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Experimental Investigation of the Effect of Nitromethane Addition to Gasoline Fuel on A Single-Cylinder Spark-Ignition Engine Performance and Emissions

Samet Çelebi[1, *], Üsame Demir[2], Gökhan Ergen[3]

0000-0002-4616-3935, 0000-0001-7383-1428

[1] *Sakarya University of Applied Science,Arifiye Vocational School, Motor Vehicles and Transportation Technologies Dep., Arifye,Sakarya, Turkey*
[2] *Bilecik Şeyh Edebali University Engineering Faculty, Mechanical Eng. Dep., Bilecik, Turkey*
[3] *Sakarya University of Applied Science, Faculty of Technology, Mechanical Eng. Dep., Esentepe,Sakarya, Turkey*

Abstract

In this study, the effect of nitromethane addition to gasoline fuel on engine performance and emissions in a single-cylinder spark-ignition engine was experimentally investigated. By adding 5% and 10% nitromethane to gasoline, experiments were carried out at full load at six different cycles. Engine load, fuel consumption, exhaust gas temperature, and emissions were measured during the experiments. According to the measured experimental data, engine power, torque, specific fuel consumption, exhaust gas temperature, average effective pressure, thermal efficiency, CO, CO_2, HC, and NO_x values were compared with each other. According to these results, nitromethane's addition improved engine power, torque, specific fuel consumption, and thermal efficiency. It is understood that the addition of nitromethane to gasoline improves combustion efficiency and increases thermal efficiency. With the addition of nitromethane, an increase in CO_2 emission, which is a product of complete combustion, and a decrease in CO emission occurred. This supports the increase in combustion efficiency. HC emissions have decreased. There has been an increase in NO_x emissionsIn addition, since the addition of more than 10% nitromethane causes engine instability, it has created difficulties in using it without modification in the engine.

Keywords: Spark ignition engine, Nitromethane, Engine performance, Exhaust emissions

Research Article

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* Corresponding author

Samet Çelebi

scelebi@subu.edu.tr

Address: Automotive Engineering Department, Faculty of Technology, Gazi University, Ankara, Turkey

Tel:+903122028653

1. Introduction

Fossil fuels used in motor vehicles significantly affect environmental pollution. In order to reduce this negative effect, alternative fuels that can be used instead of the fuels used in internal combustion engines are being investigated [1-3]. Studies have reported that fuels such as nitromethane, which have a high laminar combustion rate, increase the thermal efficiency of internal combustion engines [4-7]. If the engine's thermal efficiency can be increased by improving the fuel properties, it is possible to improve without extensive engine changes [4]. The reason for adding nitromethane to the fuel in this study is that nitromethane has a tendency to increase thermal efficiency.

It has been reported that the combustion velocity and extinction characteristics of fuels greatly affect engine performance depending on engine power, fuel consumption, and emission characteristics [8]. Studies have been carried out to measure combustion velocity and extinction properties for various fuels [4, 9-12]. Nitromethane; It is a high-energy material with a wide range of uses, such as monopropellant, liquid explosive, a solvent in chemical processes and analysis, a high-performance fuel additive in internal combustion engines and pulsed detonation engines (PDE) [13]. Nitromethane is liquid at atmospheric pressure and room temperature. When liquid nitromethane is used as an additive in propellants and explosives, it evaporates and creates nitromethane/air mixtures. The danger of an accident caused by one of the hidden problems mainly depends on the minimum ignition energy (MIE) of the gaseous nitromethane/air mixture [14]. When the studies in the literature were examined, it was seen that studies on the combustion velocity and explosion properties of nitromethane as a component of liquid explosives and propellants were reported [13-20]. In addition, there are very few studies on the use of nitromethane fuel in internal combustion engines, apart from studies investigating the effect of a single fuel on the laminar combustion rate of nitromethane [4, 21-23].

Starkman investigated the effect of nitromethane mixtures on engine performance and observed an increase in engine power with the addition of nitromethane [24]. Raine et al. and Bush et al. have reported similar results in studies [25, 26]. Nitromethane gasoline mixtures are used to increase engine power in drag races [27]. The lower calorific value of gasoline is 42-44 MJ/kg, while the lower calorific value of nitromethane is 11.3 MJ/kg. It takes 14.7 units of air to fully combustion 1 unit of gasoline, while 1.7 units of air are sufficient to burn 1 unit of nitromethane. If we consider a given cylinder volume, it is seen that 8.6 times more nitromethane fuel can be combustion in one go compared to gasoline. This means that approximately 2.3 times more power can be obtained when nitromethane is used instead of gasoline with the same amount of air [26]. Yokoo et al. investigated how different fuel mixtures affected the thermal efficiency of a spark-ignition engine and reported that the addition of 5% nitromethane increased the thermal efficiency by 1-2% [5]. They also stated that the addition of nitromethane reduced the research octane number (RON) up to 5 points and increased the probability of knocking. Similar research results Cracknell et al. It has also been reported by Cracknell et al. They investigated the effects of adding 5% nitromethane in an HCCI engine on engine performance [28]. In addition, there are studies experimentally examining the effect of nitromethane in the laboratory environment and on vehicles on exhaust emissions [29-31].

This study examined the effect of nitromethane addition to gasoline on engine performance and emissions in a single-cylinder, four-stroke, air-cooled gasoline engine. It is seen that studies in the literature are generally on the determination of nitromethane properties as a fuel. There are limited studies on the use of nitromethane as a fuel additive. The case of adding it as an additive to gasoline in a gasoline engine was investigated in this study. Experimental results of their effects on combustion properties, thermal efficiency, and exhaust emissions are presented.

2. Material and Method

A single-cylinder, four-stroke, air-cooled gasoline engine was used in the experiments. The test engine is the Honda GX160 model. Except for the fuels used in the test engine, no other parameters were changed. The specifications of the test engine are shown in Table.1. In addition, the experimental setup is shown in Figure.1.

Table 1. Test engine specifications

Test Engine	Honda GX160
Cylinder number	1
Maximum engine speed (rpm)	3600
Compression ratio	8.5/1
Cylinder diameter x stroke (mm)	68 x 45
Cylinder volume (cm^3)	163
Maximum torque (Nm/2500 rpm)	10,3
Maximum power (kW/3600 rpm)	3,6

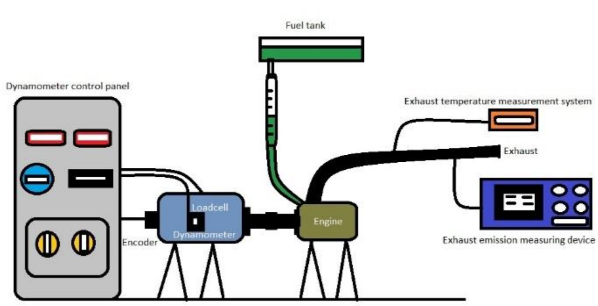

Fig. 1. Experimental Setup

Table 2. Gasoline and nitromethane fuel specifications

	Gasoline	Nitromethane
Heating Value (MJ/kg)	43.4	11.3
Specific Density (g/ml)	0.73	1.14
Air/Fuel ratio for stochiometric mixture (mass)	14.7	1.7
Autoignition temperature (ºC)	257	417

All devices in the measuring stand were calibrated before the experiments. The test engine was braked using an electric dynamometer called Theory Electric with a capacity of 15 kW. No changes were made in the experiments except for the fuel mixtures. The engine's exhaust gas temperature was measured using a type K thermocouple placed in the exhaust manifold. Exhaust emissions were measured using a BİLSA brand emission measuring device connected to the exhaust line. The uncertainty analysis of the experimental measurements is given in Table 3.

Table 3. Uncertainty of measuring device

Parameters	Measurement Range	Sensitivity
CO	0 % - 10 %	0,001 %
CO2	0 % - 20 %	0,01 %
HC	0 – 10.000 ppm	1 ppm
O2	0 % - 25 %	0,01 %
CO Corr	0 % - 10 %	0,001 %
NOx	0 – 5000 ppm	1 ppm
Lambda	0,5 – 2,00	0,001
Engine speed	0-6000 RPM	1%
Time measurement	-	1%
Exhaust gas temperature	-50 ºC-1000 ºC	±1%

It was carried out with mixtures of 100% gasoline, 95% gasoline + 5% nitromethane and 90% gasoline + 10% nitromethane. The fuel consumption measurement was determined by measuring the number of seconds in which 25 ml of fuel was consumed in volume terms, and it was calculated in grams/second, taking into account the mixture densities. Fuel properties were obtained as a report from the company supplying the fuel. Some properties of test fuels are given in Table.2.

3. Experimental Results

The first experiment was conducted with 100% gasoline (95 octane unleaded) in this study. The purpose of this is to create a reference to evaluate the results from the mixture experiments. The second experiment was carried out with a mixture prepared with 95% gasoline and 5% nitromethane. The third experiment was carried out with a mixture of 90% gasoline and 10% nitromethane. The results obtained were compared with each other, and the effects of nitromethane addition were evaluated. Fuel mixtures were prepared by calculating as volumetric mixtures.

In Figure 2, the variation of the effective power at different mixing ratios according to the engine speed is shown. It was observed that the effective power increased accordingly as the nitromethane ratios in the mixture increased. In the experiment with 10% nitromethane addition, the maximum effective power measured at 3500 RPM was 15.58% higher than the maximum effective power measured in the experiment with 100% gasoline. The addition of nitromethane appears to give better results than 100% gasoline.

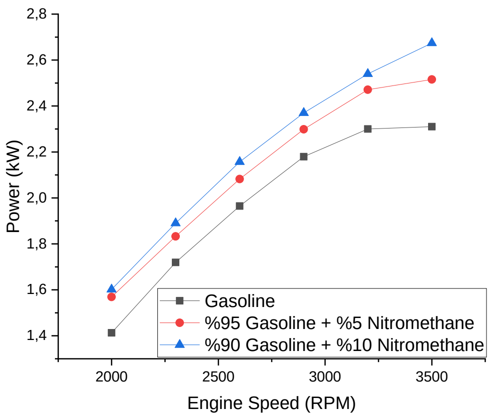

Fig. 2. Engine power variation with engine speed

In Figure 3, when the torque change with respect to the engine speed is examined, it is seen that the best torque outputs are realized at medium engine speeds. Torque values are seen to be less at low and high engine speeds. This is because the RPM ranges where the most filler can be taken into the cylinder are the mid RPM ranges. At low and high engine speeds, the scavenging losses in the engine increase and the volumetric efficiency decrease. Especially at low engine speeds, the high heat losses in the cylinder walls due to the slow operation of the engine affect this situation. When the engine reaches medium speeds, the volumetric efficiency increases, and the torque value increases as the losses decrease. At high engine speeds, the volumetric efficiency decreases due to increased losses, especially with the shortening of the intake time. In addition, friction losses increase depending on the engine speed. The highest moment value was obtained as 7.93 Nm in 10% nitromethane addition at 2600 RPM. This value has increased by 9.83% compared to 100% gasoline.

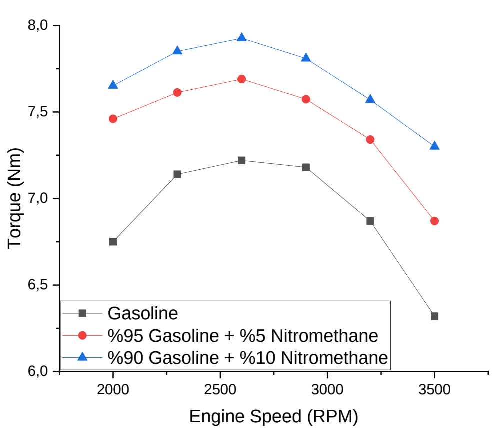

Fig. 3. Engine torque variation with engine speed

The variation of specific fuel consumption depending on engine speed is given in Figure 4. The lowest specific fuel consumption value was obtained at 3200 RPM engine speed in a 5% nitromethane mixture with a decrease of 6.7% compared to gasoline. Mixtures with 5% and 10% nitromethane addition gave similar results. It has been observed that these values are less than the fuel consumption of 100% gasoline. It is seen that the most improvement in specific fuel consumption compared to 100% gasoline was obtained from 5% nitromethane mixture with a decrease of 7.83% at 2600 RPM. Specific fuel consumption at low engine speeds gave poor results. The engine speed decreased as it reached the middle levels and showed a tendency to increase again when it came to higher speeds than 3200 RPM. When all the mixtures are considered, it is seen that the lowest value is 392.5 g/kWh in the mixture containing 5% nitromethane at 3200 RPM. It is thought that the reason why the lowest specific fuel consumption value occurs in the mixture containing 5% nitromethane is that the mixture is formed at values close to the stoichiometric ratio, with the lambda value approaching 1 compared to 100% gasoline fuel. When the lambda values are compared, it is seen that the labmda value measured in the tests with 100% gasoline fuel is in the range of 0.814 - 1. It is seen that the measured lambda values are in the range of 0.869 - 1.064 in the tests performed with a mixture containing 95% gasoline + 5% nitromethane. The lambda values measured in the tests performed with a mixture containing 90% gasoline + 10% nitromethane are in the range of 0.978 - 1.266. When the lambda values are examined, it is seen that the fuel/air mixture is in the rich mixture region in the tests performed with 100% gasoline fuel. In the tests performed with the mixture containing 5% nitromethane, it is seen that the lambda is measured at the values closest to the 1 level. In the mixture containing 10% nitromethane, it is seen that the lambda value of the mixture is measured above 1. This indicates that the mixture containing 10% nitromethane is in the poor region. The fact that the mixture is rich in the tests made with a mixture containing 100% gasoline and the mixture is poor in the tests performed with a mixture containing 10% nitromethane affects the combustion negatively. For this reason, the fact that the ideal lambda value of 1 was measured in the mixture containing 5% nitromethane shows that the best combustion was obtained in these tests. Therefore, the specific fuel consumption is considered to be the lowest in the mixture containing 5% nitromethane [32].

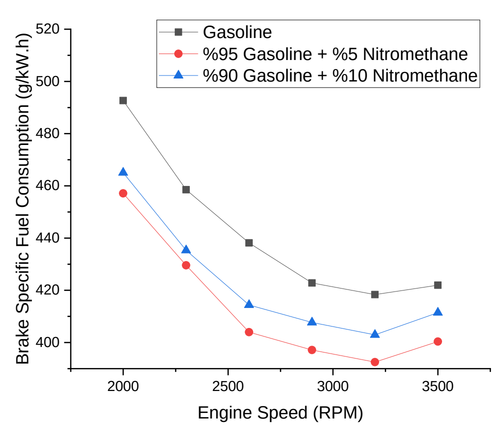

Fig. 4. Engine Brake Specific Fuel Consumption variation

Effective efficiency changes with nitromethane addition in different RPMs are given in Figure 5. When the data is examined, it is seen that the effective efficiency gives the best results in 10% nitromethane addition. However, the effective efficiency results of 5% and 10% nitromethane addition were close. In the experiments, the engine speed that gives the best result for all the mixtures is 3200 RPM. Here, there is an improvement of 14,67% compared to 100% gasoline. In addition to its depleting effect on the fuel-air mixture, nitromethane contributes to combustion improvement by creating a more homogeneous fuel-air mixture due to its easy evaporation feature and its ability to carry oxygen in its structure to every point where the fuel reaches. The increase in volumetric efficiency and combustion efficiency affects positively.

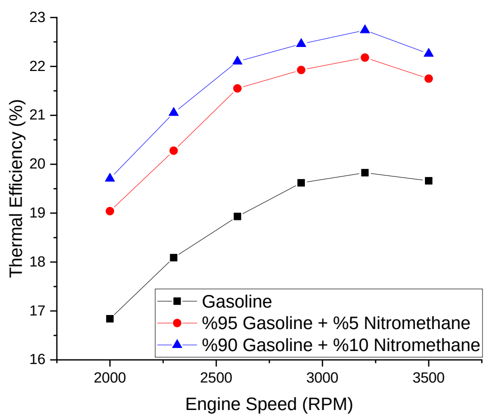

Fig. 5. Engine Thermal Efficiency variation

In Figure 6, the mean effective pressure amounts varying according to the engine speed at different mixing ratios are shown. It is concluded that the maximum mean effective pressure is realized at 2600 RPM and the mean effective pressure with the addition of 10% nitromethane increases by 8.94% compared to the mean effective pressure of the mixture containing 100% gasoline. The highly effective parameters here are the effective power and engine speed. In the RPM range where combustion is good, the mean effective pressure increased directly to this. The decrease in volumetric efficiency at low and high speeds negatively affects the engine torque and the mean effective pressure accordingly.

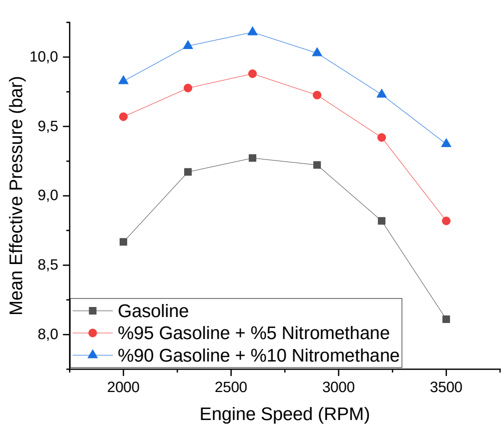

Fig. 6. Engine Mean Effective Pressure variation with engine speed

Figure 7 shows the variation of exhaust temperatures with nitromethane addition and engine speed. It is observed that the exhaust temperatures decrease with the increase of nitromethane ratios in the mixture.

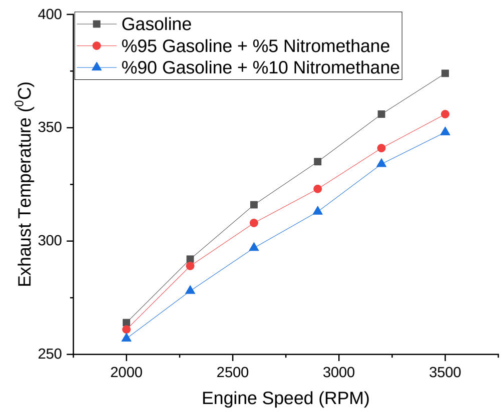

Fig. 7. Engine Exhaust Temperature variation

The variation of CO_2 emissions according to nitromethane addition is given in Figure 8. In all cases, CO_2 emissions increased with increasing engine speed. CO_2 emission is an indicator of complete combustion. It can be said that the better the combustion, the higher the CO_2 emission. It is seen that CO_2 emission increases proportionally with the addition of nitromethane. Here, it is seen that the most increasing result obtained compared to 100% gasoline occurred in the addition of 10% nitromethane with an increase of 16.45% at 2000 RPM.

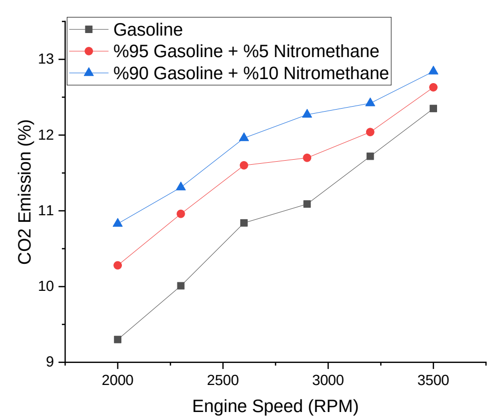

Fig. 8. CO_2 emission variation with engine speed

In Figure 9, the variation of the CO emissions obtained in the experiments performed at full load at different mixing ratios according to the engine speed is given. It is seen that CO emission decreases with increasing engine speed in all mixing ratios. It is seen that the CO emission values of the addition of 5% and 10% nitromethane are lower than the CO emission values of gasoline. The oxygen content of nitromethane causes the mixture to become depleted, thus helping to reduce the emission of CO, which is a product of incomplete combustion. It is seen that the amount of decrease in CO emission increases with the increase of nitromethane addition. The addition of 10% nitromethane which shows a 53.06% reduction at 2900 RPM, gives the best result compared to 100% gasoline.

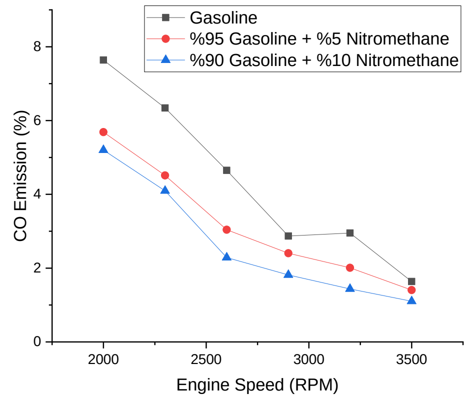

Fig. 9. CO emission variation with engine speed

In Figure 10, the variation of HC emission with respect to engine speed at different mixing ratios is given. It is seen that HC emissions decrease with engine speed increases. It is observed that HC emissions of 5% and 10% nitromethane addition compared to gasoline decrease more. An important detail that reduces HC emissions, which is a product of incomplete combustion, is that nitromethane contains oxygen and increases the amount of fuel by reducing the temperature in the cylinder before combustion since its latent heat of vaporization is higher than gasoline. Thus, combustion takes place more efficiently, and a significant reduction is observed in HC emissions. The best results were obtained in 10% nitromethane addition at 3500 RPM compared to 100% gasoline. In this RPM, HC emission of 10% nitromethane addition decreased by 41.44% compared to 100% gasoline mixture [33-35].

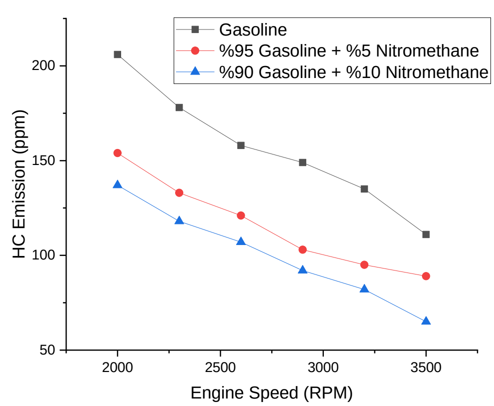

Fig. 10. HC emission variation with engine speed

Figure 11 shows the values of NO_x emissions according to engine speed at different nitromethane additions. Exhaust outlet temperatures decrease with increasing nitromethane addition. Nitromethane combustion is much faster than gasoline and suddenly increases the combustion temperature in the cylinder. Thus, a suitable environment is prepared for the formation of NO_x emissions at the end of combustion. The fact that nitromethane combustions faster than gasoline ensures that the combustion in the cylinder does not protrude into the exhaust stroke. The combustion gases have the opportunity to cool down until they go to the exhaust. Therefore, the exhaust outlet temperatures decrease with nitromethane addition. 100% gasoline gives the lowest NO_x values. It is observed that there is a serious increase in NO_x emissions as the nitromethane addition increases. It is seen that the highest increase with an increase of 322.66% at 2000 RPM was realized in 10% nitromethane addition compared to 100% gasoline [33-35].

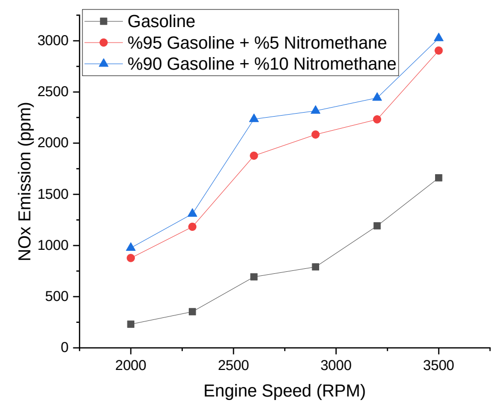

Fig. 11. NO_x emission variation with engine speed

4. Conclusions

This study investigated the effect of nitromethane addition at two different rates on engine performance and emissions in a single-cylinder, four-stroke, air-cooled engine. No changes were made to the test engine. Experiments were carried out at full load. In the experiments, engine speeds are 2000, 2300, 2600,2900, 3200, and 3500 RPM.

It increased the engine performance of nitromethane-gasoline mixtures. It is observed that there is an increase in NO_x and CO_2 emissions and a decrease in HC and CO emissions. It has been observed that the engine runs unstable and knocking occurs in mixtures made with the addition of more than 10% nitromethane. For this reason, the results of the experiments with nitromethane addition at higher ratios were unhealthy and the test engines were damaged. For this reason, it is not possible to use nitromethane addition at high rates in spark-ignition engines without making any changes.

When nitromethane is added to gasoline at a rate of 5%, the specific fuel consumption is positively affected by this situation. The fact that the density of the mixture increases proportionally to the nitromethane content is effective here. In addition, the latent heat of evaporation of nitromethane is very high compared to gasoline, increasing the filling density by lowering the temperature in the cylinder, causing an increase in the amount of filler taken in, thus ensuring more efficient combustion. The decrease in exhaust temperatures can be shown as a sign that the energy produced as a result of combustion is used more efficiently.

The engine performance provided by the mixtures prepared by adding nitromethane to gasoline gave more positive results than the performance provided by 100% gasoline. In addition, significant reductions in CO and HC emissions have occurred in parallel with the improvement of combustion efficiency.

The use of mixtures obtained by adding nitromethane to gasoline as fuel in the engine shortens the engine's life, and when it is added at high rates, it causes knocking and unstable operation. At the same time, since it is not an economical fuel, it is not recommended to be used in internal combustion engines without making any changes. In addition to these disadvantages, the fact that it increases CO_2 and NO_x emissions negatively affects the usability of nitromethane as a fuel additive.

Conflict of Interest Statement

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

CRediT Author Statement

Samet Çelebi: Conceptualization, Validation, Supervision,
Usame Demir: Conceptualization, Writing-original draft.
Gökhan Ergen: Conceptualization, Writing-original draft

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