and power values.

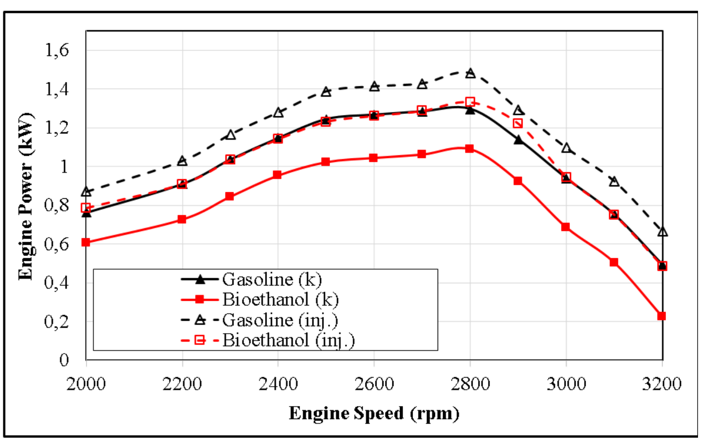


Fig. 12. Power changes of test fuels depending on engine speed in electronically controlled and standard systems.

By using the electronically controlled fuel system, the fuel/air ratio taken into the cylinder is closer to the lambda=1 value. Voltage fluctuations and mechanical losses in the conventional ignition system are minimized by the electronic ignition module, resulting in a more powerful spark at the right time. Thus, the torque and power values obtained with both gasoline and bioethanol have been increased with an electronically controlled system.

3.1.2. Specific fuel consumption

The maximum torque value of both gasoline and bioethanol was obtained at an engine speed of 2500 rpm for electronically controlled and standard systems. Therefore, different engine load tests were also performed at this engine speed. The specific fuel consumption curves of gasoline and bioethanol for both systems at different engine loads are shown in Fig. 13.

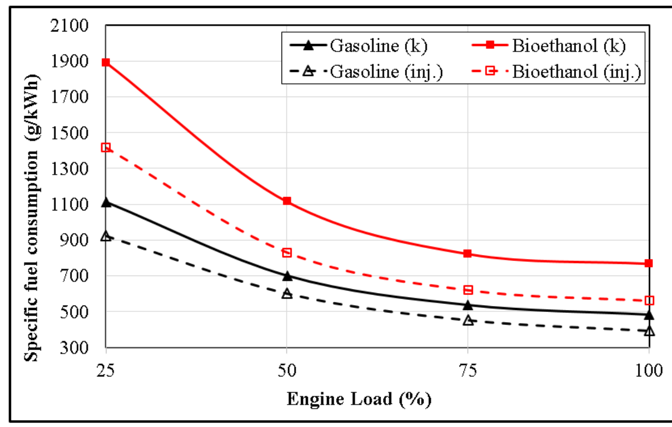


Fig. 13. Specific fuel consumption changes of test fuels depending on engine load in electronically controlled and standard systems.

In comparison of the standard system and the electronically controlled system: There was a reduction of 16.91% for gasoline and 25.07% for bioethanol at 25% load. There was a reduction of 14.08% for gasoline at 50% load and 25.42% for bioethanol. There was a reduction of 15.54% for gasoline at 75% load, and 24.61% for bioethanol. There was a reduction of 18.32% for gasoline and 26.95% for bioethanol at 100% load. Min. reduction was at 50% load for gasoline and 75% load for bioethanol. Max. reduction was at 100% load for gasoline and 100% load for bioethanol.

In comparison of gasoline and bioethanol in the standard system: 70.01% at 25% load, 59.04% at 50% load, 53.34% at 75% load, 59.08% at 100% load there was increase.

In comparison of gasoline and bioethanol in electronically controlled system: 53.31% at 25% load, 38.04% at 50% load, 36.87% at 75% load, 42.26% at 100% load there was increase.

The main reason why the specific fuel consumption values of bioethanol are higher than gasoline is that it has a lower heating value than gasoline. In addition, the fact that the amount of fuel taken into the cylinder per unit time is higher than gasoline due to its high density can be said to be another reason why the use of bioethanol increases the specific fuel consumption. Doğan [22], Keskin [23], Kul and Ciniviz [24] also suggested similar reasons, which revealed that bioethanol increases the specific fuel consumption.

It is seen that the specific fuel consumption values are significantly reduced compared to the standard system, thanks to the electronically controlled system both regulating the fuel ratio and improving the ignition.

3.1.3. Thermal efficiency

Thermal efficiency refers to the rate at which the heat energy released as a result of the combustion of fuel can be converted into useful work. This ratio is primarily related to the combustion quality and efficiency of the fuel. In Fig. 14., thermal efficiency graphs of test fuels under variable conditions and different loads are presented.

In comparison of the standard system and the electronically controlled system: There was an increase of 20.35% for gasoline and 33.46% for bioethanol at 25% load. There was an increase of 16.39% for gasoline at 50% load and 34.09% for bioethanol. There was an increase of 18.39% for gasoline at 75% load, and 32.64% for bioethanol. There was an increase of 22.43% for gasoline and 36.9% for bioethanol at 100% load. The min increase was at 50% load for gasoline and 75% load for bioethanol. The max increase was at 100% load for gasoline and 100% load for bioethanol.

In the comparison of gasoline and bioethanol in the standard system: There was a 6.17% reduction at 25% load, 0.3% at 50% load, 4.03% at 75% load, 0.28% at 100% load there was increase.

In the comparison of gasoline and bioethanol in an electronically controlled system: 4.05% at 25% load, 15.56% at 50% load, 16.55% at 75% load, 12,13% at 100% load there has been an increase.

Wu, Chen [4], Balki, Sayin [25], Göktaş [26], Kul and Ciniviz [27] showed similar results and said that thermal efficiency tends to increase.

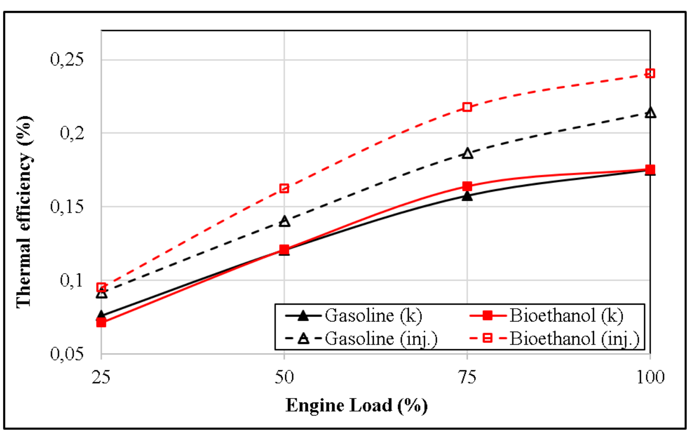


Fig. 14. Thermal efficiency changes of test fuels depending on engine load in electronically controlled and standard systems.

Bioethanol can burn much more efficiently thanks to the oxygen it contains and its low latent heat of evaporation. The ability of bioethanol to burn efficiently means that the rate of heat energy converted into useful power is high. That is, for thermal efficiency, it is important that the fuel can burn efficiently, not that the calorific value of the fuel is high.

Thanks to the electronically controlled system improving the combustion quality for both fuels, higher thermal efficiency values have been achieved compared to the standard system. Because combustion efficiency is directly related to both lambda value and ignition quality. The improvement of these two parameters increased the combustion efficiency and provided a better quality combustion.

3.2. Combustion Analysis Results

Combustion is interpreted by analyzing the cylinder pressure and heat release rate changes. The changes in both the cylinder pressure and the heat release rate along the crank angles where combustion takes place are shown in Fig. 15. Thanks to its oxygen content and low latent heat of vaporization, bioethanol ignites faster and burns faster than gasoline. In addition, due to these reasons, the maximum cylinder pressure value is lower, as it has a lower bulk modulus than gasoline.

The earlier combustion of bioethanol and the higher combustion rate caused the crank angle values, from which the maximum cylinder pressure and heat release rate values were obtained, to be closer to the TDC. This is the reason why the total burning time is shorter than gasoline. The important parameters determined according to the results of the combustion analysis performed at the end of the experiments are presented in Table 6.

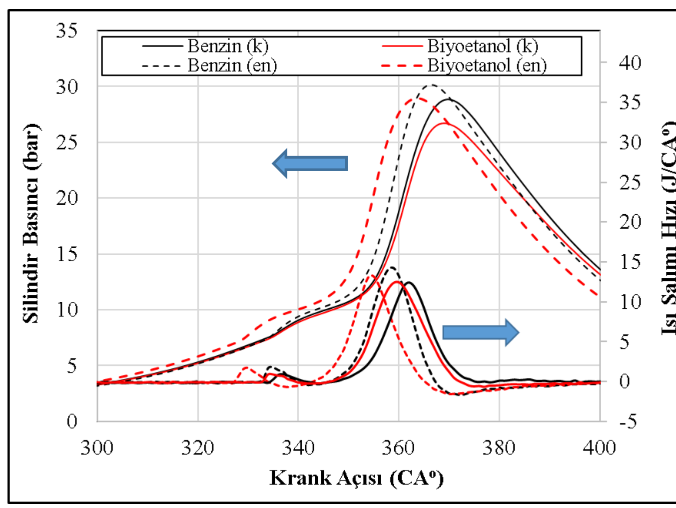


Fig. 15. Cylinder pressure and heat release rate changes of test fuels depending on crank angle in electronically controlled and standard systems (2500 rpm engine speed).

When the heat release rate curves are examined; It has been observed that the combustion initiation is more stable and effective, especially around the crank angle where the ignition takes place, thanks to the electronically controlled system, and therefore, a significant increase in the in-cylinder pressure values has been determined. The increase in cylinder pressure generally means that the engine performance parameters are improved. In addition, the fact that the crank angle values at which the maximum pressure is obtained are closer to the TDC means that the energy released at the end of combustion can be converted into work more efficiently.

Table 6. Combustion analysis results

Combustion Analysis	Gasoline (k)	Bio-ethanol (k)	Gasoline (inj.)	Bio-ethanol (inj.)
Ignition Time@CA°	335	335	335	335
Combustion Start@CA°	347	347	346	343
Ignition Delay	12	12	11	8
Combustion End@CA°	376	373	368	366
Burn Time	29	26	21	23
Max. Pressure@CA°	370	369	366	364
Max. Pressure	28,86	26,74	30,1	28,92
Max. Heat Release Rate@CA°	362	360	359	354
Max. Heat Release Rate	12,46	12,43	14,19	13,2

With the use of the electronic control system, the ignition delay values have been shortened and the combustion has been provided to be more controlled. In addition, the combustion time was shortened, thus, it was observed that the combustion efficiency was increased by ensuring that the combustion phase ended much earlier than the exhaust time.

3.3. Exhaust Emissions

3.3.1. CO emissions

In spark ignition engines, CO emission caused by rich mixture or insufficient oxygen should be kept under control since it is a seriously toxic gas. Fig. 16. shows the CO emission graphs obtained as a result of the experiments.

In comparison of the standard system and the electronically controlled system: There was a 5.3% reduction for gasoline at 25% load and a 35.7% reduction for bioethanol. There was a reduction of 10.7% for gasoline at 50% load and 16.7% for bioethanol. There was a 42.2% reduction for gasoline at 75% load and 11.8% for bioethanol. There was a 6.2% reduction for gasoline and 20% for bioethanol at 100% load. Min. reduction was 25% load for gasoline and 75% load for bioethanol. Max. reduction was at 75% load for gasoline and 25% load for bioethanol.

In the comparison of gasoline and bioethanol in the standard system: 89.4% at 25% load, 94.4% at 50% load, 91.7% at 75% load, 84.5% at 100% load, there has been a decrease.

In the comparison of gasoline and bioethanol in an electronically controlled system: 92.8% at 25% load, 94.8% at 50% load, 87.3% at 75% load, 86.8% at 100% load, there has been a decrease.

The reduction in CO emissions can be related to the fact that bioethanol makes the combustion better with the help of the oxygen it contains and brings it closer to the full combustion conditions. The reduction in CO emissions of bioethanol is also seen in the results of many studies in the literature. [25, 28-33]

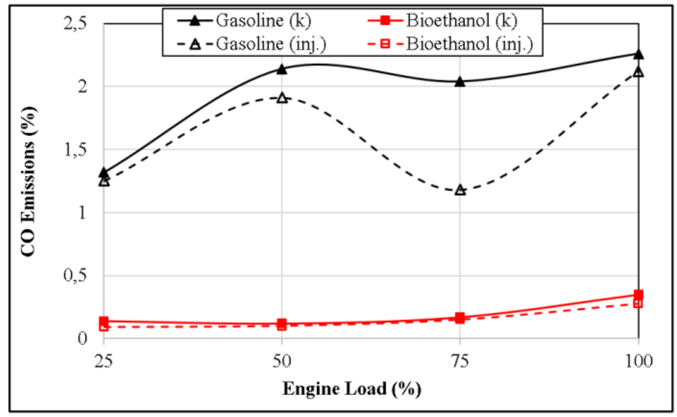


Fig. 16. CO emission changes of test fuels depending on engine load in electronically controlled and standard systems (2500 rpm engine speed).

3.3.2. CO_2 emissions

CO_2 gas is a common gas that is found in the combustion products of all carbon-containing fuels and is formed as a result of combustion. Fig. 17. shows the CO_2 emissions obtained as a result of the tests.

In comparison of the standard system and the electronically controlled system: There was an increase of 1.6% for gasoline and 0.8% for bioethanol at 25% load. There was an increase of 1.1% for gasoline at 50% load and 1.2% for bioethanol. There was an increase of 1.5% for gasoline at 75% load and 1.3% for bioethanol. There was an increase of 4.1% for gasoline and 0.7% for bioethanol at 100% load. Min. increase was at 50% load for gasoline and 100% load for bioethanol. Max. increase was at 100% load for gasoline and 75% load for bioethanol.

In the comparison of gasoline and bioethanol in the standard system: 17.6% at 25% load, 9.4% at 50% load, 10.5% at 75% load, 6.3% at 100% load there has been a decrease.

In the comparison of gasoline and bioethanol in an electronically controlled system: 18.2% at 25% load, 9.3% at 50% load, 10.6% at 75% load, 9.4% at 100% load there has been a decrease.

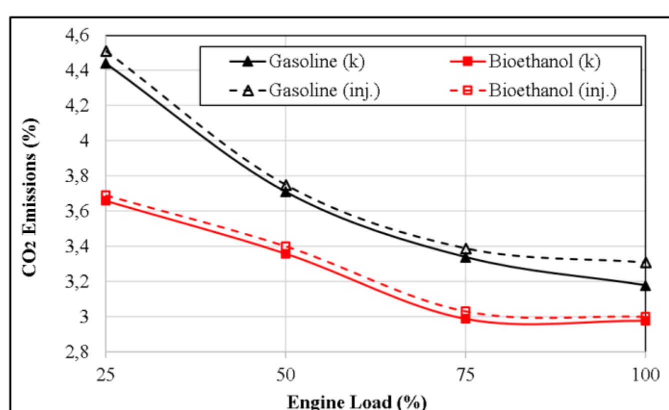


Fig. 17. CO_2 emission changes of test fuels depending on engine load in electronically controlled and standard systems (2500 rpm engine speed).

CO_2, which contributes significantly to global warming, depends on the amount of carbon in the fuel. The fact that one mole of bioethanol contains approximately 3.5 times less carbon atoms than gasoline is the most important reason for the lower CO_2 emissions from bioethanol. Since the electronically controlled system also increases the combustion quality and efficiency, it is seen that more carbon atoms react with oxygen to form CO_2 instead of CO. The CO_2 results obtained are similar to previous studies. [20, 34, 35]

3.3.3. HC emissions

HC emission, just like CO emission, occurs due to rich mixture formation or insufficient oxygen. The absence of sufficient oxygen atoms during combustion causes carbon atoms to react with hydrogen atoms. [36, 37]

As seen in Fig. 18., in comparison of the standard system and the electronically controlled system: There was a reduction of 2.1% for gasoline and 1.7% for bioethanol at 25% load. There was a 2.3% reduction for gasoline at 50% load and 2.3% for bioethanol. There was a 2.7% reduction for 3% bioethanol for gasoline at 75% load. There was a 3.8% reduction for gasoline and 7.5% reduction for bioethanol at 100% load. Min. reduction was at 25% load for gasoline and 25% load for bioethanol. Max reduction was at 100% load for gasoline and 100% load for bioethanol.

In the comparison of gasoline and bioethanol in the standard system: 12.4% at 25% load, 14% at 50% load, 13.9% at 75% load, 12.7% at 100% load there has been a decrease.

In the comparison of gasoline and bioethanol in an electronically controlled system: 12.1% at 25% load, 14% at 50% load, 13.7% at 75% load, 16.1% at 100% load there has been a decrease.

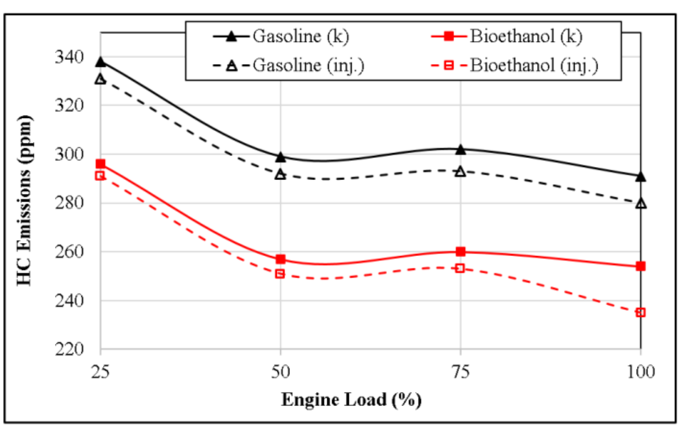


Fig. 18. HC emission changes of test fuels depending on engine load in electronically controlled and standard systems (2500 rpm engine speed).

The fact that the hydrogen content of bioethanol is lower than that of gasoline, and the higher oxygen content, caused lower HC emissions. In addition, thanks to the electronically controlled system, it has been observed that there is a significant reduction in HC emissions, especially at full load. Many studies in the literature showing that the addition of bioethanol reduces HC emissions, reports that bioethanol has a positive effect on reducing HC emissions as extra oxygen increases oxidation. [29, 38, 39]

3.3.4. NO_x emissions

Nitrogen and oxygen are two gases that can react at very high temperatures. The high in-cylinder temperature value formed as a result of combustion also enables this reaction to occur. Since spark ignition engines operate at much lower air excess coefficient values than diesel engines, NO_x emission values are also much lower than diesel engines. However, nowadays, the control of NO_x emission, which causes acid rain, has become important for spark ignition engines as well.

Fig. 19 shows the NO_x emission values obtained from the test fuels as a result of the experiments.

In comparison of the standard system and the electronically controlled system: There was a 6% increase for gasoline and 7.4% increase for bioethanol at 25% load. There was an increase of 3.9% for gasoline at 50% load and 4.4% for bioethanol. There was an increase of 3.7% for gasoline at 75% load, and 5.3% for bioethanol. There was an increase of 14.9% for gasoline and 5.6% for bioethanol at 100% load. Min increase was 75% load for gasoline and 25% load for bioethanol. Max increase was at 100% load for gasoline and 25% load for bioethanol.

In the comparison of gasoline and bioethanol in the standard system: 90% at 25% load, 74.8% at 50% load, 80.7% at 75% load, 141.8% at 100% load there has been an increase.

In the comparison of gasoline and bioethanol in an electronically controlled system: 92.5% at 25% load, 75.7% at 50% load, 83.6% at 75% load, 122.1% at 100% load there has been an increase.

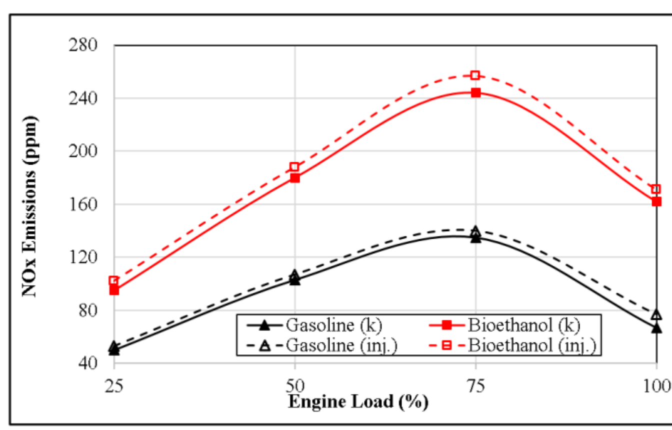


Fig. 19. NOx emission changes of test fuels depending on engine load in electronically controlled and standard systems (2500 rpm engine speed).

It is also seen in Fig. 19. that the oxygen content of bioethanol significantly increases the NOx values compared to gasoline. As can be seen in Fig. 20, there is a high level of oxygen in the combustion products with the use of bioethanol. The source of this oxygen is that besides the oxygen content of bioethanol, it needs less oxygen to burn than gasoline. The reaction of a large amount of oxygen during the combustion of bioethanol caused the oxygen atoms to react with nitrogen atoms and to produce higher NOx emissions. It has also been reported by many researchers that bioethanol causes an increase in NOx emissions. [40-42]. The increase in combustion efficiency, thanks to the electronically controlled system, caused both an increase in the in-cylinder temperature and a more stable combustion. Thus, the NO_x ratio in the exhaust gases has increased.

3.3.5. O_2 emissions

The presence of excess oxygen among the combustion products indicates that either the fuel is not fully combusted or the engine is running with a lean mixture. The formation of other emissions is also largely dependent on the amount of oxygen taken into the cylinders. Oxygen causes CO and HC emissions to decrease, while CO_2 and NO_x emissions generally increase. In the test results, the amount of oxygen in the exhaust gas is shown in Fig. 20 for each fuel.

In comparison of the standard system and the electronically controlled system: There was an increase of 1.2% for gasoline and 0.5% for bioethanol at 25% load. There was an increase of 0.6% for gasoline at 50% load and 0.5% for bioethanol. There was a 0.8% increase for gasoline at 75% load, and a 0.6% increase for bioethanol. There was an increase of 0.7% for gasoline and 0.4% for bioethanol at 100% load. Min. increase was at 25% load for gasoline and 100% load for bioethanol. Max. increase was at 25% load for gasoline and 75% load for bioethanol.

In the comparison of gasoline and bioethanol in the standard system: 22.8% at 25% load, 22.3% at 50% load, 22.5% at 75% load, 21.9% at 100% load there has been an increase.

In the comparison of gasoline and bioethanol in an electronically controlled system: 26% at 25% load, 22.2% at 50% load, 22.2% at 75% load, 21.6% at 100% load there has been an increase.

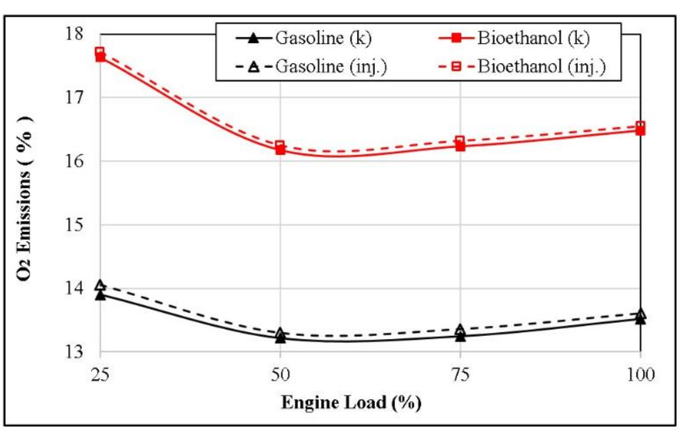


Fig. 20. O_2 emission changes of test fuels depending on engine load in electronically controlled and standard systems (2500 rpm engine speed).

The oxygen content of bioethanol caused extra O_2 in the combustion products. The mixing ratio, which is more stable thanks to the electronically controlled system, allowed the lambda to remain almost constant and thus the O_2 emission to increase a little bit.

3.4. Uncertainty Analysis

The calculation of the uncertainty analysis of the results of an experimental study can be performed in the most accurate and sensitive way with the method developed by Kline and McClintock and given in equation 1.The error rates of the measured or calculated values in experimental studies in the field of engineering are expected to be less than 5%. Uncertainty analysis is performed to ensure the accuracy of the results obtained and to show that they are within acceptable limits.[43,44]

$$W_R=\left[\left(\frac{\partial R}{\partial x_1}w_1\right)^2+\left(\frac{\partial R}{\partial x_2}w_2\right)^2+\left(\frac{\partial R}{\partial x_3}w_3\right)^2+\ldots+\left(\frac{\partial R}{\partial x_n}w_n\right)^2\right]^{1/2} \quad (1)$$

According to this equation; R is a function that depends on n variables and depends on n independent variables such as x_1,x_2, x_3,..,x_n. w_1,w_2,w_3,w_4…..,w_n are the error rates of n independent variables. WR is the total uncertainty of the experimental system.

The uncertainty analysis results of the results obtained from the motor tests performed in this study are presented in Table 7.

Table 7. Uncertainty of the calculated parameters

Calculated Parameters	Uncertainty (%)
Power	0.089
Specific Fuel Consumption	0.711
Thermal Efficiency	0.0015

The uncertainty of the calculated parameters below 5% indicates that the experimental setup and the measurements made are reliable.

4. Conclusions and Recommendations

4.1. Conclusion

In this study, the injection and ignition system of a single-cylinder spark-ignition engine was made electronically controllable. Before converting to electronically controlled system, engine performance and emission results were obtained with gasoline and bioethanol fuels in their standard form, and the same tests were carried out with the electronically controlled version. When the results are evaluated;

•Electronic control of the ignition and injection system has resulted in an increase in engine torque and power. The main reason for this is the provision of a homogeneous mixture of fuel with air. In addition, the increase in ignition quality causes the combustion to take place more efficiently

•When the specific fuel consumption data is examined, a significant decrease has been detected in the tests performed with the electronically controlled system. Electronic control of the systems provides better adjustment of the fuel-air ratio. In addition, the injection system sends the fuel atomized into the air, providing a homogeneous mixture and preventing the fuel from sticking to the intake manifold walls.

•Considering the thermal efficiency data, it was determined that the efficiency increased in all load cases. Since the main factor affecting the thermal efficiency is the combustion quality, an increase in thermal efficiency is an expected situation.

•When the in-cylinder pressure values are examined, it has been observed that the electronically controlled system creates higher cylinder pressure. Better control of the combustion and the approach of the combustion initiation increased the in-cylinder pressure values.

When the two systems are compared in terms of exhaust emissions,

• A significant reduction in CO emissions has been detected. The increase in combustion quality has led to a decrease in CO emissions.

• It has been determined that CO_2, another emission showing the quality of combustion, has increased at a certain rate in the experiments. Since the electronically controlled system also increases the combustion quality and efficiency, it can be thought that more carbon atoms react with oxygen to form CO_2 instead of CO.

• A reduction in HC emissions, known as unburned fuel residue, has been detected. The main reason for these emissions is that the rich mixture is sent to the cylinder. Thanks to the electronically controlled ignition and injection system, better adjustment of the mixture has led to a decrease in HC emissions.

• An increase has been detected in NO_X emissions, which are released into the air and cause acid rain by combining with water. The main reason for the formation of these emissions is the high in-cylinder temperature that occurs at the end of combustion. The quality combustion created by the electronically controlled ignition and injection system increased the combustion end temperature in the cylinder and caused an increase in NO_X emissions.

• It was observed that O_2 emissions increased in the test results. The increase in these emissions is what is considered to be an indicator of poor mix.

4.2. Recommendations

In the study, an engine with a classical type ignition and fuel system was transformed into an electronically controlled ignition and fuel system with a series of modifications. Tests were carried out with two different fuels (gasoline, bioethanol) to determine the usefulness of the modifications made. Controlling the system with a computer made engine tests more efficient. When we evaluate the test results, it is seen that the electronically controlled system provides significant advantages. In general, electronic control of mechanical systems on engines will provide advantages. In subsequent studies, the effects on engine performance can be determined by changing parameters such as injection timing, injection amount, ignition timing. With the system, these parameters can be easily changed via the computer.

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Nomenclature

SI	spark ignition
ATDC	after top dead center
BTDC	before top dead center
LPG	liquefied petroleum gas
LNG	liquefied natural gas
CNG	compressed natural gas
TDC	top dead center
k	carburetor
Inj	injector

References

[1] İlker, Ö. R. S., Gülcan, H. E., KUL, B. S., Yelbey, S., & Ciniviz, M. Evaluation of the Effects of Methanol and Ethanol Additions on Performance and Emissions in a Spark Plug Ignition Engine Fueled with Gasoline. International Journal of Automotive Science And Technology, 6(2), 156-164.

[2] Yücesu HS, Topgül T, Cinar C, Okur M. Effect of ethanol–gasoline blends on engine performance and exhaust emissions in different compression ratios. Applied thermal engineering. 2006;26(17-18):2272-8.

[3] Topgul T, Yucesu H, Cýnar C, editors. The experimental investigation of the effect of ethanol–gasoline blends on engine performance in different compression ratios on a spark ignition engine. Eighth international combustion symposium Ankara, Turkey; 2004.

[4] Wu C-W, Chen R-H, Pu J-Y, Lin T-H. The influence of air–fuel ratio on engine performance and pollutant emission of an SI engine using ethanol–gasoline-blended fuels. Atmospheric Environment. 2004;38(40):7093-100.

[5] Gülcan, H. E., Gültekin, N., & Ciniviz, M. The Effect of Methanol-Dodecanol Addition on Performance and Smoke Emission in a CI Engine with Diesel Fuel. International Journal of Automotive Science And Technology, 6(2), 207-213.

[6] Cinar, C., Ozdemir, A. O., Gulcan, H. E., & Topgül, T. (2021). Theoretical and experimental investigation of the performance of an Atkinson cycle engine. Arabian Journal for Science and Engineering, 46(8), 7841-7850.

[7] GÜLCAN, H., ÖZDEMİR, A., ÇINAR, C., & CİNİVİZ, M. Otto Çevrimine Göre Çalışan Buji İle Ateşlemeli Bir Motorun Atkinson Çevrimine Dönüşümünün İncelenmesi.

[8] Wang Z, Zuo H, Liu Z, Li W, Dou H. Impact of N2 dilution on combustion and emissions in a spark ignition CNG engine. Energy conversion and management. 2014;85:354-60.

[9] Erkuş B. Otto motorlarının farklı yakıt tiplerinde optimum performanslarının araştırılması: Bursa Uludag University (Turkey); 2011.

[10]El-Emam S, Desoky A. A study on the combustion of alternative fuels in spark-ignition engines. International journal of hydrogen energy. 1985;10(7-8):497-504.

[11]Çolak A. Buji ateşlemeli bir motorda farklı sıkıştırma oranlarında etanol kullanımının performans ve emisyonlara etkisinin incelenmesi. Zonguldak Karaelmas Üniversitesi, Bilim Uzmanlığı Tezi, Karabük. 2006.

[12]Zvonov V, editor Technical, economical, and ecological characteristics of methanol application as a fuel for internal combustion engines. Fuel and Energy Abstracts; 1996.

[13]Yüksel F, Yüksel B. The use of ethanol–gasoline blend as a fuel in an SI engine. Renewable energy. 2004;29(7):1181-91.

[14]İçingür Y, Yamık H. METİL VE ETİL ESTERİN DİZEL YAKITI OLARAK KULLANILMA İMKANLARININ DENEYSEL OLARAK ARAŞTIRILMASI. Politeknik Dergisi. 2003;6(2):459-64.

[15]Liu S, Clemente ERC, Hu T, Wei Y. Study of spark ignition engine fueled with methanol/gasoline fuel blends. Applied Thermal Engineering. 2007;27(11-12):1904-10.

[16]Pulkrabek WW. Engineering fundamentals of the internal combustion engine. 2004.

[17]Stan C. Direct injection systems for spark-ignition and compression-ignition engines1999.

[18]Kume T, Iwamoto Y, Iida K, Murakami M, Akishino K, Ando H. Combustion control technologies for direct injection SI engine. SAE transactions. 1996:704-17.

[19]Soruşbay C. Direkt Püskürtmeli Benzin Motorları. Otomotiv Dergisi, ISOD, Mart-Nisan. 2000(73):16-9.

[20]Yelbey S, Ciniviz M. Investigation of the effects of gasoline-bioethanol blends on engine performance and exhaust emissions in a spark ignition engine. European Mechanical Science. 2020;4(2):65-71.

[21]Geçgel K. Farklı oranlarda biyoetanol-benzin karışımlarının benzinli bir motorda kullanımının performans ve ekserji analizi: Necmettin Erbakan University (Turkey); 2018.

[22]Doğan B, Erol D, Yaman H, Kodanli E. The effect of ethanol-gasoline blends on performance and exhaust emissions of a spark ignition engine through exergy analysis. Applied Thermal Engineering. 2017;120:433-43.

[23]Keskin A, Reşitoğlu İA, Özcanli M. Butanol, Etanol ve Benzin Karışımlarının Buji ile Ateşlemeli Motorlarda Özgül Yakıt Tüketimi ve Emisyona Olan Etkisi. Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi. 2009;24(1).

[24]Kul BS, Ciniviz M. Assessment of waste bread bioethanol-gasoline blends in respect to combustion analysis, engine performance and exhaust emissions of a SI engine. Fuel. 2020;277:118237.

[25]Balki MK, Sayin C, Canakci M. The effect of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline engine. Fuel. 2014;115:901-6.

[26]Göktaş M. Farklı Alkol Yakıt Kullanılan Buji Ateşlemeli Motorlarda Performans, Emisyon Ve Yanma Karakteristiklerindeki Değişimlerin Incelenmesi: Marmara Universitesi (Turkey); 2019.

[27]Kul BS, Ciniviz M. An evaluation based on energy and exergy analyses in SI engine fueled with waste bread bioethanol-gasoline blends. Fuel. 2021;286:119375.

[28]Topgül T, Yücesu HS, Cinar C, Koca A. The effects of ethanol–unleaded gasoline blends and ignition timing on engine performance and exhaust emissions. Renewable energy. 2006;31(15):2534-42.

[29]Koç M, Sekmen Y, Topgül T, Yücesu HS. The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. Renewable energy. 2009;34(10):2101-6.

[30]Yoon S, Ha S, Roh H, Lee C. Effect of bioethanol as an alternative fuel on the emissions reduction characteristics and combustion stability in a spark ignition engine. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 2009;223(7):941-51.

[31]Wang X, Chen Z, Ni J, Liu S, Zhou H. The effects of hydrous ethanol gasoline on combustion and emission characteristics of a port injection gasoline engine. Case Studies in Thermal Engineering. 2015;6:147-54.

[32]Kasmuri NH, Kamarudin S, Abdullah SRS, Hasan H, Som AM. Process system engineering aspect of bio-alcohol fuel production from biomass via pyrolysis: An overview. Renewable and Sustainable Energy Reviews. 2017;79:914-23.

[33]Deng X, Chen Z, Wang X, Zhen H, Xie R. Exhaust noise, performance and emission characteristics of spark ignition engine fuelled with pure gasoline and hydrous ethanol gasoline blends. Case Studies in Thermal Engineering. 2018;12:55-63.

[34]Costa RC, Sodré JR. Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions. Fuel. 2010;89(2):287-93.

[35]Iodice P, Langella G, Amoresano A. Ethanol in gasoline fuel blends: Effect on fuel consumption and engine out emissions of SI engines in cold operating conditions. Applied Thermal Engineering. 2018;130:1081-9.

[36]Özçelik, Z. & Gültekin, N. (2019). Effect of iridium spark plug gap on emission, noise, vibration of an internal combustion engine . International Journal of Energy Applications and Technologies , 6 (2) , 44-48 . DOI: 10.31593/ijeat.561307

[37]Gültekin, N. & Mayda, M. (2018). Investigation of effects of spark plug gap on vibration, noise and HC emission in a gasoline engine . International Journal of Energy Applications and Technologies , 5 (1) , 56-60 . DOI: 10.31593/ijeat.407684

[38]Turner D, Xu H, Cracknell RF, Natarajan V, Chen X. Combustion performance of bio-ethanol at various blend ratios in a gasoline direct injection engine. Fuel. 2011;90(5):1999-2006.

[39]de Melo TCC, Machado GB, Belchior CR, Colaço MJ, Barros JE, de Oliveira EJ, et al. Hydrous ethanol–gasoline blends–Combustion and emission investigations on a Flex-Fuel engine. Fuel. 2012;97:796-804.

[40]Najafi G, Ghobadian B, Tavakoli T, Buttsworth D, Yusaf T, Faizollahnejad M. Performance and exhaust emissions of a gasoline engine with ethanol blended gasoline fuels using artificial neural network. Applied energy. 2009;86(5):630-9.

[41]Schifter I, Diaz L, Rodriguez R, Gómez J, Gonzalez U. Combustion and emissions behavior for ethanol–gasoline blends in a single cylinder engine. Fuel. 2011;90(12):3586-92.

[42]Keskin A, Gürü M. The effects of ethanol and propanol additions into unleaded gasoline on exhaust and noise emissions of a spark ignition engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2011;33(23):2194-205.

[43]Holman, J. P., 2012, Experimental methods for engineers.

[44]Genceli, O. F., 1998, Ölçme tekniği:(boyut, basınç, akış ve sıcaklık ölçmeleri), Birsen Yayınevi, p.