

**Research Article****The effects of the use of acetylene gas as an alternative fuel in a gasoline engine****Salih Özer<sup>a</sup> , Mehmet Akçay<sup>a,\*</sup> , Erdinç Vural<sup>b</sup> and İlker Turgut Yılmaz<sup>c</sup>** <sup>a</sup>*Muş Alparslan University Faculty Of Engineering-Architecture Mechanical Engineering, Muş, 0490100, Turkey*<sup>b</sup>*Aydın Adnan Menderes University Germencik Yamantürk Vocational School, Aydin, 090100, Turkey*<sup>c</sup>*Marmara University Faculty Of Technology Automotive Engineering, İstanbul, 0340100, Turkey***ARTICLE INFO***Article history:*

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**ABSTRACT**

In internal combustion engines, the use of gas fuels is becoming widespread due to its advantages such as low cost and being more environmentally friendly. Acetylene is one of the gas fuels seen as an alternative to petroleum-based fuels in internal combustion engines. In this experimental study, the availability of acetylene gas, a gas fuel, at 1600 rpm, 2400 rpm and 3200 rpm engine speeds in a spark plug-fired engine was investigated. Acetylene gas was added to gasoline by 5% and 10% of the mass and its effect on exhaust emissions was studied. The results showed that adding acetylene gas to gasoline by mass increased CO, CO<sub>2</sub> and NOx emissions and exhaust gas temperature. HC, oxygen emissions and air supply coefficient decreased.

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**1. Introduction**

In recent years, increasing environmental problems and the rapid reduction of energy resources have exposed the world to an energy crisis. Approximately eighty percent of the world's energy need is met by fossil fuels [1, 2]. Considering the ratio of existing reserves to production, it is said that there is an oil reserve of approximately 40 years [3]. The fact that the emission values of fossil fuels are not suitable and such fuels will be exhausted after a while makes it compulsory to take new measures and look for new options. According to recent studies, if there is no change in the use of energy resources, the prices will rise rapidly and global energy deficit and pollution will increase up to 50% by 2030 [1]. This has led to a quest for alternative energy resources that are renewable and environmentally safe.

Fossil fuels, which are widely used in industrial applications, heating buildings, motor vehicles, etc., cause significant damage to human health and nature with harmful emissions (hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), sulfur dioxides (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), etc.). Particularly in big cities, the share of

air population caused by motor vehicles in the whole air pollution is said to be around 50% [4-6]. For this reason, significant importance has been attached to efforts towards reducing emissions from internal combustion engines.

Among more than 100 polluting emissions generated by internal combustion engines, the most important emissions that negatively affect the environment and human health are CO, HC, NOx, sulphur oxides (SO<sub>x</sub>), aldehydes (HCHO) and particles [3]. Natural gas, liquefied petrol gas (LPG), hydrogen, acetylene, alcohols and vegetable oils can be used as an alternative fuel in internal combustion engines directly or as additions of certain ratios to the main fuel [7, 8]. In studies on gas fuel applications in compression-ignition (CI) and spark-ignition (SI) engines, the gas fuel is taken into the cylinder by adding it to the intake air, and then the ignition is triggered by either pilot fuel or ignition spark [7-9].

**1.1 Acetylene Gas and Its Properties**

Acetylene gas that has a chemical formula of C<sub>2</sub>H<sub>2</sub> is a gas that is colorless, garlic-smelling and highly flammable [10]. The density of acetylene is around 1.1

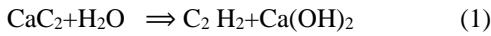
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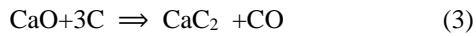
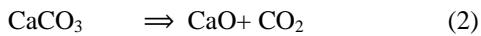
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kg/m<sup>3</sup> and it is approximately 10% lighter than air [8, 9]. It is used in the synthesis process of various organic compounds as well as in the cutting and welding of metals. Acetylene gas is formed during the decomposition of calcium carbide (CaC<sub>2</sub>) under the action of water (H<sub>2</sub>O) according to the exothermal chemical reaction. The chemical equation is as follows [11,12].



The calcium carbide (CaC<sub>2</sub>) mentioned here is produced by the burning of calcium carbonate (limestone-CaCO<sub>3</sub>). The initial temperature of CaC<sub>2</sub> formation is between 1700-1800°C. CaCO<sub>3</sub> is formed by burning calcium oxide (lime-CaO), then coal (C) is reacted with CaC<sub>2</sub> and CO<sub>2</sub> is obtained. These chemical equations as follows ; [12, 13]



Because of acetylene gas has low ignition energy, high flame velocity, wide flammability limits, and short quenching distance, these properties lead to engine knocking, a major problem in engines powered with acetylene [7]. Although acetylene gas has a potential of being an alternative fuel in internal combustion engines in terms of its high combustion temperature and rate, rapid ignition and being economical, it has not been widely used so far due to difficulties in its storage and use.

Gas fuels have importance as an alternative fuel with their abundant nature and clean combustion. In the literature, there are many studies on the use of hydrogen gas, a gas fuel, in internal combustion engines [14-19]. When hydrogen and acetylene are compared, the acetylene gas have mostly similar combustion properties in terms of combustion velocity, ignition energy, adiabatic flame temperature and flammability limit. In addition, the self-ignition temperature and production and storage costs in acetylene are lower than in hydrogen [10]. Due to this and other positive properties, it is of significance to investigate the use of acetylene gas as an alternative fuel in internal combustion engines. The physical and chemical properties of acetylene, hydrogen and gasoline (iso-octane) are generally presented in Table 1 [8, 20-25].

As can be seen in Table 1 presenting the general properties of acetylene, hydrogen and gasoline comparatively, acetylene shows properties similar to hydrogen with its low density, high self-ignition temperature and very low ignition energy. Acetylene gas, which has a faster energy yield as well as a high combustion velocity, is more suitable for the

thermodynamically ideal engine cycle efficiency in engines that operate with a stoichiometric mixture. Low ignition energy, high combustion velocity, wide ignition ranges and short quenching distance lead to early ignition and a phenomenon of undesired combustion that is called knocking. This is one of the major problems encountered in engines using acetylene gas. One way to prevent the backfire is the time-adjusted injection of fuel before the fuel is sent and after the intake time when the intake air is taken in. This makes a pre-cooling effect, thus neutralizing the early ignition source [26].

The use of acetylene as an alternative fuel in internal combustion engines is said to compete with hydrogen in the future [8]. When recent studies on gas fuels are examined, it is possible to find many studies on the use of acetylene gas as fuel in internal combustion engines. Some of the related studies are as follows;

İlhak et al., [27], investigated the effects of the use of gasoline and acetylene gas mixtures on the engine performance and emissions of a SI engine. In experiments, acetylene flow rates were fixed at 500 g/h and 1000 g/h. Thermal efficiency decreased with the use of acetylene at almost all loads. Hydrocarbon emissions decreased in all engine loads while NO emissions increased in low loads compared to gasoline.

Lakshmanan and Nagarajan [8], examined the effect of the addition of different rates of acetylene gas on engine performance and exhaust emissions in a single cylinder four-stroke direct injection diesel engine. Diesel fuel was injected as the primary fuel and various proportions of acetylene was sent to the cylinder as secondary fuel. Thermal efficiency decreased with the use of acetylene. Compared to the use of pure diesel fuel, the addition of acetylene led to a reduction in HC and CO emissions. There was a significant increase in NOx emissions due to the high combustion rate with the use of acetylene.

Lakshmanan and Nagarajan [20], investigated the effect of the addition of acetylene gas to diesel fuel as a secondary fuel in a single-cylinder diesel engine on engine performance and exhaust emissions. The brake thermal efficiency was found to be lower with dual fuel application than with diesel fuel when the engine was in full load condition. With the dual fuel application of acetylene, the exhaust gas temperature was observed to decrease when compared to diesel fuel, and the CO, CO<sub>2</sub> and HC emissions were reduced in certain amounts. However, NOx showed a significant increase.

Lakshmanan and Nagarajan [21], examined the effects of the addition of 110 g/h, 180 g/h and 240 g/h of acetylene gas to diesel fuel and the different ratios of EGR application on exhaust emissions and engine performance. Acetylene gas added to diesel fuel led to a decrease in NOx, CO and HC emissions and a considerable increase in smoke emissions.

Table 1. Physical and chemical properties of acetylene, hydrogen and gasoline.

Properties	Acetylene	Hydrogen	Gasoline
Chemical Formula	C <sub>2</sub> H <sub>2</sub>	H <sub>2</sub>	C <sub>8</sub> H <sub>18</sub>
Density, (1 atm, 20°C) kg/m <sup>3</sup>	1.092	0.08	730
Molecular Weight (kg/kmol)	24.06	2.02	114.18
Stoichiometric air fuel ratio (kg/kg)	13.2	34.3	14.7
Flammability Limits (volume %)	2.5-81	4-74.5	1.3-7.6
Adiabatic flame temperature (K)	2500	2400	2226
Lower Calorific Value (kJ/kg)	48225	120000	43400
Lower Calorific Value (kJ/m <sup>3</sup> )	50636	9600	-
Auto Ignition Temperature (K)	578	845	530
Ignition energy (Mj)	0.019	0.02	0.24
Flame Speed (m/s)	6.097	2.37	0.415

Nathan et al., [22], conducted a study with different pressure rates of acetylene gas in a homogeneous charge compression ignition (HCCI) engine. In the study, they stated that acetylene could be used in an HCCI engine individually without any fuel additives. Optimum exhaust gas recirculation (EGR) and brake thermal efficiency was found to increase slightly compared to diesel fuel application. Hot EGR at the high brake mean effective pressure (BMEP) caused the engine to knock. While nitrogen oxide and smoke levels went down, HC emissions went up.

In a study by Laksmanan et al., [28], investigated the effect of water injection on acetylene and diesel dual fuel diesel engine performance and exhaust emissions. Acetylene gas was delivered to the intake manifold of a single cylinder diesel engine with a flow rate of 390 g/h. The thermal efficiency and exhaust gas temperature decreased according to the diesel fuel and dual injection of diesel-acetylene by water injection. Water injection to the inlet port caused a significant decrease in NOx levels. Compared to the acetylene diesel dual fuel operation, there has been an increase in HC and smoke emissions.

Lakshmanan and Nagarajan [26], used a timed manifold injection (TMI) technique to deliver acetylene gas to a direct injection diesel engine. In the study, a four-stroke diesel engine with 4.4 kW power was used. A small modification was made in the intake manifold to mount the gas injector controlled by an electronic control unit (ECU). The study was carried out at gas flow rates of 110 g/h, 180 g/h and 240 g/h. The engine performance achieved by the addition of acetylene gas at full load was reported to be very close to the performance with pure diesel fuel. NOx, CO, CO<sub>2</sub> and HC emissions decreased although there was a slight increase in smoke emissions.

Choudhary et al., [29], added acetylene to diesel fuel at

constant flow rate in a compression engine, and examined the results. They replicated the experiment by setting the diesel engine at the values of 18:1, 18.5:1, 19:1 and 19.5:1. As a result of the experiment, they examined combustion and motor performance parameters. They stated that the temperature of the exhaust gas increased as the in-cylinder pressure values and brake thermal efficiency increased. They also reported that the highest increase in efficiency was 21.18% maximum in the combustion rate of 19.5:1.

In the literature, there have been very few studies on the effects of acetylene gas on performance and emissions in SI engines [27], but the applications in diesel engines were widely studied [26,28]. Therefore, in the present study, it was preferred to test the acetylene gas in a gasoline engine. Additionally, in this study, the effects of acetylene gas added to the gasoline by mass are investigated in fixed engine speed and fixed throttle opening in terms of emission.

İlhak et al., [30] they studied the effects of the addition of acetylene using ethanol and gasoline as Pilot fuel. For this purpose, they operated a gasoline engine at 1500 RPM under 25% and 50% load. They found that ethanol lowers emissions.

Raman and Kumar [31] they studied the effects of the addition of acetylene gas in a compressed engine. For this purpose, they added 5% and 10% butanol to the fuel used as pilot fuel. They then examined the internal combustion and performance data of the acetylene gas, which they added at different rates by mass. their results showed that they reported that acetylene gas burned more efficiently with pilot fuel use.

İlhak et. al., [32] They studied the effects of the addition of acetylene in a gasoline engine at different air/fuel ratios. They repeated their experiments at 25% and 50% engine loads at 1500 rpm. They showed that the air/fuel ratio is effective in engine parameters.

The aim of this study was to improve exhaust emissions by adding acetylene gas to gasoline by mass. In the study, it was preferred to add 5-10% of acetylene gas into gasoline by mass, at ratios where smooth operation can be ensured without any changes on the engine. The effect of acetylene gas addition into gasoline on exhaust emissions was thus investigated. In the study, experiments were carried out at different engine speeds (1600 rpm, 2400rpm and 3200 rpm) and at different engine loads (20%, 40%, 60%, 80% and 100% (full load)).

## 2. Material and Method

Engine experiments were conducted at low (1600 rpm), medium (2400 rpm) and high engine (3200 rpm) engine speeds. For this purpose, the engine was primarily operated with 100% gasoline. For engine experiments,

fuel consumption and exhaust emission values were recorded by loading at 20%, 60%, 80% and 100% engine loads at the full throttle position of the engine operated with 100% gasoline at each engine speed. After these preliminary studies, hourly fuel consumption values of the engine were calculated. Based on these calculated values, 5% (5% acetylene+95% gasoline) and 10% (10% acetylene+90% gasoline) were added to the intake manifold by mass. The mixtures used in the experiments are expressed as 5% Act and 10% Act in the graphs. In all these stages, the engine was expected to become stable and the emission values of the pilot fuel-powered engine and fuel consumption values were measured again and the values were recorded. With the addition of acetylene gas, the rising engine speed has been reduced to the desired state with the reduction of gasoline fuel. Acetylene gas was added with kg/h value over flow meter. The hourly rate of the gas, which will be added over the amount of liquid fuel flow calculated at this stage, is adjusted via a sensitive flow sensor and given to the intake manifold. All experiments were repeated three times and the averages of the data were taken.

In the experiment, an electric dynamo-meter that was capable of measuring up to 5000 rpm and absorbing 80 kW of power was used. During the engine experiments, acetylene gas was provided from a RAL 1018-type tube that was compatible with TSE 11169 standards. Acetylene gas initially got out of the manometer on the tube and then passed through a wet type Flash back arrestor. The acetylene gas that passed through a spherical precision valve and then through a safety valve was finally sent to the intake manifold from a hole opening into the intake passage of the carburetor by passing through the check valve. As in other studies on this issue [22-24, 33] the gas was mixed with the intake air of the fuel to be taken into the cylinder.

The MRU Delta 1600L exhaust gas analyzer was used to measure exhaust gas components (CO, CO<sub>2</sub>, HC, NOx and O<sub>2</sub>). A schematic view of the experimental setup is given in Figure 1. The sensitivity and properties of the tools used in the experiment are given in Table 2. Properties of the test engine are shown in Table 3.

In the graphs, 5% Act refers to the gas addition of 5% (i.e. 95% gasoline + 5% acetylene gas) and 10% Act refers to the gas addition of 10% (i.e. 90% gasoline + 10% acetylene gas).

### 3. Results and Discussion

The data yielded by means of the engine experiments are presented in graphs and the results are discussed in this section. Here, the emission values obtained in tests at (a) low, (b) medium and (c) high engine speeds are shown.

Table 2. Measurement sensitivity of the tools used in the experimental setup.

Measurement	Accuracy
Load (N)	±%0.6
Load arm (m)	±%0.1
Velocity (rpm)	±1
Time (s)	±%1
Temperature (°C)	±1
CO (%vol)	±0.01
CO <sub>2</sub> (%vol)	±0.01
O <sub>2</sub> (%vol)	±0.1
NOx (ppm)	±1
HC (ppm)	±1

Table 3. Properties of the test engine

Engine	Honda
Number of cylinders Type	1 4 stroke, air cooled,
Bore x Stroke	70 x 55
Fuel system	Carburetor
Compression ratio	8:1
Maximum Force	1.937 kW (2600 rpm)

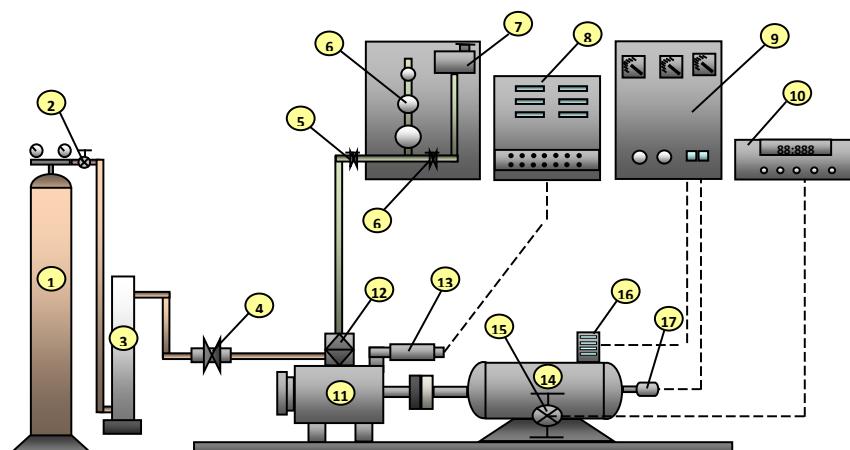


Figure 1. Schematic view of the experimental setup

- Acetylene gas tube, 2. Acetylene gas valve, 3. Flame trap, 4. Flow meter, 5. Gasoline fuel valve, 6. Fuel measurement apparatus, 7. Gasoline tank, 8. Exhaust gas analyzer, 9. Dynamometer control panel, 10. Force display, 11. Gasoline engine, 12. Carburetor, 13. Exhaust pipe, 14. Dynamometer, 15. Load-Cell Sensor, 16. Dynamometer cooler, 17. Encoder

Figure 2 presents the effect of the addition of acetylene gas to gasoline by mass on exhaust gas temperature. Exhaust gas temperature is a function of the combustion inside the cylinder. As the exhaust temperature is an indicator of combustion inside the cylinder, it is also described as an important parameter that indicate combustion in internal combustion engines [29]. In general, the increase in the amount of fuel inside the cylinder would increase the temperature of the exhaust gas, which is reported in many studies [34]. By boosting the throttle opening in gasoline engines, the vacuum inside the cylinder increases and more air/fuel mixture (A/F) is taken into the cylinder. This also varies based on the engine load and revolutions, and the increase of the load and revolutions varies depending on the position of the throttle.

As is seen in Figure 2, the exhaust gas temperature went up with the engine speed and load. Furthermore, the exhaust gas temperature increased depending on the increasing acetylene addition rate to the gasoline. The exhaust gas temperature has reached its maximum value at full engine load for each fuel. Gasoline exhaust gas temperature for different engine speeds of 1600 rpm, 2400 rpm and 3200 rpm it is 287°C, 298°C and 330°C, respectively at full engine load. For 5% acetylene addition 290°C, 310°C and 333°C, for 10% acetylene addition 297°C, 324°C and 337°C, respectively at full engine load. When compared to baseline gasoline operation, the maximum increase in exhaust gas temperature was obtained as 8.7% with 10% acetylene additive at 2400 rpm engine speed and full engine load. This seems to be due to the higher flame temperature of acetylene gas compared to that of gasoline. As is shown in Table 2, the flame temperature of acetylene gas is higher than that of gasoline. The flame temperature can be seen as a value that can partly increase the exhaust gas temperature by changing the combustion temperature. However, there are also studies made with gas fuels that indicate that there is not enough time for the gases to burn after taking them into the cylinder and that some of the combustion continues in the exhaust. Therefore, it is thought that the increase in exhaust gas temperatures may be due to this situation. In accordance with the referee's recommendation, a text such as the following is added to the appropriate place in the article [31]. Similar results have been obtained in previous studies [35].

In internal combustion engines, nitrogen in the air form nitrogen oxides at high temperatures. Nitrogen oxides (NOx) are particularly unwanted groups of gas in internal combustion engines.

Formation of NOx emissions depends on three main factors; combustion temperature, oxygen concentration and high temperature exposure time of nitrogen [36-39]. Maximum NOx emission occurs at 1600-1800°C, but starts to decrease at higher temperatures. In general, the maximum NOx concentration occurs in slightly poorer

mixtures ( $\lambda=1.05-1.1$ ) in terms of stoichiometric conditions [2018, 2020]. The effect of acetylene gas addition to gasoline on NOx emissions is shown in Figure 3.

As seen in Figure 3 the NOx emissions went up with the engine speed and load similar to exhaust gas temperature. Besides, NOx emissions increased with addition of acetylene gas for all engine speeds and loads. NOx emission has reached its maximum value at full engine load for each fuel. NOx emission, at full engine load and engine speeds of 1600 rpm, 2400 rpm and 3200 rpm is 112.2 ppm, 278.7 ppm and 369.5 ppm for gasoline, 131.9 ppm, 298.5 ppm and 379.1 ppm for 5% acetylene addition, 151.1 ppm, 319.6 ppm and 401.5 ppm for 10% acetylene addition, respectively.

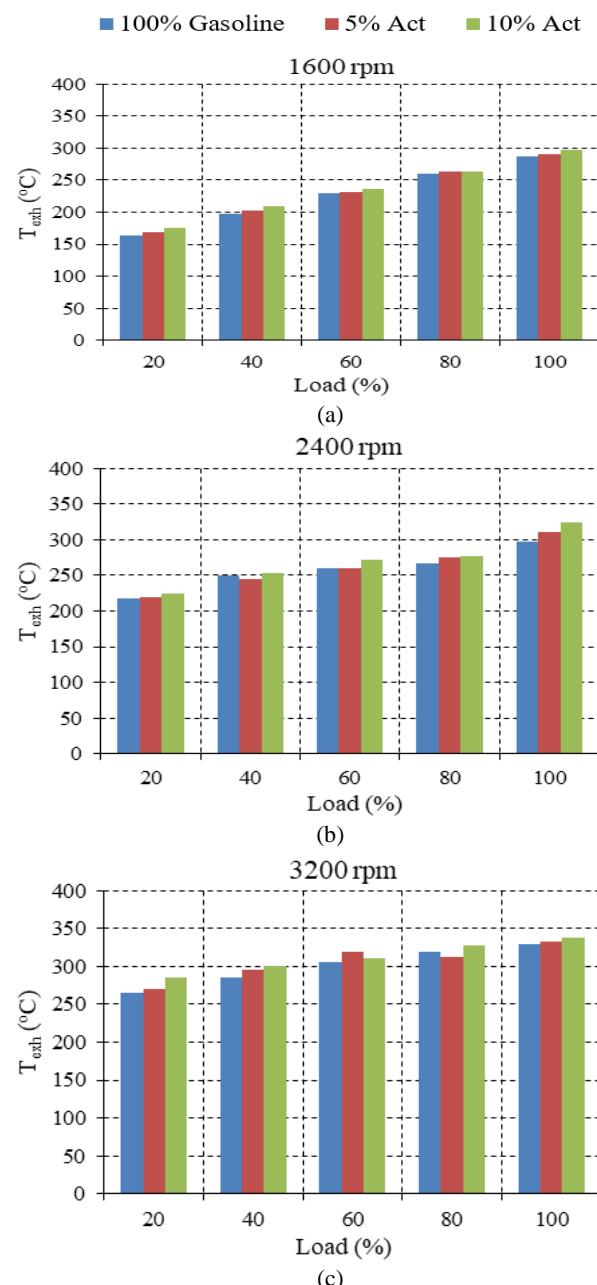


Figure 2. The effect of the mixture of gasoline-acetylene gas on exhaust gas temperature

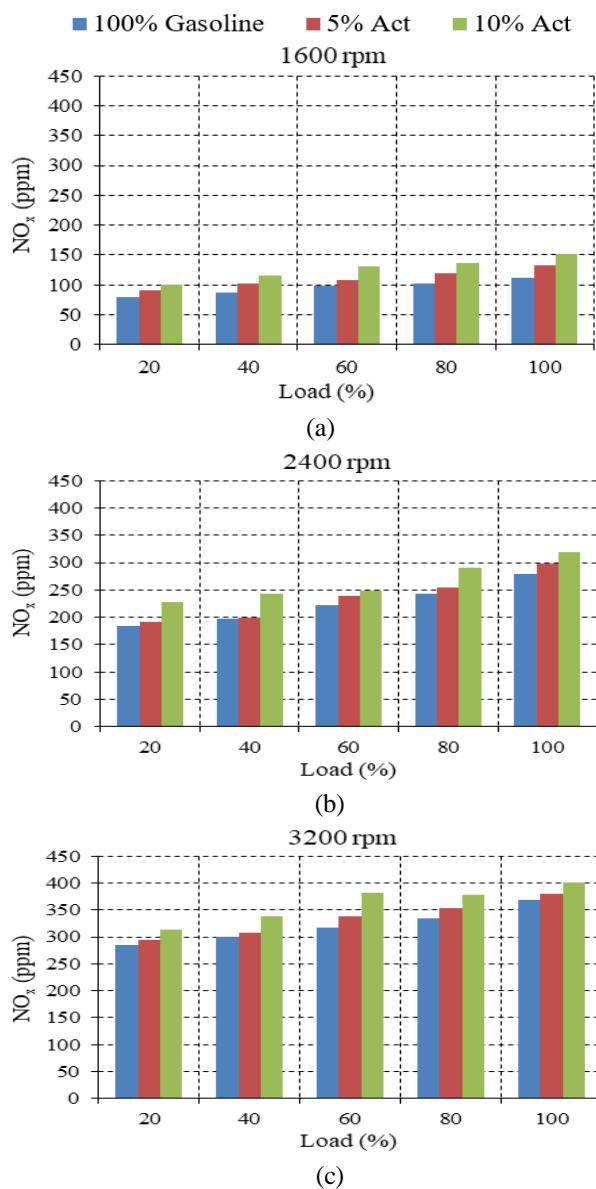


Figure 3. The effect of gasoline-acetylene gas fuel mixture on nitrogen oxide emissions

When compared to baseline gasoline operation, the maximum increase in NO<sub>x</sub> emission was obtained as 34.6% with 10% acetylene addition at 1600 rpm engine speed and full load. Considering exhaust gas temperature in the interpretation of NO<sub>x</sub> emissions would make the interpretation easier. The increase in exhaust gas temperature indirectly leads to an increase in NO<sub>x</sub> emissions. Another factor in the increase of NO<sub>x</sub> emissions is that acetylene gas, which is delivered to the intake air, creates a partially poor fuel mixture in the cylinder. Acetylene gas sent into the air creates a poor mixture in the cylinder and may lead to an increase in NO<sub>x</sub> emissions. When the exhaust gas temperature is examined, it is observed that it increases with acetylene gas. NO<sub>x</sub> emissions increase the upward trend with increased in-cylinder temperature. Therefore, NO<sub>x</sub> emissions are thought to be increasing. Furthermore, the high flame temperature of acetylene gas is also considered to be an

important parameter in the increase of NO<sub>x</sub> emissions. The increase in NO<sub>x</sub> emissions by acetylene addition is similar to the studies in the literature [35].

The ratio of the actual amount of air involved in the combustion to the amount of air theoretically required to combust that fuel is called the air supply coefficient. If the actual amount of air involved in the combustion is equivalent to the amount of air theoretically required, this is called a stoichiometric mixture [40]. Table 2 shows that acetylene gas forms a richer mixture than gasoline. The effect of the addition of acetylene gas to gasoline on air supply coefficient is presented in Figure 4.

As seen in Figure 4, in general, a reduction in the air surplus coefficient with increasing engine speed and load has occurred. The reduction in the air surplus coefficient is due to an increase in the amount of fuel delivered to the cylinder parallel to the increased engine load [41, 42]. In addition to, as the ratio of acetylene gas added to gasoline increased, air supply coefficient decreased for each engine speed and load. Air supply coefficient has reached its minimum value at full engine load for each fuel. When compared to baseline gasoline operation, the maximum reduction in air supply coefficient was obtained as 15.7% with 10% acetylene addition at engine speed of 1600 rpm and full engine load. The stoichiometric ratio of acetylene gas can be regarded as one of the main reasons for this finding. Acetylene gas burns with less air compared to gasoline. Therefore, the mixture is enriched with the addition of acetylene gas in all fuel mixture ratios.

Figure 5 shows the effect of adding acetylene gas to gasoline on oxygen (O<sub>2</sub>) emissions. O<sub>2</sub> emissions decreased with increasing engine speed and then showed a tendency to increase again, for each fuel. Besides, a decrease in O<sub>2</sub> emissions was observed with the addition of acetylene gas to gasoline. This decrease was in parallel to the ratio of acetylene gas. As is shown in Table 2, the amount of air required for the combustion of acetylene gas is less than the case for gasoline. Thus, the F/A mixture is enriched by adding acetylene gas to gasoline. In the enriched F/A mixture, O<sub>2</sub> emissions are reduced. As is seen in Figure 4, as the engine load increased, the air supply coefficient value decreased and thus, as is shown in Figure 5, O<sub>2</sub> emissions also decreased. As seen in Figure 5, when compared to baseline gasoline operation, the lowest O<sub>2</sub> emission value was obtained at an engine speed of 2400 rpm with 5% acetylene addition and 60% engine load. Except for 40% and 60% engine loads in engine speed of 2400 rpm, generally, the maximum reduction in O<sub>2</sub> emissions was obtained with 10% acetylene addition for all engine speeds and loads.

Hydrocarbon (HC) emissions in the exhaust gases indicate that some part of the fuel is expelled out without burning. HCs are generally stinky and have an irritating and narcotic effect on the inner skin of the respiratory tract [40].

Two factors come to the forefront, considering the ways in which HC emissions in the engine occur. These are the insufficiency of O<sub>2</sub> atoms present in the cylinder and the inability to provide the sufficient heat to combust the whole fuel [43-45]. The effect of adding acetylene gas to gasoline on HC emissions is shown in Figure 6.

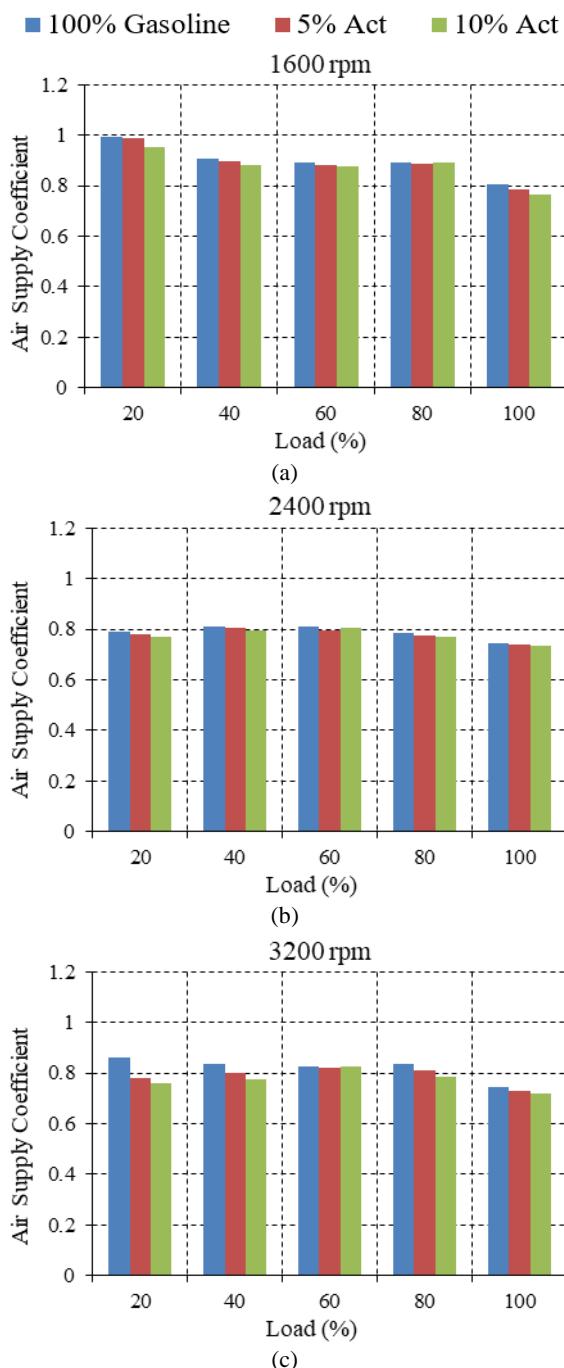


Figure 4. The effect of gasoline-acetylene gas fuel mixture on air supply coefficient

As seen in Figure 6, the HC emission values with the acetylene additive were generally lower than the gasoline at all engine speed and loads. According to working with gasoline, with the addition of acetylene gas, the maximum reduction in HC emissions generally was obtained with a 10% acetylene addition for each engine speed. When compared to baseline gasoline operation, the maximum

reduction in HC emissions, for an engine speed of 1600 rpm was obtained as 15.7% at full engine load. For 2400 rpm and 3200 rpm engine speeds at 80% engine load were obtained as 18.9% and 32.6% respectively. The reason for the decrease in HC emissions by adding acetylene gas to gasoline can be shown as more homogeneous mixture and high burning speed of acetylene [32, 33]. Similar results have been obtained in previous studies [46].

The effect of adding acetylene gas to gasoline on carbon monoxide (CO) emissions is given in Figure 7. CO emissions are due to incomplete combustion of fuel and this is largely due to air fuel ratio [27].

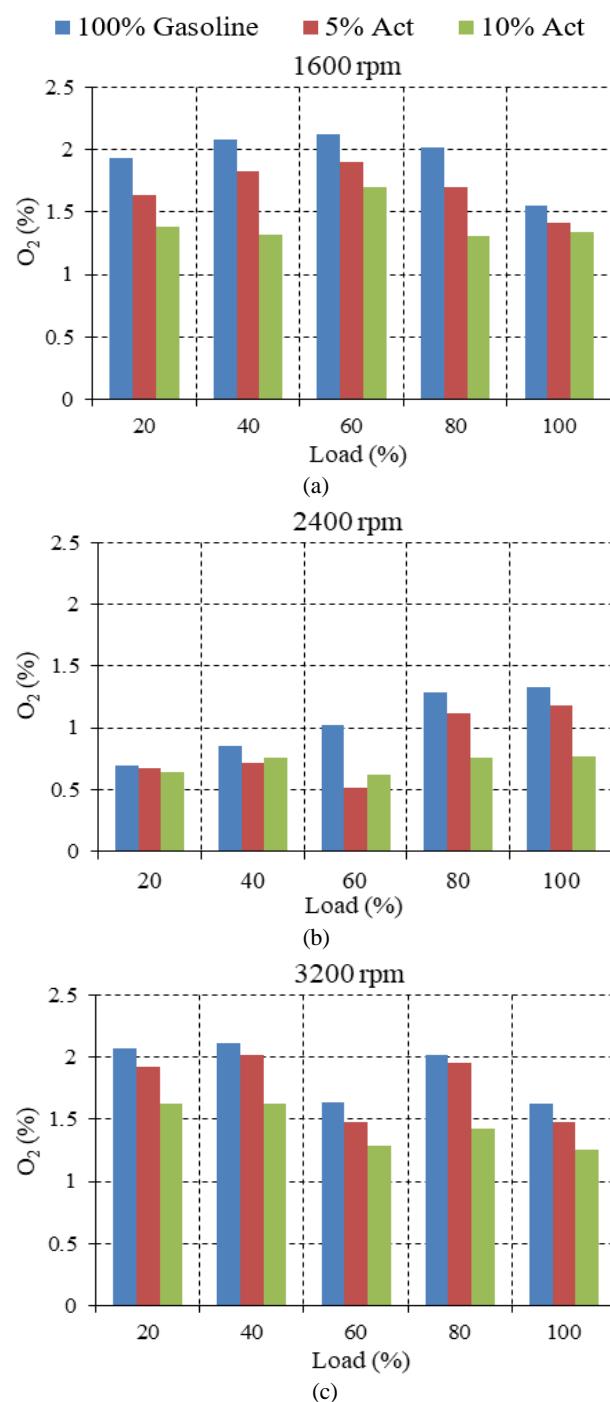


Figure 5. The effect of gasoline-acetylene gas fuel mixture on oxygen emission

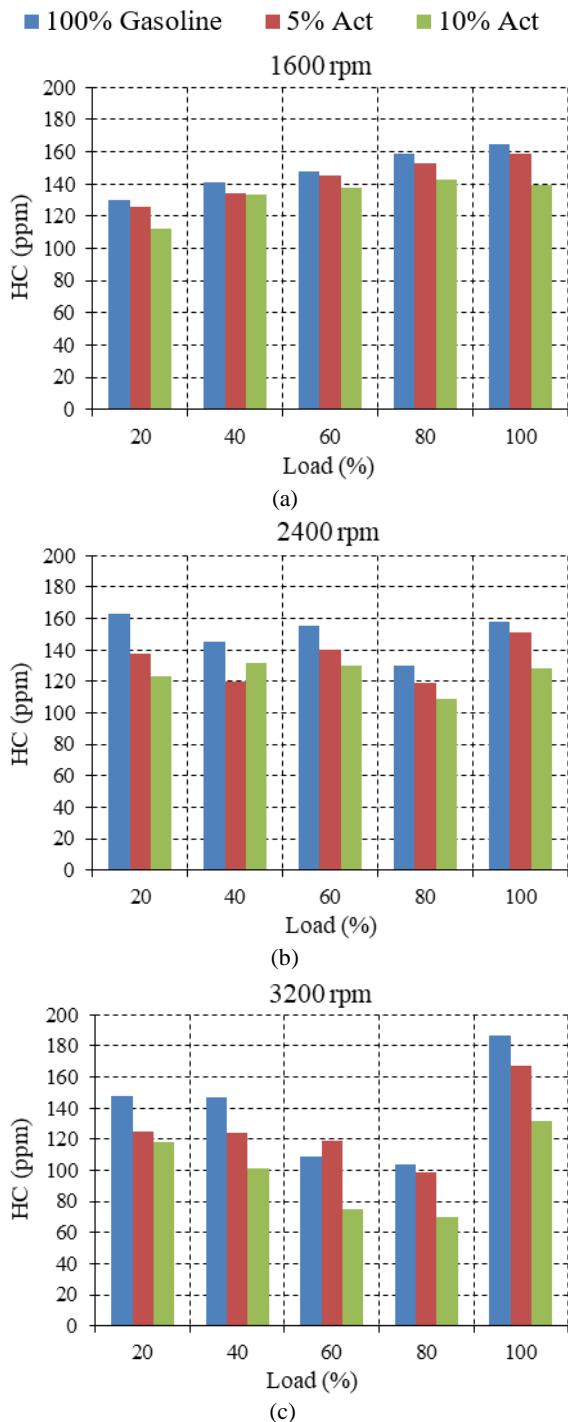


Figure 6. The effect of gasoline-acetylene gas fuel mixture on hydrocarbon emission.

The CO emission is formed by the expulsion of carbon (C) atoms as partially burned by not being able to react fully with O<sub>2</sub> due to O<sub>2</sub> deficiency in the environment [40]. A rich mixture is created with the addition of acetylene gas to the gasoline, which leads to the presence of more fuel than the air in the cylinder can combust, and thus the formation of a non-combusted fuel front. In this way, CO emissions increase in parallel with the increase in the rate of acetylene gas at different engine speeds and engine loads. As seen in Figure 7, the highest increase in CO emissions for

each engine speed and load was obtained with 10% acetylene addition. When compared to baseline gasoline operation, the maximum increase in CO for an engine speed of 1600 rpm was obtained as 16.8% at 20% engine load, for 2400 rpm and 3200 rpm engine speeds were obtained as 9.9% and 14.5% respectively at 40% engine load. The reduction in O<sub>2</sub> by the addition of acetylene gas can be clearly seen in Figure 5. Furthermore, the high combustion rate of the acetylene gas is thought to cause the A/F mixture to burn rapidly without forming a complete mixture, which increases CO emissions.

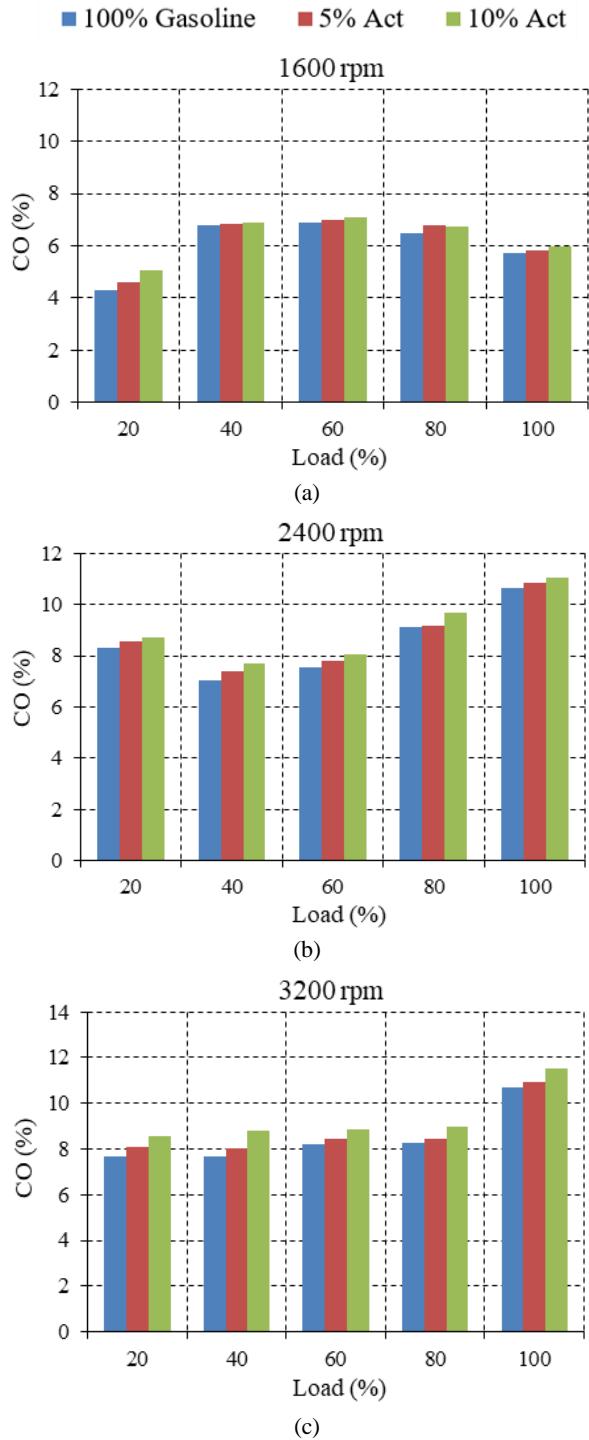


Figure 7. The effect of gasoline-acetylene gas fuel mixture on carbon monoxide emission

Figure 8 shows the effect of the addition of acetylene gas on carbon dioxide ( $\text{CO}_2$ ) emissions.  $\text{CO}_2$  emissions are a product of complete combustion. They are formed by the oxidation of C atoms in gasoline and acetylene gas by combining with sufficient  $\text{O}_2$  [47]. In addition, the amount of  $\text{CO}_2$  emissions in hydrocarbon fuels varies depending on the C/H ratio. As the C/H ratio of acetylene gas is higher than that of gasoline, the  $\text{CO}_2$  emission amount is higher than that of gasoline [32]. As is shown in Figure 8,  $\text{CO}_2$  emissions increased with the addition of acetylene gas to gasoline and the maximum increase was obtained with a 10% acetylene addition for each engine speed and load.

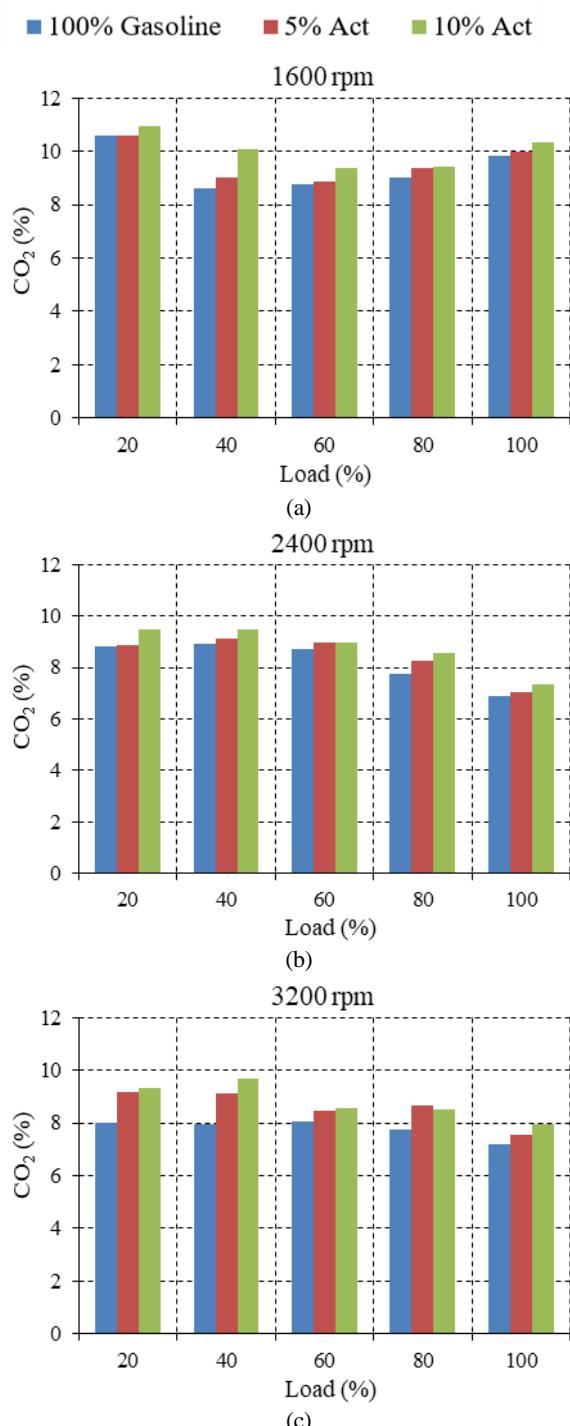


Figure 8. The effect of gasoline-acetylene gas fuel mixture on carbon dioxide emission.

Especially at low engine speeds, there was better combustion compared to high speeds, and accordingly  $\text{CO}_2$  emissions were high. When compared to baseline gasoline operation, the maximum increase in  $\text{CO}_2$  emissions for an engine speed of 1600 rpm was obtained as 17% at 40% engine load. For an engine speed of 2400 rpm was obtained as 10.8% at 80% engine load and for 3200 rpm engine speed was obtained as 21.3% at 40% engine load. Similar results have been obtained by literature [32].

#### 4. Conclusions

Acetylene gas is an energy resource that can be used as an alternative fuel with its low cost, high thermal value and availability. In present conditions, it cannot be used as fuel in internal combustion engines due to safety problems arising from the storage and transport of acetylene gas. It can be used in welding and cutting processes in heavy industry with its high thermal value. In this study, the effect of the addition of acetylene gas to gasoline in different mass ratios on exhaust emissions was investigated in a single-cylinder gasoline engine. The results can be summarized as in the following;

- Exhaust gas temperature increased with the addition of acetylene gas to gasoline by mass. The maximum increase in exhaust gas temperature was obtained in the addition of 10% acetylene gas at an engine speed of 2400 rpm and full load, compared to the use of baseline gasoline.

- NOx emissions increased with increasing engine speed and load. Compared to baseline gasoline, the maximum increase in NOx emissions was achieved as 34.6% at an engine speed of 1600 rpm and at full engine load with the addition of 10% acetylene gas.

- HC emissions decrease with the addition of acetylene gas. The maximum decrease in HC emissions was obtained at an engine speed of 3200 rpm and with 10% acetylene, compared to baseline gasoline fuel operation.

- CO and  $\text{CO}_2$  emissions also increased with the addition of acetylene gas. The maximum increase in CO emissions was obtained by adding 10% acetylene at each engine speed (1600, 2400 and 3200 rpm). Compared to baseline gasoline use, the maximum increase in CO emissions was obtained as 16.8% at an engine speed of 1600 rpm and at 20% engine load with the use of 10% acetylene. The maximum increase in  $\text{CO}_2$  emissions was obtained by adding 10% acetylene at each engine speed (1600, 2400 and 3200 rpm). Compared to baseline gasoline use, the maximum increase in  $\text{CO}_2$  emissions was achieved as 21.33% at an engine speed of 3200 rpm and at 40% engine load with the use of 10% acetylene.

- The addition of acetylene gas to gasoline by mass was found to reduce air supply coefficient. The maximum reduction in air supply coefficient was achieved as 11.6% with 10% acetylene usage at 3200 rpm engine speed and 20% engine load.

• Similarly, O<sub>2</sub> emissions are among those that were reduced by the addition of acetylene gas. The maximum reduction in O<sub>2</sub> emissions, except for 40% and 60% engine loads in engine speed of 2400 rpm, was obtained with 10% acetylene addition for all engine speeds and loads in generally.

According to the results of this study, acetylene gas can be used by mixing in certain proportions to the gasoline without major structural changes in the gasoline engine. It has been observed that acetylene gas can be considered as an alternative fuel that reduces the harm to human and environment health of fossil fuels.

## Declaration

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author(s) also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

## References

- Alptekin E. and M. Çanakçı, *Biodiesel and the situation in Turkey*, Engineer and Machinery, 2006. **47**(561): p. 57-64.
- Özel S., Vural, E., M, Binici, *Taguchi method for investigation of the effect of TBC coatings on NiCr bond-coated diesel engine on exhaust gas emissions*, International Advanced Researches and Engineering, 2020. **04**(01): p. 014-020.
- Batmaz, İ. *Experimental analysis of the effect of hydrogen addition to the fuel on performance and exhaust emissions in spark ignition engines*, J. Fac. Eng. Arch. Gazi Univ., 2007. **22**(1): p.137-147.
- Sayın, C., Çanakçı, M., Kılıçaslan, İ N. Özsezen, *An experimental analysis of influence of using dual fuel (gasoline+LPG) on engine performance and emissions*, J. Fac. Eng. Arch. Gazi Univ., 2005. **20**(4): p. 483-490.
- Sayın, C., Çanakçı, M. İ. Kılıçaslan, *Influence of using gasoline+LPG on the performance and emissions of a gasoline engine*, Erciyes University Journal of Institute of Science and Technology, 2005. **21**(1-2):p.117-127.
- Çalışır, A. and M. Gümüş, *The effect of gasoline-methanol blends on the engine performance and exhaust emission in a spark ignition engine*, 5th International Advanced Technologies Symposium (IATS'09), 13-15 May, Karabuk, Turkey, (2009).
- Lakshmanan, T. and G. Nagarajan, *Experimental investigation on dual operation of acetylene in a DI diesel engine*, 2010 Fuel Processing Technology, 2010. **91**(2010): p. 496-503.
- Lakshmanan, T. and G., Nagarajan, *Performance and emission of acetylene-aspirated diesel engine*, JJMIE, 2009. **3**(2): p. 125-130.
- Jaikumar, S. and S.K., Bhatti, Srinivas, *Experimental Explorations of Dual Fuel CI Engine Operating with Guizotia abyssinica Methyl Ester-Diesel Blend (B20) and Hydrogen at Different Compression Ratios*, Arabian Journal For Science and Engineering, 2020. **44**(12): p. 10195-10205.
- Meda, V.S. *Optimization of Induction Length and Flow Rates of Acetylene in Diesel Engine*, Ms Thesis, National Enstitute of Technology, Orissa, India, 2011.
- Paizullakhhanov, M.S. and S.A Faiziev, *Calcium carbide synthesis using a solar furnace*, Technical Physics Letters, 2006. **32**(3): p. 211-212.
- Poděbradská, J., Maděra, J. and V. Tydlitát, *Determination of moisture content in hydrating cement paste using the calcium carbide method*, Ceramics-Silikáty, 2000. **44**(1): pp.35-38.
- Krammart, P. and S. Tangtermsirikul, *Properties of cement made by partially replacing cement raw materials with municipal solid waste ashes and calcium carbide waste*, Construction and Building Materials, 2004. **18**: p. 579-583.
- Liu, Z., *National carbon emissions from the industry process: Production of glass, soda ash, ammonia, calcium carbide and alumina*, Applied Energy, 2019. **166**(2019): p. 239–244.
- Wang, S. and C.B. Ji, Zhang, *Effect of hydrogen addition on combustion and emissions performance of a spark-ignited ethanol engine at idle and stoichiometric conditions*, International Journal of Hydrogen Energy, 2010. **35**(17): p. 9205–9213.
- Miyamoto, T., Hasegawa, H., M., Mikami, *Effect of hydrogen addition to intake gas on combustion and exhaust emission characteristics of a diesel engine*, International Journal of Hydrogen Energy, 2011. **36**(20): p.13138–13149.
- Tsujiimura, T. and Y., Suzuki, *Development of a large-sized direct injection hydrogen engine for a stationary power generator*, International Journal of Hydrogen Energy, 2018. **52**(2018): p.1-15.
- Koten, H., *Hydrogen effects on the diesel engine performance and emissions*, International Journal of Hydrogen Energy, 2018. **43**(2018): p.10511-10519.
- Ghazal, O.H., *Combustion analysis of hydrogen-diesel dual fuel engine with water injection technique*, Case Studies in Thermal Engineering, 2019. **13**(100380):p.1-10.
- Lakshmanan, T. and G., Nagarajan, *Experimental investigation of port injection of acetylene in DI diesel engine in dual fuel mode*, Fuel, 2011. **90**(2011): p.2571-2577.
- Lakshmanan, T. and G., Nagarajan, *Study on using acetylene in dual fuel mode with exhaust gas recirculation*', 2011. Energy, **36**(2011):p. 3547-3553.
- Nathan, S., Mallikarjuna, J.M., A., Ramesh, *Effect of charge temperature and exhaust gas re-circulation on combustion and emission characteristics of an acetylene fuelled HCCI engine*, Fuel, 2010. **89**(2010): p. 515-521.
- Koşar, M., *Effects of using hydrogen in gasoline engines on performance and emissions*, Ms Thesis, Graduate School of Natural and Applied Sciences, Karabuk, Turkey (2007).
- Çelik, M.B. and A., Çolak, *The use of pure ethanol as alternative fuel in a spark ignition engine*, J. Fac. Eng. Arch. Gazi Univ., 2008. **23**(3): p. 619-626.
- Andrea, T., Henshaw, P.F., D.S.K., Ting, *The addition of hydrogen to a gasoline-fuelled SI engine*, International Journal of Hydrogen Energy, 2004. **29**(2004): p.1541-1552.
- Lakshmanan, T. and G., Nagarajan, *Experimental investigation of timed manifold injection of acetylene in direct injection diesel engine in dual fuel mode*, Energy, 2010. **35**(2010): p.3172-3178.
- İlhan, M.İ., Akansu, S.O., N., Kahraman, *Experimental study on an SI engine fuelled by gasoline/acetylene mixtures*, Energy, 2018. **151**(2019): p.707-714.
- Lakshmanan, T., Ahmed, A.K., G., Nagarajan, *Effect of Water Injection in Acetylene-Diesel Dual Fuel DI Diesel Engine*, Proceedings of the ASME 2012 Internal Combustion

- Engine Division Fall Technical Conference (ICEF2012), September 23-26, Vancouver, Canada.*
29. Choudhary, K.D., Nayyar, A., M.S., Dasgupta, *Effect of compression ratio on combustion and emission characteristics of C.I. Engine operated with acetylene in conjunction with diesel fuel*, Fuel, 2018. **214**(2018):p. 489-496.
30. İlhan, İ.İ., M., Doğan, R., Akansu, S.O., N., Kahraman, *Experimental study on an SI engine fueled by gasoline, ethanol and acetylene at partial loads*, Fuel, 2020. **261**(2020): p.116148.
31. Roshan, R. and N., Kumara, *The utilization of n-butanol/diesel blends in Acetylene Dual Fuel Engine*, Energy Reports, 2019. **5**(2019):p.1030-1040.
32. İlhan, İ.İ., M., Doğan, R., Akansu, S.O., N., Kahraman, *An experimental investigation of the use of gasoline-acetylene mixtures at different excess air ratios in an SI engine*, Energy, 2019. **175**(2019):p. 434-444.
33. Sudheesh, K., and J.M., Mallikarjuna, Effect of cooling water flow direction on performance of an acetylene fuelled HCCI engine, *Indian Journal of Engineering & Materials Sciences*, 2010. **17**: p.79-85.
34. İlkiliç, C., Behçet, R., Aydin, S., H., Aydin, *NOx formation in diesel engines and control methods*', 5th International Advanced Technologies Symposium (IATS'09), 13-15 May, Karabuk, Turkey.2009.
35. Behera, P., Murugan, S., G., Nagarajan, *Dual fuel operation of used transformer oil with acetylene in a DI diesel Engine*, Energy Conversion and Management, 2014. **87**(2014): p.840–847.
36. Hosseini, S.M., R., Ahmadi, *Performance and emissions characteristics in the combustion of co-fuel diesel-hydrogen in a heavy duty engine*, Applied Energy, 2017. **205**(2017): p. 911-925.
37. Yilmaz, İ.T., M.,Gümüş, *Investigation of combustion characteristics and exhaust emissions in a dual fuel (hydrogen-diesel) engine*, 8th Transist International Transportation Technology Symposium and Fair, December 17 to 19, 538-547, Istanbul, Turkey. 2017.
38. Barrios, C.C., Saez, A.D., D., Hormigo, *Influence of hydrogen addition on combustion characteristics and particle number and size distribution emissions of a TDI diesel engine*, Fuel, 2017. **199**(2017): p.162-168.
39. Kacem, S.H., Jemni, M.A., Z., Driss, *The effect of H<sub>2</sub> enrichment on in-cylinder flow behavior, engine performances and exhaust emissions: Case of LPG-hydrogen engine*, Applied Energy, 2016. **179**(2016): p.961-971.
40. Ergeneman, M., Mutlu, M., O.A., Kutlar, *Exhaust Pollutants through Vehicles*, Birsen Publishing, Istanbul, p.13-15, (in Turkish). 1998.
41. Morais, A.M., Justino, M.A.M., O.S., Valente, *Hydrogen impacts on performance and CO<sub>2</sub> emissions from a diesel power generator*, International Journal of Hydrogen Energy, 2013. **38**(2013): p.6857-6864.
42. Kılıçarslan, A. and M., Qatu, *Exhaust gas analysis of an eight cylinder gasoline engine based on engine speed*, Energy Procedia, 2017. **110**(2017):p.459-464.
43. Lin, C.Y and R.J., Li, *Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish*, Fuel Processing Technology, 2009. **90**(2009):p.883–888.
44. Küçükşahin, F., *Diesel Engine*, Birsen Publishing, p.788-790, (in Turkish). 2008.
45. Heywood, J.B. *Internal Combustion Engine Fundamentals*, McGraw-Hill Publishing Company, p.586-592, New York. 1988.
46. Brusca, S., Lanzafame, R., A.M.C., Garrano, *On the possibility to run an internal combustion engine on acetylene and alcohol*, Energy Procedia, 2014. **45**(2014): p.889–898.
47. Özer, S. and E., Vural, *Effects of CNG addition in a diesel engine using diesel/n-heptane, diesel/toluene as pilot fuel*, Gazi Mühendislik Bilimleri Dergisi, 2020. **6**(1): p.1-15.