EFFECTS OF LIQUEFIED PETROLEUM GAS USE IN A TURBOCHARGED STRATIFIED INJECTION ENGINE USING ETHANOL/GASOLINE AS PILOT FUEL

by

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The production of engines using turbocharged stratified injection technology has increased rapidly in recent years. In addition, the use of liquefied petroleum gas, which is an environmental and economical fuel, is increasing in vehicles. While liquefied petroleum gas cannot be used in turbocharged stratified injection engines before, liquefied petroleum gas kits have become applicable to these types of engines with the development of technology. Turbocharged stratified injection is used to provide the first ignition of liquid fuel in engines. Therefore, liquid fuel is sprayed from the injector and then added on liquefied petroleum gas to burn liquefied petroleum gas. Thus, unlike other systems, liquefied petroleum gas in use with the increase in efficiency is also provided. Alcohols (ethanol, methanol, butanol, etc.) biomass fuels are alternative fuel characteristics. There are many studies on the use of alcohols in internal combustion engines. What distinguishes this study is that turbocharged stratified injection is used as a pilot fuel to burn liquefied petroleum gas in an engine. In the study, a vehicle with a turbocharged stratified injection motor equipped with prins liquefied petroleum gas system was used. For this purpose, the effects of 5% (E5), 10% (E10), and 20% (E20) ethanol addition on engine power, engine torque and exhaust emissions were investigated. The vehicle experiments were carried out by increasing the engine speed from 500-5500 rpm in the chassis dynamometer. The findings showed that with E10+liquefied petroleum gas fuel, there is an increase in engine power and engine torque. There is also a reduction in all CO, CO_2, and HC emissions.

Key words: *turbocharged stratified injection engines, ethanol, alcohol, engine performance, exhaust emission*

Introduction

While the environmental pollution caused by the use of gasoline and diesel fuels is widely talked about, many countries impose limits on the emissions that occur after the use of these fuels. These limitations have put some motor manufactures in a difficult situation and they have stopped producing Diesel engines. The search for alternative fuels and their applications are increasing with each passing day. Increases on gas fuels in particular are increasing every day. One of them is liquefied petroleum gas (LPG). This continues to be used by many vehicle manufacturers in internal combustion engines because it is environmentally friendly and economical [1]. The LPG is a gas mixture consisting mainly of propane and butane. The high

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octane number of this gas mixture makes its use in gasoline engines an advantage. For this reason, many vehicle manufacturers are making the vehicles LPG compatible with factory or later additional methods [2]. There are many studies that indicate that exhaust emissions decrease with the use of LPG with high H/C ratio [3].

In order to use LPG in gasoline engines, some regulations must be made on the engine. A special LPG tank is placed on the vehicle. The LPG gas stored in the LPG tank comes into a regulator fed by the engine coolant. Here, LPG from liquid phase to gas phase is sent from carburetor to cylinders with a mixer mounted on the intake manifold in the most classic way. Thus, the first generation LPG systems started to be used in gasoline engines [4]. The LPG systems used today have made great progress since their first production. So much so that it has now started to be used from LPG work machines to high cylinder luxury vehicles. Besides this, LPG technology continues to show continuous development and has reached the stage of using LPG in liquid form by spraying directly into cylinders. With the development of LPG systems, motor technology has improved. The use of injector systems in gasoline vehicles and its support with turbo have led to a breakthrough in the engine World. Innovations in fuel economy and improvements in emissions from such engines have increased the use of engines. Of course, the use of LPG in turbocharged engines is a problem with the invention of injector systems with the use of gas LPG has brought with it another problem. Companies working on this issue ultimately by developing 4th generation LPG systems, it has paved the way for LPG to be used in turbocharged stratified injection (TSI) engines. Nowadays, TSI, gasoline direct injection (GDI) type engines with these systems developed by many companies increases the use of LPG [5]. These types of systems are also called dual fuel systems [6] in this system some liquid fuel is sprayed from the injector and sent into the cylinder via the gaseous LPG intake manifold after the ignition is achieved. Thus, more efficient and more positive results in terms of performance can be summarized in the studies [7].

Another emission limitation method currently used in the world is biomass-derived (biodiesel, bioethanol, bio methanol, *etc.*) to use fuels directly or by blending them with petroleum based fuels. Countries make this situation by mixing the liquid fuels they obtain from ethanol, methanol, and vegetable-based oils produced by domestic sources with gasoline and diesel fuel. There are many studies that report that alcohol fuels offer advantages especially when used in gasoline engines with low emission values and high octane numbers [8-10]. Therefore, countries generally add alcohol to gasoline. With such mixtures, countries that cannot produce their own oil save a small amount and reduce emissions from motor vehicles. It is observed that ethanol is involved in gasoline in commercial use throughout the world [11]. There is a limitation on the addition of alcohol to gasoline in Turkey. According to this limitation, a maximum of 7% alcohol and its derivatives are allowed to be added to gasoline [12]. However, different companies do different applications and some companies sell as E5 (5% ethanol + 95% gasoline) fuel. Therefore, in this study, ethanol was used. The effects of E5 and E20 fuel mixtures with LPG addition were discussed.

In their study, Alexander *et al*. [13] removed the spark plug of a four-cylinder, air-cooled, 10:1 compression ratio and made it compression-fired. Then they tried to make it operational with LPG by adding 5%, 10%, and 15% ethanol to the engine, which they operated at 1500 rpm. They reported increased brake thermal efficiency with the addition of 10% ethanol, reducing HC and CO emissions.

Gong *et al*. [14], studied the effects of the addition of methanol to the engine's pilot fuel to overcome the difficulties of running an LPG-powered vehicle in the cold. In their findings, they reported that the addition of methanol enables the regular combustion of LPG in cold weather conditions.

Gong *et al*. [15], tested the LPG system he connected to the motorcycle on a chassis dynamometer and found that LPG could be used on the motorcycle. Engine experiments were repeated at engine speeds of 2000-7000 rpm. Its results showed that the use of LPG reduces engine emissions.

Gumus [16], was studied on the effect of LPG usage rate on engine performance, emissions and fuel economy in a spark ignition engine with gasoline and LPG injection system. He carried out his experiments by modifying a four-cylinder 4-stroke engine with a dual fuel system. For this purpose, vehicle dynamometer, different LPG usage rates (as heat value 0%, 25%, 50%, 75%, 100%), fixed speed (3800 rpm) and various engine loads (5%, 30%, 60%, 90%) he carried out all his experiments. The results of the experiment showed that exhaust emissions and fuel economy decreased in all LPG usage rates compared to gasoline, but in terms of vehicle performance, only 25% LPG usage rate achieved positive results.

The LPG, which is a cheap and environmentally friendly fuel, is now at the top of alternative fuels today. With the use of LPG and the spread of this usage to almost all vehicle brands, efforts to strengthen LPG systems and increase the combustion efficiency of LPG on vehicles are gaining momentum. The LPG kits, which have become a commercial product, are now rapidly preferred by car users. This study also focused on a study that would encourage the use of LPG in vehicles and increase its capacity for use.

Unlike other studies, TSI technology on a vehicle with E0 (100% 95 octane gasoline), E5 (5% ethanol + 95% gasoline), E10 (10% ethanol + 90% gasoline) and E20 (20% ethanol + 80% gasoline) as a fuel of the pilot fuel use impacts were investigated. At the same time, this work, which is done without any modifications on the engine, contains more realistic values than the work done in laboratory conditions. For this purpose, experiments were carried out on the chassis dynamometer. In the experiments, the engine torque, engine power and exhaust emission parameters for each fuel mixture were examined and charted and examined in the next section.

Material method

Technical specifications of test vehicle and engine

For the vehicle experiments, the 2013 model used a gasoline-powered vehicle with a motor volume of 1.4 liters, with direct injection. Detailed information about the vehicle is given in tab. 1 and the technical features of the experiment engine are given in tab. 2.

Table 1. Technical characteristics of test vehicle

Brand and model	Volkswagen Tiguan
Net weight	1590 kg
Dimensions	1839 mm/4486/1654 mm
Wheelbase	2677 mm
Tire Size	215/60/R16
Transshipment	Front-wheel drive
Transmission	6-speed manual
Storage volume	58 liters

Table 2. Technical characteristics of the test engine

Engine Volume	1390 cm3
Number of cylinders	4
Valve number	16
Piston diameter	76.5 mm
Cylinder stroke	75.6 mm
Compressions ratio	10:1
Engine power	122 hp (5000 rpm)
Engine torque	200 Nm (3500 rpm)
Fuel system with	Injector
Air system	Turbo

Exhaust emission device

Emission measurements were carried out with BOSH BEA060 brand emission device. During the experiments, CO, CO_2, and HC emissions were measured separately under working conditions with gasoline and LPG. The device used is sensitive to measurement for CO emission (0.001%), CO_2 emission (0.010%), HC emission (1 ppm). All measurements were carried out in accordance with TSE 13231 standards.

Vehicle testing dynamometer

Vehicle tests of the engine were carried out in Mates brand engine test dynamometer. The dynamometer is capable of measuring a maximum engine power of 535 hp, a maximum engine torque of 1500 Nm and a vehicle speed of up to 300 km/h. The schematic picture of the experiment Assembly is as shown in fig. 1.

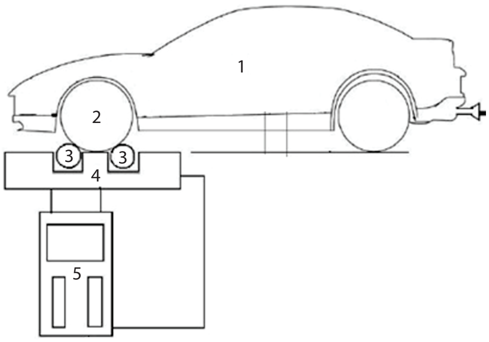

Figure 1. Schematic illustration of the experimental set-up: *1 – experimental transport, 2 – drive wheel, 3 – dynamometer drum, 4 – dynamometer, 5 – control panel*

Test fuels

The technical specifications of the fuels used during the measurements are given in tab. 3. The LPG used in experiments has a content of 70% butane and 30% propane [17]. In this study, the effects of driving E5 (5% ethanol + 95% gasoline), E10 (10% ethanol + 90% gasoline), and E20 (20% ethanol + 80% gasoline) fuels on a vehicle with TSI technology are examined. The experimental fuels were prepared volumetrically. Each time after test procedure for each fuels, all of the fuel in the tank is removed from the pipe on the fuel filter and the tank is cleaned. The specifications of the test fuels are given in tab. 3 and the technical specifications of the fuel mixtures are given in tab. 4.

Table 3. Technical properties of test fuels [18-21]

Properties	Gasoline	Ethanol	Propane	Butane
Density [kgm^{-3}]	765	785	509	585
Latent heating value [$Mjkg^{-1}$]	44	26.9	46.34	45.56
Boiling point [°C]	27-225	78	–42	–0.5
Auto-ignition temperature [°C]	257	425	510	490
Combustion rate [ms^{-1}]	0.35	0.45	0.4	0,4
Stoichiometric air/fuel ratio	14.6	9	15.8	15.6
Ignition classes [vol.%]	1.3-7.6	3.3-19	2.1-9.5	1.5-8.5
Research octane number	88-100	108.6	111	103
Motor octane number	80-90	89.7	97	89

Table 4. Technical properties of test fuels

Fuel mixture	E5	E10	E20
Density, 15 °C [gcm^{-3}]	769	771	774.6
Thermal value [$kJkg^{-1}$]	43.1	41.9	39.97
Octane count	98	99.8	101.8
Oxygen Content [% mount]	2.04	4.08	8.11
Copper strip corrosion	1a	1a	1a

The petroleum gas sequential system used in vehicle

The LPG kits produced by many companies around the world are available. These kits are used in many vehicle models. In recent years, along with developing technology, LPG systems have jumped to a new level. Although there is an evolutionwards the types of liquid LPG systems used in vehicles, gas-phase LPG systems are more preferred because of the high cost and not yet fully tested. Especially in recent years, the use of LPG system has started to increase with the spread of turbocharged vehicles. Now many companies have started to produce LPG kits for these types of vehicles [22]. The process of using gas LPG kits in turbocharged vehicles is handled together with gasoline. The system first sprays gasoline from the injector for ignition, while LPG + gasoline fuel as gasoline, some can only send fuel to the cylinders as liquid LPG [23]. In these types of LPG systems, line LPG injectors with solenoid control are used instead of the mixer. In these systems LPG intake manifold is supplied with injectors. These injectors are controlled by an external electronic control unit. This control unit is a system of its own that works by taking information from the main electronic control unit of the engine. This electronic control unit provides optimum fuel consumption and engine power [24, 25]. Schematic representation view of LPG system is given in fig. 2.

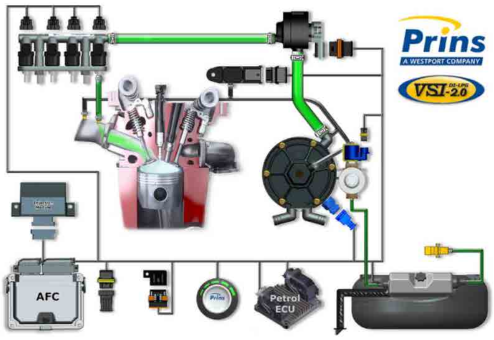

Figure 2. Schematic view of the LPG system [24]: *1 – injector rail, 2 – filtering, 3 – LPG temperature sensor, 4 – regulator, 5 – solenoid valve, 6 – engine coolant sensor, 7 – LPG manifold input, 8 – LPG ECU*

The LPG system installation of the vehicle was made by Prins LPG-CNG conversion systems. The VSI-2.0 model of the Prins brand was used. This model is easily applied to many turbocharged vehicles. Current LPG systems adjust the pressure of the LPG fuel through a regulator to convert the fuel from liquid to gas. However, unlike other systems, Prins LPG conversion system works with the principle of spraying gasoline fuel directly into cylinders by means of injectors and injecting LPG on it. An advanced electronic control unit (ECU) is available in the LPG system. Thanks to this unit, the gas pedal adjusts the amount of gasoline according to its position. In this way, it provides optimum combustion of LPG fuel sprayed on the cylinders.

Test procedure

Experiments were carried out on the chassis dynamometer. For this purpose, the vehicle was taken to dynamometer and experiments were started after the necessary safety measures were taken. All experiments it was repeated in the gear position between 2000-5500 rpm, increasing to 500 rpm. The power, torque and emission (CO, CO_2, HC) values are read from the computer screen and recorded at each engine speed. With each fuel mixture, all experiments were repeated three times. After each fuel mixture, 50 km of new fuel was put in the tank of the vehicle in order to completely clean the tank from the fuel.

Results and discussions

Engine performance

Figure 3 shows the effect of each pilot fuel and LPG fuel addition on engine power depending on engine speed. In TSI engines, the fuels sprayed into the cylinder as pilot fuel provide the first ignition, and onp of that, LPG is added from the intake manifold. In this case, the pilot fuel acts as an important effect that initiates ignition starts of ignition within the cylinder. In studies on LPG, it is stated that LPG causes power loss at low engine speeds [26, 27]. While researchers have found that this situation is partly due to the deterioration of the combustion in the cylinder, they claim the opposite of this situation and the performance of LPG usage increases [24]. In this study, positive results were obtained at low and medium engine speeds due to the increase in the ratio of ethanol added to gasoline. A decreases in engine power were observed in all fuel mixtures with the increase in engine speed over 5000 rpm. The highest engine power was achieved with 109.3 kW at 5500 rpm with E0 + LPG fuel. In addition, 108 kW of engine power was produced with E5 + LPG fuel, 108.8 with E10 + LPG fuel and 107 kW with E20 + LPG fuel at the same engine speed. Considering all engine speeds, an improvement of 4 kW was achieved with E10 + LPG fuel compared to E0 + LPG fuel at 4000 rpm. Especially with the E10 pilot fuel, it is seen that a significant improvement in engine power has been achieved. It is possible to express this situation with the increase in octane number of pilot fuel [28]. Because with the increase in octane number, the first stage of ignition approaches the moment LPG is taken into the cylinder. Thus, the total amount of energy in the cylinder increases and a maximum efficiency is obtained from the fuels. Thus, this affects the maximum engine power in the cylinder [29]. In addition, the thermal value of LPG and the high temperature of the end of combustion and the high number of octane combined with each cycle before the end of combustion temperature increases. Thus it caused some increase in engine power [30]. On the other hand, although the octane number of the E20 + LPG fuel mixture is high, it is thought that the falling thermal value and the evaporation heat of ethanol prevent the increase in motor power.

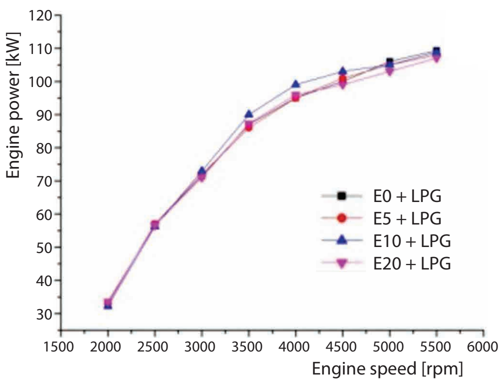

Figure 3. Effect of engine speed on engine power

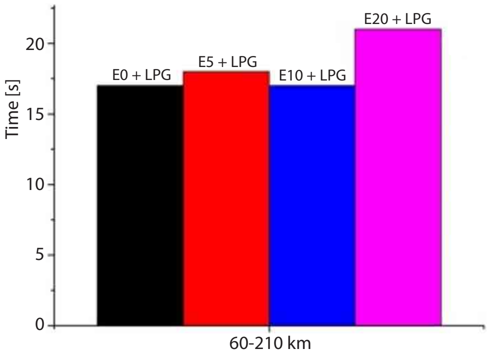

Figure 4. The 60-120 km acceleration time with different fuel mixtures

Figure 4 shows the number of seconds the vehicle reaches from 60-210 km speed with the use of fuel mixtures. These tests are carried out by the driver in the vehicle. Measuring the time at the speed limits specified by the computer is done automatically. Maximum vehicle speed with E0 + LPG fuel was reached at 17 seconds, E5 + LPG fuel at 18 seconds, E10 + LPG fuel at 16 seconds and E20 fuel at 21 seconds. A better acceleration performance was observed with the E10 + LPG fuel. It is possible to explain this situation with the high octane number of E10+LPG fuel compared to other fuels. Although the number of octane E20 + LPG fuel increased, the decrease in thermal value caused the acceleration decrease compared to other fuels.

Figure 5 shows the effect of the use of gasoline and fuel mixtures on engine torque depending on engine speed. Engine torque can also be expressed as the thrust of the energy obtained from the fuel burned in the cylinder acting on the piston. In gasoline engines, it is expected that the fuel will ignite after passing the top dead point TDC of the piston in order to obtain maximum engine torque from the cylinder. Therefore, the octane number is an important parameter in increasing engine torque [31, 32]. While an increase in engine torque was seen with the E10 + LPG fuel mixture at low and medium engine speeds, some decrease was seen after the 4500 rpm engine speed. In this case, the highest engine torque was measured at 178 Nm at 3000 rpm with E10 + LPG fuel. Engine torque of 173.5 Nm with E0 + LPG fuel, 172 Nm with E5 + LPG fuel and 174 Nm with E20 + LPG fuel were measured at the same engine speed. With the amount of ethanol added to gasoline, the number of Octane increases. Therefore, an increase in engine torque is expected. Here, it is thought that the octane number of E5 + LPG fuel mixture does not reach an amount that can generate awareness, but with the use of E10 + LPG fuel mixture the octane number of fuel mixture remains at a level that will generate awareness. In addition this, it is seen that the amount of ethanol in gasoline decreases with increasing the thermal value negatively affects the engine torque.

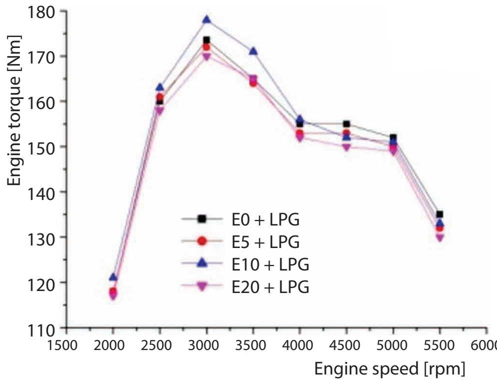

Figure 5. Effect of engine speed on engine torque

Exhaust emissions

The CO emissions by incomplete combustion of the remaining fuels, CO_2 emissions are released from the exhaust as a result of full combustion of the fuels with oxygen in the engine cylinder, and HC emissions by fuels that do not burn at all [33]. Figure 6 shows the effect of the use of fuel mixtures on CO emissions based on engine speed. It is expected that all engine revs will be reduced in CO emissions with the use of LPG in gasoline vehicles in general [34]. The LPG is a more environmentally friendly fuel than gasoline. In addition, the high heat value of LPG and the process of creating a good mixture partially improve combustion and reduce CO emissions. The results of the experiment show that at low engine speeds, CO emissions are almost non-existent. As can be seen from the fig. 6, CO emissions almost do not occur at low engine speeds with the use of E20 + LPG. In addition, with the increase in the amount of ethanol added to gasoline, the decrease in CO emissions gains speed. It is possible to explain this situation by the presence of oxygen in ethanol. There are many studies that indicate a reduction in CO emissions by using oxygen-rich fuels in engines [35]. In addition, LPG's octane number and high thermal value are added to the optimum level of combustion in the cylinder and therefore, reduced CO emissions are thought to be. The highest CO emission was determined by E0 + LPG fuel with a motor speed of 5500 rpm with a value of 0.12. All emission values obtained are far below the specified standards.

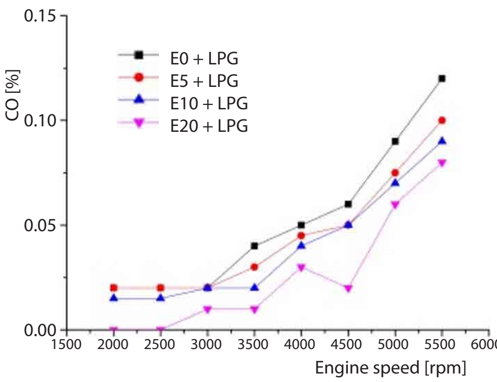

Figure 6. Effect of engine speed on CO emissions

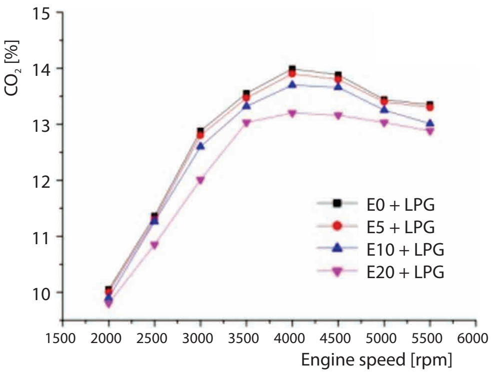

Figure 7. Effect of engine speed on CO_2 emissions

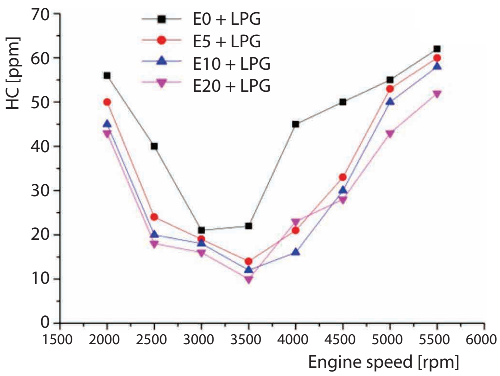

Figure 8. Effect of engine speed on HC emissions

Figure 6 shows the effect of the use of fuel mixtures on CO_2 emissions according to engine speed. In internal combustion engines, the C atoms in the fuels are combined with oxygen and CO_2 emissions are released from the exhaust as a result of full combustion. With the addition of ethanol into gasoline, CO_2 emissions are reduced at all motor speeds. The lowest amount of CO_2 emissions was obtained by E20 + LPG fuel mixture. The number of C atoms is an important factor in the formation of CO_2 emission. With the addition of ethanol into gasoline, the total number of atoms in the fuel mixture decreases. This results in reduced CO_2 emissions [36]. The highest CO_2 emissions were achieved with E0 + LPG fuel at 4000 rpm at 13.99%, while the lowest CO_2 emissions were achieved with E20 + LPG fuel at 9.8% at 2000 rpm.

Figure 7 shows the effect of gasoline and LPG usage on HC emissions according to engine speed. The HC emissions are generated in internal combustion engines by disposing of the fuel taken into the cylinder from the exhaust by not burning [37].

The HC emissions are increased by factors such as the impact of cold cylinder walls when spraying the fuel into the cylinder, worsening the partial combustion and the irregularity of the air/fuel ratio [38]. While HC emissions are high at low engine speeds, they decrease at medium engine speeds and increase again with increased engine speed. With the increase in the amount of ethanol in gasoline, HC emissions decrease at each engine speed. The highest HC emission value was found to be 62 ppm with E0 + LPG fuel at 5500 rpm, while the lowest HC value was obtained to be 16 ppm with E20 + LPG fuel at 3000 rpm. The oxygen content of ethanol is thought to be an important factor in the reduction of HC emissions. In addition, TSI engines with the electronic control of the fuel are sprayed by the formation of an ideal fuel air mixture by preventing the formation of extremely poor and extremely rich mixture.

Conclusions

This study examines the effects of 5%, 10%, and 20% ethanol addition by mass into the fuel used as pilot fuel in a vehicle equipped with LPG system, turbocharged gasoline and injector. The results obtained are to show that.

The amount of ethanol in the Pilot fuel changed the engine power. While some improvement in engine power is observed at low and medium engine speeds, a reduction in engine power is observed with the increase in engine speed above 5000 rpm. The E10 + LPG fuel mixture E5 + LPG and E20 + LPG mixture compared to the engine power has been shown to achieve more ideal results. The E0 + LPG fuel 4000 rpm engine speed 95 kW while E5 + LPG fuel 95 kW and E10 + LPG fuel 99 kW and E20 + LPG fuel 86 kW power is produced. In this case, a power increase of 4 kW was achieved with E10 + LPG fuel. The highest power generation was achieved by E0 + LPG fuel with a motor speed of 109.3 kW at 5500 rpm.

It is observed that engine torque changes with the change in the amount of ethanol in the Pilot fuel. Between 2000 rpm and 4000 rpm engine speeds, the E10 + LPG fuel mixture has the highest engine torque among all fuel mixtures. In this case, the highest engine torque was determined to be 178 Nm with E10 + LPG fuel at 3000 rpm. At 3000 rpm, the highest engine torque was achieved with a fuel mixture of E0 + LPG 173.5 Nm, a fuel mixture of E5 + LPG 172 Nm, and a fuel mixture of E20 + LPG 174 Nm.

The best results in the acceleration tests on the vehicle were obtained with E10+LPG fuel mixture with a value of 16 seconds.

With ethanol added to the pilot fuel, CO emissions decreased from all motor speeds. The best results of all mixtures were determined by using the E20 + LPG fuel mixture. The most improvement was at 4500 rpm. With the E20 + LPG fuel mixture, CO emissions decreased by 0.02% at 4500 rpm. This engine speed was 0.06% with E0 + LPG fuel mixture, 0.05% with E5 + LPG mixture and 0.05% with E10 + LPG mixture.

With the increase in the amount of ethanol added to gasoline, CO_2 emissions were reduced at all motor speeds. The highest amount of reduction was determined by E20 + LPG fuel. The highest CO_2 emissions were determined by E0 + LPG fuel mixture with a ratio of 13.99% at 4000 rpm engine speed. the same engine speed was determined by 13.9% in E5 + LPG fuel mixture, 13.7% in E10 + LPG fuel mixture and 13.2% in E20 + LPG fuel mixture.

With the increase in the amount of ethanol added to the Pilot fuel, HC emissions decreased at all engine speeds. At least HC emission value is achieved with E20 + LPG fuel at 3000 rpm engine speed. The engine speed was 21 ppm with E0 + LPG fuel mixture, 19 ppm with E5 + LPG fuel mixture and 18 ppm with E10 + LPG fuel mixture.

The findings show that the addition of ethanol into the pilot fuel that will be the igniter of LPG in a vehicle with a TSI engine has positive results in terms of engine performance and emissions. Besides, it is important to do long-term studies on engine materials.

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