INVESTIGATION OF EFFECTS ON FUEL CONSUMPTION AND EXHAUST EMISSIONS BY USING BIOETHANOL GASOLINE MIXTURE IN AN ENGINE WITH ULTRASONIC FUEL SYSTEM

by

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Original scientific paper
https://doi.org/10.2298/TSCI230318163O

This study compared the fuel consumption and exhaust emissions of a spark-ignition engine using a carburetor fuel system, an injection fuel system, and an ultrasonic fuel system. When using gasoline only, the ultrasonic fuel system showed a 31% decrease in fuel consumption compared to the carburetor system and a 15% decrease compared to the injection system. When adding 10% bioethanol to the gasoline, fuel consumption increased in all three systems, with the ultrasonic system showing the largest increase of 10%. Exhaust emissions were also measured, and the ultrasonic system showed a significant decrease in CO, HC, and NO_x compared to the carburetor and injection systems, with the largest decrease in CO emissions. The addition of bioethanol to the fuel resulted in reducing exhaust emission values in all three systems, with the ultrasonic system showing the largest decrease in CO and HC emissions compared to the carburetor and injection systems, but with an increase in NO_x emissions compared to the injection system. When comparing three fuel systems, it was observed that injection fuel systems have the highest CO_2 values. Although the addition of alcohol to the fuel does not cause a significant change in CO_2 emission values for injection and ultrasonic fuel systems, an increase is observed in the carburetor fuel system. Overall, the ultrasonic fuel system showed promising results for reducing fuel consumption and improving exhaust emissions.

Key words*: ultrasonic fuel system, fuel injection system, alternative fuel, bioethanol*

Introduction

Significant increases in exhaust emissions as a result of the use of fossil fuels in internal combustion engines significantly affect the world's ecological balance [1, 2]. The rising number of vehicles in use, the depletion of petroleum-based fuels, and their harmful effects on the environment have led to an increased search for alternative fuels [3, 4]. There is a lot of research being done on alternative fuels that can replace gasoline and diesel. Examples of such alternative fuels for internal combustion engines include alcohols such as methanol, ethanol,

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butanol, and non-petroleum fuels such as hydrogen and biodiesel obtained from vegetable oils [5], compressed natural gas and liquefied petroleum gas (LPG) such as butane propane are seen [6]. In studies, the main aim is to use alternative fuels without making radical changes in engines. It is known that preparing the appropriate air/fuel mixture in internal combustion engines is effective on combustion and exhaust emissions [7].

The article discusses the use of alcohols as fuel in internal combustion engines. Ethanol, methanol, and butanol are the most preferred alcohols due to their clean emission values and absence of heavy metals and carcinogenic substances. Alcohols burn faster and brighter than traditional motor fuels and can improve combustion rates when added to engine fuel. Increasing the octane number of the fuel by adding alcohol reduces the knocking tendency of the blended fuel and increases engine efficiency and thermodynamic activation. However, too much alcohol can cause phase separation and so precautions must be taken to prevent damage to engine parts [8-11].

Bioethanol, which is produced from biomass sources and has a high octane number, making it suitable for use in internal combustion engines. It is often used as a substitute for gasoline or mixed with gasoline as a bulking agent and octane booster in the transportation industry. Low-level bioethanol-gasoline mixtures have no significant effect on engine characteristics, and bioethanol can be used up to a mixture of E85 (85% bioethanol-15% gasoline) in specially manufactured engines [12-14].

Nibin *et al*. [15] In their study, it is to inject bioethanol into the inlet port with varying energy needs. They have seen significant improvement in combustion behavior, emission and performance characteristics.

Ozer *et al*. [16] demonstrated that when ethanol is added to the pilot fuel that will feed LPG in the TSI engine, it has a positive effect on engine performance and emissions.

The study conducted by Abdel-Rahman *et al*. [17] investigated the effects of different ratios of ethanol-gasoline fuel mixtures on a spark ignition engine. They found that increasing the amount of ethanol in the blend fuel resulted in lower heating values but higher densities and octane numbers.

Ameri *et al*. [18] investigated the power and heat combination of different ratios of gasoline-ethanol mixtures in an internal combustion engine. They measured the lower calorific value of the mixture fuels they prepared. As a result of these measurements, they stated that the lower calorific value decreased as the amount of ethanol in the gasoline increased.

The effects of adding 10% ethanol to gasoline in vehicles on exhaust emissions and fuel consumption were investigated by the Apace research company. The study found that the blended fuel had an increased octane number but a decreased lower calorific value. The presence of 3.5% oxygen in ethanol was found to lower the stoichiometric fuel/air ratio of the blended fuel compared to gasoline [19].

Injectors are used to ensure the atomization of the fuel sprayed into the intake manifold or combustion chambers in the engines [20]. Ultrasonic disintegration methods are being developed instead of these injectors with different structural features. Ultrasonic transducers are devices that convert energy from one form to another. Each converter has its own resonant frequency, in this sense it has an effective frequency range or bandwidth [21].

Electrical voltage is obtained with a mechanical pressure applied on some crystal and ceramic materials, this phenomenon is called piezoelectricity. When a piezoelectric crystal material is subjected to pressure, polarizations are obtained on its surfaces, leading to the generation of ultrasound through the mechanical stretches caused by these polarizations. The piezoelectric effect is bidirectional and can be used to both generate and detect ultrasound [22, 23].

In his research, Suslick and Nyborg [24] found that the cavitation effect, which involves the growth and sudden bursting of bubbles in a liquid, only occurs in the liquid. Intense ultrasound waves cause expansion waves that create voids in the liquid if the negative pressure exceeds the local tensile strength of the liquid. The cavity grows until it reaches a critical point where it can no longer absorb any more energy. When the ultrasound intensity exceeds the acoustic cavitational threshold, the cavity explodes and surrounding liquid rushes in to fill the void.

As seen in fig. 1., the fuel is pumped from the inlet and when it passes through the center of the tube and reaches the nozzle tip, ultrasonic vibrations transform the fuel into ultrafine particles without using pressure. Piezo ceramic material converts the electrical signal into mechanical vibrations. Ultrasonic fuel systems work by mechanically contracting and expanding two piezoelectric transducers between two electrodes fed by a high frequency electrical signal. This movement causes ultrasonic vibrations at the titanium tip, which is the atomization part of the fuel system. As a result of this vibration energy, capillary waves are formed in the center of the liquid in the center of the nozzle. When the ultrasonic wave intensifies and reaches a critical level, small droplets break off from the surface of the liquid [25].

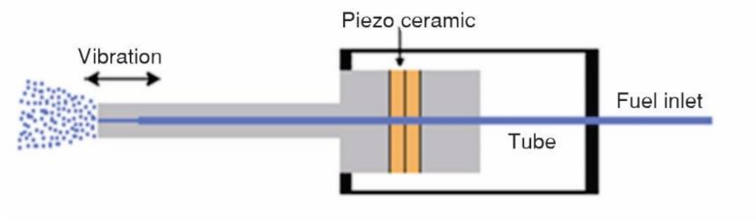

Figure 1. Working principle of ultrasonic fuel system

Ultrasonic spraying system uses only low ultrasonic vibration energy for atomization. The liquid can be atomized continuously or intermittently by being brought to the spray nozzle by gravity or a low pressure conveying pump. The rate of spraying to liquid atmosphere is dependent, within limits, only on the volume and frequency delivered to the atomizing surface [26].

Although the underlying cause of droplet formation in this technique is not fully understood, two theories have been accepted in this field.

The first of these theories is the theory of cavitation. In this theory, ultrasonic sound waves create hydraulic vibrations on the liquid. These hydraulic vibrations cause the formation of microbubbles known as cavitation. The microbubbles are expanded and contracted very quickly by the ultrasonic energy and eventually burst. The droplets are separated from the liquid surface by the shock wave caused by the explosion of micro bubbles. Observations have shown that cavitation has sufficient energy to create fog droplets on the liquid [27].

The second theory is the capillary wave theory. High-frequency ultrasonic sound waves create non-stationary oscillations on the liquid. The capillary wave theory states that the droplets separated from the liquid by disintegrating at the peak point where these non-stationary oscillations move away from the liquid surface form a nano-sized fog cloud [28, 29].

In this study, ultrasonic fuel system was used to provide micron-sized atomization by breaking down gasoline and bioethanol mixture fuels used in spark ignition engines. In this way, it is aimed to prepare a homogeneous air/fuel mixture, to provide better combustion and improvement in exhaust emissions. In addition, 10% bioethanol is added to gasoline and its effects on exhaust emissions are investigated. The aim is to contribute to scientific advancements in this field and enhance the existing literature.

Materials

In this study, Kama By Reis KGP20 brand carbureted single-cylinder gasoline engine was used. Technical specifications of Kama By Reis KGP20 brand engine are given in tab. 1. The water pump used to load the engine was taken with the test engine.

Table 1. Kama By Reis KGP20 brand

Engine type	4-stroke single cylinder carburetor gasoline engine
Diameter × stroke	68 × 45 mm
Cylinder displacement	163 cm^3
Compression ratio	9.0 : 1
Net power	3.6 kW / 3600 rpm
Maximum Net torque	10.3 Nm / 2500 rpm
Ignition system	Magnetic ignition
Manner of Work	Starter motor/manual
Fuel consumption	1.4 Lph
Oil capacity	0.6 L
Engine power	5.5 hp
Weight	24 kg
Fuel type	Unleaded gasoline

Bosch BAE 350 brand exhaust analyzer was used in the studies. It can precisely measure both Diesel engine exhaust emission and gasoline engine exhaust emission analysis. Emissions and sensitivity level that the device can measure in gasoline measurement mode are given in tab. 2.

Table 2. Bosch BAE 350 Petrol mod emission values and sensitivity

Emission	Measuring Range	Sensitivity
CO	0.000-10.00 %.vol	0.001%.vol
CO_2	0.00-18.00 %.vol	0.01 %.vol
HC	0-9.999 ppm vol	1 ppm vol
O_2	0.00-22.00 %.vol	0.01 %.vol
λ	0.500-9.999	0.001
NO	0-5000 ppm vol	<=1 ppm vol

In order to create a piezo electric effect, two piezoceramic sensors are used in the system. The technical specifications of the piezoelectric ceramic sensors used are given in tab. 3. Piezoelectric ceramic sensors are fixed to the bottom of the fuel tank. When the system is started, the fuel splits into steam. By adjusting the air-fuel ratio with a valve placed at the tank outlet, the vaporous fuel is sent to the combustion chamber of the engine.

Table 3. Properties of piezoelectric ceramic

Components	Lead Zirconate Titanate [PZT]
Input voltage (Max) [V]	48 ±10%
Power consumption [W]	30 ±5
Ultrasonic frequency [kHz]	1600-1750
External potentiometer [kΩ]	5
Liquid temperature [°C]	0-45
Transducer lifetime [hour]	10000
Parallel connection studies	Proper

An adapter (reducing 220 V to 12 V) and two generators (one for each piezoelectric ceramic sensor) were used in the experimental set-up. The maximum operating voltage of the piezoelectric sensor used in ultrasonic atomization is 40 V. The amplifier circuit can change the 5 V DC voltage on it with the help of the adjustment screw in the range of 5 V to 40 V by driving the relays. It has input and output sockets, input capacitors, coil, adjustable resistor, transistor and finned coolers and microprocessors that determine the output voltage.

When choosing a piezoelectric sensor, the highest frequency piezoelectric ceramic that can form the largest number of droplets was selected. That is, the generated frequency is on the order of 1.6 MHz. Frequency circuit is one of the most important elements of the system. It is the circuit that produces the frequency that will make the sensor, which is a piezoelectric ceramic, vibrate mechanically at the molecular level. It has a socket for the input of the voltage coming from the amplifier circuit, the necessary circuit elements and the output as frequency. Frequency output cables are directly connected to the piezoelectric ceramic.

In order to convert the test engine to an injection fuel system, an injector kit produced for Howdytubor brand single-cylinder engines was supplied. The part where the carburetor is attached from the engine was removed and the injector system was installed instead.

Method

In the experimental studies, unleaded 95 octane gasoline purchased from Opet company and bioethanol produced from Starfire brand corn were used. In studies, two different fuel mixtures were prepared as BE0 (100% gasoline + 0% bioethanol), BE10 (90% gasoline + 10% bioethanol). The BE0 and BE10 fuels were used in the test engine. The water pump integrated into the engine presses the water drawn from the water tank at the engine level to the 3.5 m high water tank. In this way, it is ensured that he engine works under partial load. The engine was operated under the same load with the carburetor, injection and ultrasonic fuel systems. Fuel consumption and exhaust emission results were measured.

While converting the ultrasonic fuel system, the carburetor bowl of the carburetor system and the needle through which the fuel passes were removed, instead the fuel tank where ultrasonic atomization was made was connected with a hose and valve. The air filter of the engine was removed and a valve was installed in its place. The air-fuel ratios of the engine are adjusted with the help of these valves. Adjustments were made using the air and fuel adjustment valves to set the λ value provided by the exhaust emission device to 1. The fuel broken down in the ultrasonic fuel system is drawn by the vacuum effect and mixed with air in the intake manifold and sent to the cylinder. Figure 2. shows the state of the fuel before and after the ultrasonic atomization starts. Figure 3 presents the engine testing methodologies.

Figure 2. Ultrasonic atomization

Experimental uncertainties are influenced by various factors, including elements such as instrument selection, calibration, experimental set-up and design, and data collection techniques. In the field of engineering applications, one of the widely accepted methods for error analysis among researchers is the root-sum-square method [30-32].

The total uncertainty was calculated using:

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

where R represents a function of the dependent factor and independent variables, where x_1, ..., and x_n denote the independent variables. The uncertainty value of the results is represented by W_R, while w_1, w_2, *etc*., represent the uncertainties associated with the independent variables.

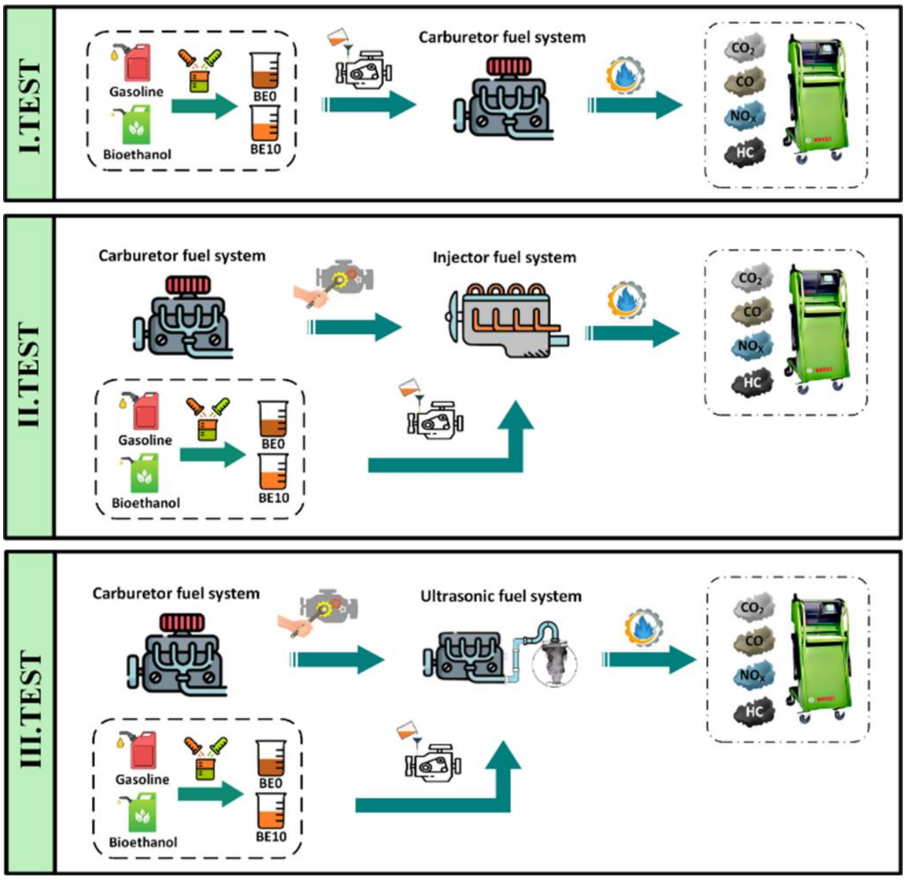

Figure 3. Engine testing methodologies

Overall uncertainty of emissions = [(uncertainty of HC)^2 + (uncertainty of CO)^2 + (uncertainty of CO_2)^2 + (uncertainty of NO_x)^2]$^{1/2}$

$$= \sqrt{(0.0033)^2 + (0.00014)^2 + (0.0008)^2 + (0.0051)^2} = 0.0061 = 0.61\%$$

Therefore, the square root technique proposed by Holman was employed in this study to calculate the uncertainties in the obtained results [33]. Based on the uncertainty analysis of the emission measurements, it has been determined that there is a combined uncertainty of 0.61% for HC, CO, CO_2, and NO_x.

Results and discissions

Fuel consumption

Describes an experiment in which an engine with a carburetor, ultrasonic and injector fuel system three different was operated using two different fuel (BE0, BE10), and the fuel consumption and exhaust emission values were measured and compared. The results showed that the ultrasonic fuel system had the lowest fuel consumption, and its combustion was improved due to better fuel splitting and mixture preparation, resulting in better emission values. At 2300 rpm (engine's most efficient rpm), the fuel consumption decreased by 31% compared to the carburetor system and 15% compared to the injection fuel system. The injection and ultrasonic fuel systems were found to be more effective than the carburetor system at high speeds. The changes in fuel consumption engine speed are presented in fig. 4. In fig. 5., fuel consumption was measured using BE10 (90% gasoline + 10% bioethanol) fuel in three different fuel systems. At 2300 rpm, the fuel consumption decreased by 26% compared to the carburetor system and 1% compared to the injection fuel system.

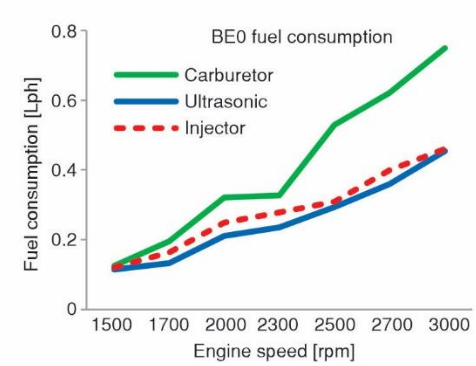

Figure 4. Variation of BE0 fuel consumption in three different fuel systems

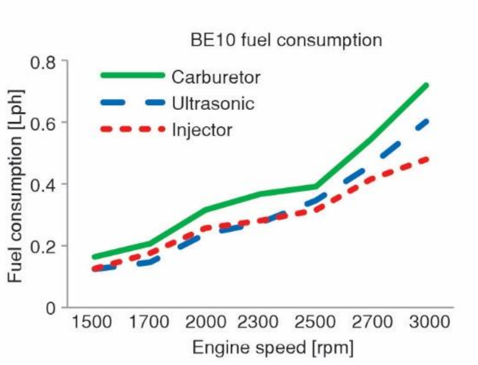

Figure 5. Variation of BE10 fuel consumption in three different fuel systems

It is seen that the bioethanol additive increases the fuel consumption for all fuel systems. The reason for this can be shown as the low heating value of bioethanol due to the presence of oxygen in it. It can be said that the carburetor and injection fuel system has a more positive effect on mixture preparation at high engine speeds. It is understood that the positive effect of the ultrasonic fuel system on fuel consumption at high engine speeds is lower than that of the carburetor and injection fuel systems [34].

Exhaust emission

The CO, CO_2, HC and NO_x components constituting the exhaust gas content were measured after the engine was run with three different fuel systems. The changes of these components with the engine speed were drawn graphically and the data of the three fuel systems were compared.

Figure 6 shows the CO emission values when working with gasoline. The CO emission values were compared with different fuel systems. The carburetor system produces the best emission value in the 1600-1800 rpm range due to better volumetric efficiency and combustion. However, at high speeds, the volumetric efficiency decreases, and the CO values increase due to the decrease in combustion reaction time. The injection system produces lower CO values than the carburetor system, and CO values increase linearly with rpm. The ultrasonic fuel system produces minimal CO change in all rev ranges due to the fuel's smaller pieces and the acceleration of the combustion reaction with the resonance effect. In the ultrasonic fuel system, CO emissions exhibited a reduction of 98% compared to the carburetor fuel system, and a reduction of 97% compared to the injection fuel system.

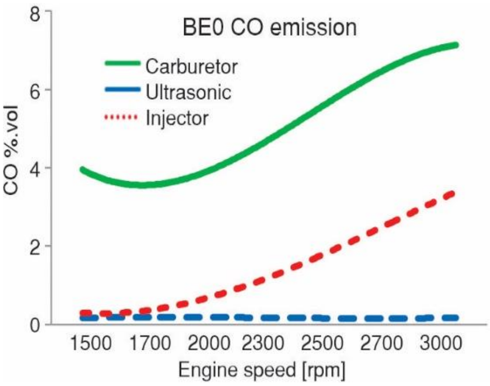

Figure 6. Change of CO emission values of BE0 fuel in three different fuel systems

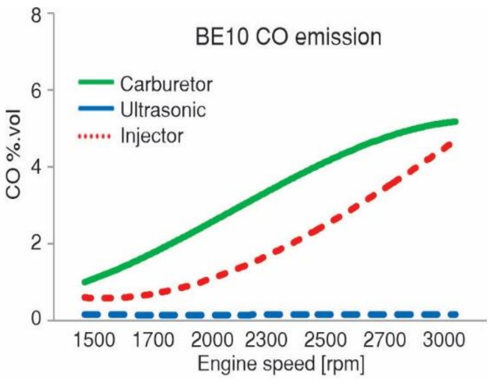

Figure 7. Change of CO emission values of BE10 fuel in three different fuel systems

When bioethanol is added to gasoline, the CO value decreases in the carburetor fuel system, fig. 7. The effects of gasoline-bioethanol mixtures on combustion performance when used with different fuel systems were compared. Bioethanol's presence improves combustion due to the higher linear combustion rate and the presence of oxygen. However, when used with the injector fuel system, the CO emission slightly increases with bioethanol addition, and the CO ratio increases due to the formation of rich ethanol regions in the filler, causing flame extinction points. Studies have shown that as the ethanol ratio increases, flame extinction points form, and CO emission increases [35].

In the studies carried out with BE0 and BE10 fuels using the ultrasonic fuel system, it was observed that the CO emission value was 2% and did not change as the rev increased. It has been determined that the excess air coefficient, λ, does not change with the engine rev in the operation with the ultrasonic fuel system and the engine works with the ideal air/fuel mixture ratio. As a result, CO emissions remain constant at the minimum value. The lowest CO emission values among the three fuel systems were realized in the ultrasonic fuel system and the highest CO emission values were realized in the carburetor fuel system.

The CO_2 emission change in the study conducted with three different fuel systems using gasoline as a fuel is shown in fig. 8. Compares the CO_2 emissions of different fuel systems, and it is observed that the highest CO_2 emission occurs in the injector fuel system, slightly less in the ultrasonic system, and the lowest CO_2 emission occurs in the carburetor system. The best combustion occurs with the fuel system with injectors. The study shows that the CO_2 value remains unchanged in the ultrasonic fuel system, while it changes with the revolution in the carburetor and injection fuel systems. In the injection fuel system, the CO_2 value is highest at around 2300 per minute. However, in the carburetor fuel system, the CO_2 emission decreases with increasing revolutions, indicating poor mixture preparation at high speeds.

In the studies carried out by adding 10% bioethanol to gasoline, the change in CO_2 emissions for three different fuel systems is shown in fig. 9. The carburetor system shows the highest CO_2 value at low revs, while the ultrasonic fuel system has a constant CO_2 value. The injector system has an increasing CO_2 value with an increase in revs, but it decreases after reaching the maximum value around 2300 rpm. The addition of bioethanol has a positive effect on combustion, especially in the carburetor system.

The most important problem encountered when bioethanol is added to gasoline is the formation of two separate phases in systems that are expected to be continuously homogeneous.

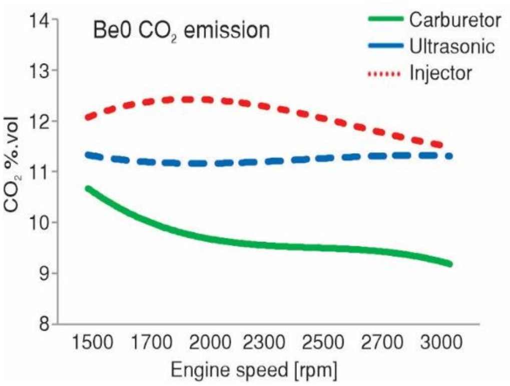

Figure 8. Change of CO_2 emission values of BE0 fuel in three different fuel systems

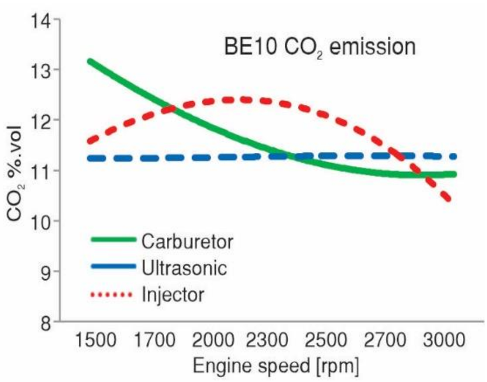

Figure 9. Change of CO_2 emission values of BE10 fuel in three different fuel systems

Therefore, when the phase-separated mixture reaches the engine, it can be said that when the bioethanol phase burns in the engine alone, it causes flame extinction in some parts of the engine, and therefore the CO_2 emission value decreases. The fact that this negative effect is not seen in the ultrasonic fuel system can be considered as an advantage. It is seen that at 3000 1/min engine speed, CO_2 increases in the carburetor system, decreases by 10% in the injection system, and does not change in the ultrasonic system. In the ultrasonic fuel system, the CO_2 emission value generally exhibited an overall increase of approximately 16% compared to the carburetor fuel system, and an overall decrease of approximately 9% compared to the injection fuel system.

Figure 10 shows the variation of HC emissions with engine speed for three fuel systems in tests using only gasoline as fuel. The carburetor fuel system shows the highest HC emissions while the ultrasonic fuel system shows the lowest HC emissions. The injection fuel system has an increase in HC emissions with an increase in engine speed, which is due to insufficient air movements for ideal mixture preparation. In contrast, the ultrasonic system is not significantly affected by the engine speed. Low HC values have a positive impact on engine performance and fuel economy. In tests performed by adding 10% bioethanol to gasoline, it was observed that HC emissions were reduced for the three fuel systems, fig. 11.

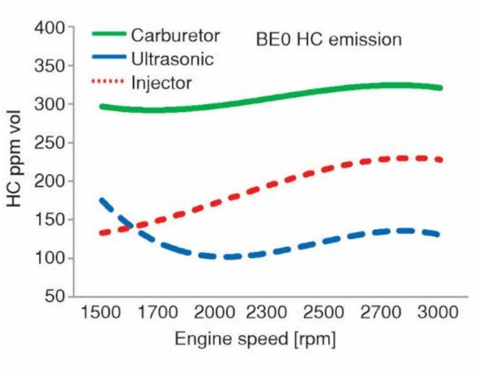

Figure 10. Change of HC emission values of BE0 fuel in three different fuel systems

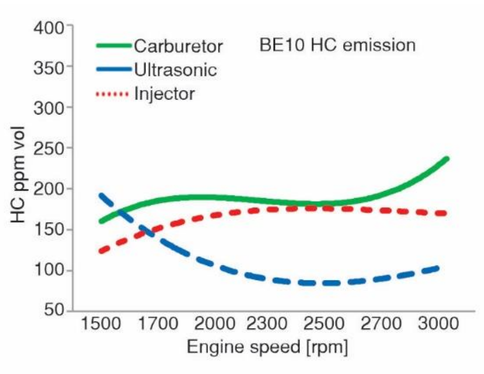

Figure 11. Change of HC emission values of BE10 fuel in three different fuel systems

It is understood that the oxygen in bioethanol contributes positively to this decrease. In studies with carburetor and ultrasonic fuel system, the lowest values were found in the region where the engine was running at 2300 rpm. When ultrasonic fuel system and injection fuel system are used, it is seen that there is no significant change in HC emission at engine speeds above 2300 rpm, while HC increases in the carburetor fuel system. It can be said that the mixture preparation and combustion process in the ultrasonic and injection fuel system are not adversely affected by high engine speeds. In the ultrasonic fuel system, HC emission values demonstrated an approximate reduction of 68% compared to the carburetor fuel system, and an approximate reduction of 47% compared to the injection fuel system.

Figure 12 shows the change in engine speed and NO_x for three fuel systems when the engine is running only with gasoline, and in fig. 13, when it is started with BE 10 fuel. It is seen that NO_x emission values are maximum at 2300 rpm in the carburetor fuel system and at 2600 rpm in the ultrasonic fuel system in working with gasoline. It is understood that the combustion chamber temperature is quite high at the mentioned revolutions. As a matter of fact, it was measured that the exhaust gas temperature was at the highest value at the mentioned revolutions. It is seen that there is no significant change in NO_x values in the fuel system with injectors. The NO_x emissions were maximum 200 ppm. This is a very low level and can be said to be an expected result for gasoline engines.

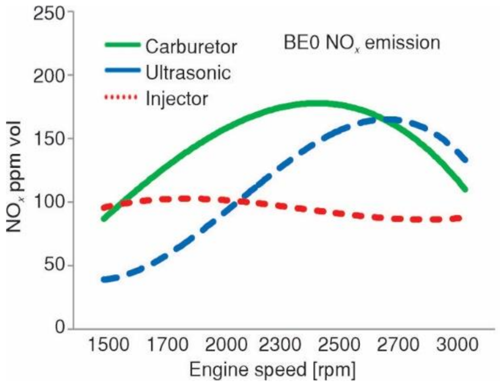

Figure 12. Change of NO_x emission values of BE0 fuel in three different fuel systems

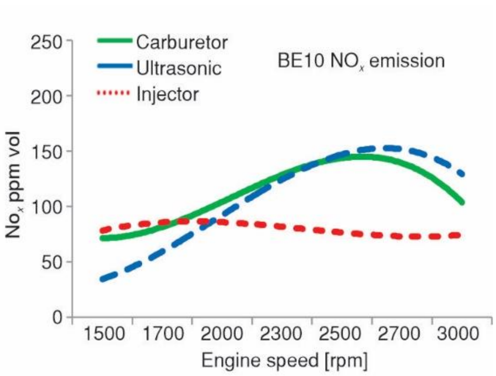

Figure 13. Change of NO_x emission values of BE10 fuel in three different fuel systems

The variation of NO_x values in the three fuel systems in operation with BE10 fuel is similar to the results of working with gasoline. It is observed that the maximum NO_x value decreases somewhat in operation with only the carburetor fuel system.

Conclusions

In this study, experimental studies were carried out in a carbureted spark ignition engine by converting it injection and ultrasonic fuel system in order to increase combustion performance. Fuel consumption and exhaust emissions were measured by using gasoline and gasoline-bioethanol mixture fuel. The lowest fuel consumption and CO and HC emissions were seen in the ultrasonic fuel system. While reducing HC emissions, the addition of bioethanol increased fuel usage and CO_2 emissions. The carburetor system had the highest NO_x emission levels, and the injector systems had the lowest values. This study demonstrates the potential utilization of the ultrasonic fuel system as a viable alternative to carburetor and injection fuel systems.

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Paper submitted: March 18, 2023
Paper revised: June 16, 2023
Paper accepted: June 24, 2023