



Experimental Study of the Effect of a Non-oxygenated Additive on Spark-ignition Engine Performance and Pollutant Emissions

S. Davari^a, F. Ommi^{*a}, Z. Saboohi^b, M. Safar^a

^a Department of Mechanical Engineering, Tarbiat Modares University, Tehran, Iran

^b Aerospace Research Institute (ARI), Ministry of Science, Research, and Technology, Tehran, Iran

PAPER INFO

Paper history:

Received 23 November 2020

Received in revised form 19 January 2021

Accepted 02 February 2021

Keywords:

Fuel Additive

Pollutant Emissions

Engine Performance

Four-stroke Spark Ignition Engine

Spark Plugs

ABSTRACT

In this study, effects of adding butene, homopolymer to gasoline on the performance of a four-stroke spark ignition (SI) engine and pollutant emissions have been investigated. This additive increases the octane number of gasoline. In this research, the additive was combined with a non-leaded gasoline. Also, in addition to fuel changes and the use of additives, engine spark plugs were replaced and three types of spark plugs were used for this study. These include single electrode spark plug, dual electrode spark plug and Platinum+4 spark plug. The results of experimental tests showed that with the addition of additive to gasoline, the brake torque and braking power were increased with the use of each of the three spark plug type. The results revealed that by combining gasoline and additive, carbon dioxide and nitrogen oxides emissions were increased. On the other hand, unburned hydrocarbons and carbon monoxide emissions from the engine were reduced. In addition, it was concluded that changing the spark plugs had slight effect on engine performance and pollutant emissions, and that the results of experimental tests using all three types of spark plugs were almost identical.

doi: 10.5829/ije.2021.34.04a.30

1. INTRODUCTION

Nowadays, internal combustion engines play an important role in human social life. In addition to the automotive industry, different types of internal combustion engines are widely used in other industries such as aviation, power generation, petroleum industries, etc. The limited availability of fossil fuels on the one hand and the pollutant emissions restriction laws on the other hand, have led researchers to move continuously towards optimization in the design of internal combustion engines as well as the development of new fuels with the highest efficiency and lowest levels of emissions [1].

The use of fuel additives or the improvement of combustion properties of fuel has always been one of the important issues in improving the performance of internal combustion engines. Tetraethyl lead (TEL), with the molecular formula $((\text{CH}_3\text{CH}_2)_4\text{Pb})$, was blended with

gasoline in the early 1920s as an octane number enhancer. The burning of TEL causes the emission of lead oxide, which is a very toxic substance [2]. Methyl tert-butyl ether (MTBE) has been used in the United States since late 1970s in a small amount as an octane number enhancer. Most of the refineries have used this substance as an additive because of the desired structural properties of MTBE and its cost-effectiveness. MTBE is a cancerous substance known to humans and animals, due to its solubility in groundwater [3]. Stratiev and Kirilov [4] investigated the effect of adding ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$) to gasoline as an octane enhancer and concluded that the motor octane number (MON) increased by 2.7 units, and the research octane number (RON) increased by 5.7 units. Ferrocene is known as an inexpensive additive, therefore the refineries replaced this substance with tetraethyl lead. One of the disadvantages of using ferrous as an additive is the formation of iron deposits. These deposits form on a

Corresponding Author Institutional Email: fommi@modares.ac.ir (F. Ommi)

Please cite this article as: S. Davari, F. Ommi, Z. Saboohi, M. Safar, Experimental Study of the Effect of a Non-oxygenated Additive on Spark-ignition Engine Performance and Pollutant Emissions, International Journal of Engineering, Transactions A: Basics Vol. 34, No. 04, (2021) 1035-1045

spark plug and produce a conductive surface. Rashid et al. [5] experimentally studied the effect of three gasoline fuels (RON 95, 97 and 102) on engine performance and emission of hazardous gases. They stated that increasing the fuel octane number, gives rise to increase the amount of power and torque while it decreases the amount of NO_x emissions. Ebrahimi and Mercier [6] investigated the effect of simultaneous use of gasoline and natural gas on the performance of the SI engine. He concluded that the use of natural gas increased the specific fuel consumption and the thermal efficiency. On the other hand, brake torque, exhaust gas temperature and lubricant oil temperature were reduced compared to gasoline.

Oxygenated additives have been abundantly used in fuels. Pan et al. [7] investigated the effect of 2-phenylethanol on gasoline. 2-Phenylethanol is an additive with a high octane number (about 110) that is derived from biofuel. They observed that if this additive was added, the pressure of the cylinder and the released heat decrease. They also found that, adding this additive also reduces combustion time and ignition delay. According to their results, 2-phenylethanol has a very good resistance to engine knock, due to its high octane number and its chemical structure. They concluded that the addition of this additive to gasoline leads to a reduction in nitrogen oxides, while it gives rise to increase the amount of unburned hydrocarbons and carbon dioxide. Okoronkwo et al. [8] used petrol-ethanol-diethyl-ether blend with various percentage proportion in a spark ignition (SI) engine to reduce carbon monoxide emissions. Their results showed that by increasing the amount of oxygen in the fuel, the amount of carbon monoxide emissions reduces. Srinivasan et al. [9] investigated the effect of ethanol-gasoline blend with additives on a multi-cylinder spark ignition engine. The fuel additive used by them included a mixture of toluene, methanol, isopropyl alcohol, acetone, and xylene. They concluded that the brake thermal efficiency increases with the use of alternative fuels. Also, their results showed that the amount of CO , CO_2 , HC, and NO_x emissions appreciably decreased. Zaharin et al. [10] examined the effect of iso-butanol additives in ethanol-gasoline blend on fuel properties, performance and emission characteristics of a four-cylinder spark-ignition engine. They determined that the blended fuels displayed higher brake power than pure gasoline. Also, significant reduction in brake specific fuel consumption obtained compared to base gasoline fuel. In addition, they found that with these blended fuel samples, the exhaust gas temperature increased. According to their research, carbon monoxide and unburned hydrocarbons emissions were reduced. In contrast, carbon dioxide and nitrogen oxides emissions increased. Zamankhan et al. [11] and Valihesari et al. [12] used a new combination of fuel with oxygenate additives and metal nanoparticles in a spark ignition

engine to study the effects of the novel blends on the engine parameters and also the amount of emissions. Based on their results, the performance parameters of the engine were improved and the amount of pollutants was reduced. Amirabedia et al. [13] investigated the effect of adding ethanol and Mn_2O_3 and Co_3O_4 nano additives to pure gasoline on the performance parameters and pollutant emissions of a spark ignition engine. They concluded that a combination of 10% ethanol and 20ppm Mn_2O_3 was the best fuel blend.

Another group of fuel additives used in gasoline is the additives containing aromatic hydrocarbons. Patil et al. [14] examined the effect of adding aromatic hydrocarbons to gasoline and concluded that adding aromatic hydrocarbons to gasoline increases RON and MON simultaneously. While the effect of Alkylbenzene on MON is more than RON. Also, with the addition of aromatic alcohols to gasoline, the octane number was increased by more than 10%. Demirbas et al. [3] used a catalyst in the internal combustion engine to reshape the structure of hydrocarbons and convert them into ring compounds. This catalyst converts alkanes with direct chain structures into cycloalkanes, and then converted them into aromatic compounds that have high octane numbers. They studied the effect of the naphtha catalyst on gasoline, in which 60% of saturated hydrocarbons with a low octane number turned into aromatic compounds with higher octane numbers.

As discussed, the use of innovative compounds in fuel additives is a broad field. Using fuel additives is one of the main ways to ameliorate engine performance, and decrease pollutant emissions. In this study, the effect of a non-oxygenated additive has been studied. In this way, the effect of fuel additive was tested using three different types of engine spark plugs. In this study, the new additive was examined with 15 percent of volumetric ratio. The aim of this study was to investigate changes in engine performance and pollutant emissions with varying fuels and spark plugs. In the following, the additive used, the laboratory equipment, as well as the experimental tests methodology are stated. Finally, the main results of this research are presented and analyzed.

2. MATERIALS AND METHODS

2. 1. Fuel Preparation

The fuels used in this study include unleaded gasoline and gasoline with butene, homopolymer. Table 1 shows the values of octane number of fuels used in this study, which include one unleaded gasoline and another gasoline with the addition of additive.

2. 2. Engine and Experimental Setup

Tests were performed in the engine and propulsion laboratory

TABLE 1. Values of octane number of fuels used in this study

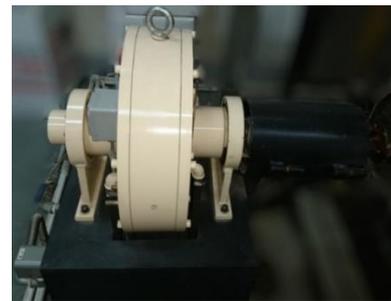
	Normal gasoline	Gasoline with additive
Motor Octane Number (MON)	83.6	92.1
Research Octane Number (RON)	87.3	96.7
Antiknock Index (AKI)	85.45	94.4
Lower heating value (MJ/kg)	43.5	45.7
Latent Heat of Vaporization (kJ/kg)	350	331

at Tarbiat Modarres University employing a spark ignition engine model number XU7JP/L3. The specifications of the XU7JP/L3 engine are presented in Table 2. A 130kW eddy-current dynamometer (manufactured by MPA Company) was used to gauge power and torque of the engine. Figure 1 shows the rig used dynamometer and the engine test bed. The dynamometer was connected to the crankshaft through a rotating shaft, and by applying load to the engine, the engine power and torque were determined at each speed. The dynamometer was located inside a steel chamber to provide the necessary safety when its working. The load was applied to the engine using a computer dynamometer software. In this study, in addition to fuel changes and the use of additives, engine spark plugs were also replaced and three types of spark plugs were used for this research. These include single electrode spark plug, dual electrode spark plug and Platinum+4 spark plug. Figure 2 shows the three spark plugs used in the experiments. A cooling tower was used to prevent overheating of the dynamometer. In order to measure the pollutants, the CAP3200 analyzer, made by Capelec Company (France) was used. The pollutants measured by the analyzers include carbon dioxide, carbon monoxide, unburned hydrocarbons (UHCs) and nitrogen oxides. The analyzer is shown in Figure 3.

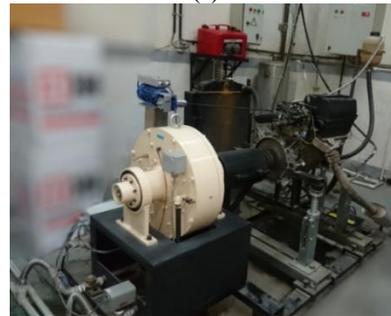
2. 3. Experimental Tests Methodology In this section, the steps of measuring the engine performance as well as the emission levels of the pollutants are discussed.

TABLE 2. The test engine characteristics

Company	Peugeot
Engine Model	XU7JP/L3
Number of cylinder	4
Capacity (cm ³)	1761
Compression ratio	10.2:1
Cylinder Bore (mm)	81.4
Stroke (mm)	83
Maximum Power (hp)	100 at 6000 rpm
Maximum Torque (Nm)	153 at 3000 rpm



(a)



(b)

Figure 1. View of (a) the dynamometer and (b) the engine test bed

(a)



(b)



(c)

Figure 2. Three types of used spark plug: (a) Single electrode spark plug, (b) Dual electrode spark plug, (c) Platinum+4 spark plug

In the laboratory test stand, the engine was initially turned on, and it operated with fixed rotational speed for 10 minutes to reach steady state condition. The studied additive with a 15% volumetric ratio was combined with lead-free gasoline, and the resulting fuel and gasoline without additives were subjected to performance tests.



Figure 3. CAP3200 Analyzer

The tests were carried out in such a way that in order to investigate the impact of the additive in different engine conditions, the single electrode spark plug was first examined with both types of fuel. Then, in the second stage, the dual electrode spark plug was studied with both types of fuel, and finally, the platinum+4 spark plug was examined with both types of fuel. For each fuel mixture, the engine performance tests were performed for four different modes of the engine operational conditions at 1500, 2000, 2500, and 3000 (rpm). All tests were carried out with a fixed (50 percent Throttle) engine load, and the engine speed was automatically applied by the test stand software. During each run, the engine operated for 5 minutes to get a steady state operating condition. Power and torque of the engine were measured through the dynamometer and these data were automatically saved in a folder. The sensor of the analyzer was connected to the exhaust outlet and the amount of pollutants was obtained during the test and at different engine speed. At the end of each test, the sensor was cleaned to increase the accuracy of the measurement. Then, characteristics such as power, torque, fuel consumption, pollutant emissions, exhaust outlet temperature and pressure, oil temperature and pressure, etc., were compared for each fuel type and at different engine speed as functional parameters. Experimental tests were repeated three times to evaluate the repeatability of the test results, and the mean value was reported at the end. Also, in this research, at each stage of the test, the comparison of the results between ordinary gasoline and gasoline with the additive in a fixed engine speed was conducted. In order to validate the results, the experimental results were compared with those published by the engine manufacturer. The amount of throttle considered was equal to 50 percent in all graphs provided by the manufacturer. For this reason, in this experiment, the amount of throttle was considered constant (equal to 50 percent), and throttle is not a variable parameter. It should be noted that all experiments were repeated three times and the maximum error rate of the results was 0.5%. Also, all sources of experimental error were identified and eliminated as much as possible. These sources of error include emissions measuring errors, dynamometer errors, data

averaging errors and etc. In this way, each of the experiments that were repeated three times were compared with each other, and then their error percentage was calculated. Another important issue was determining the volume fraction of the additive, which should be considered both in terms of improving engine performance and reducing pollutants, as well as in terms of cost. Therefore, this additive was studied and analyzed from all aspects of this study. The theoretical implications of improving engine performance as well as reducing emissions if using this additive, which has higher octane and LHV content than pure gasoline, were tested by experimental tests.

3. RESULTS AND DISCUSSION

3.1. Engine Performance Parameters As shown in Figure 4, the addition of an additive to the fuel increases the brake torque, due to the process and the combustion cycle were completed, and the chemical energy of the fuel was more efficiently converted to mechanical work. It is also necessary to explain that with increasing engine speed to 2500 rpm, brake torque increases. This is due to the complete filling of the cylinder at engine breathing. However, at higher speeds due to less breathing time, the cylinder is not fully filled, and as a result the brake torque decreases.

As shown in Figure 5, the brake power increases with the addition of the additive to the fuel, and this phenomenon is evident at all engine speeds. This can be attributed to the increase in octane number (As shown in Table 1) due to the mixing of fuel with additives, since the increase in octane number delayed the occurrence of combustion. Accordingly, the pressure in the piston compression stage decreases, and increases in its expansion stage. Consequently, the enclosed surface of the P-V curve increases and therefore the brake power increases. The brake power is directly related to the engine speed, hence as the engine speed increases the brake power increases as well. The heating value of the fuel increased by adding butene, homopolymer to gasoline and as result increases the engine power. As the engine speed increases, the effect of adding additive becomes more apparent, since fuel consumption increased and leads to enhanced engine power [15]. As presented in Table 1, the heating value of fuel with additive is more than that of normal gasoline. This means that the engine requires a higher amount of neat gasoline to generate the identical engine power as in fuel with additive. As a result, using fuel with butene, homopolymer increases power and torque compared to regular gasoline. Typically, engine power and torque are closely related to pressure inside cylinder. As shown in Figure 6, the fuel with additive displayed a higher pressure inside cylinder.

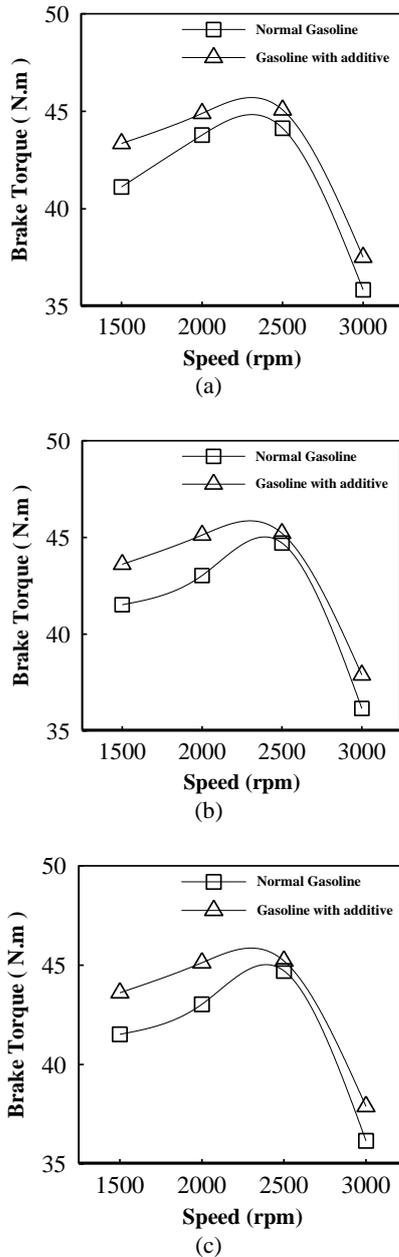


Figure 4. Experimental results of brake torque for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

Figure 6 shows the pressure inside cylinder changes against the crank angle for various fuel mixtures. Combustion chamber pressure is one of the most important parameters in determining the combustion process characteristics [16]. It can be seen that the pressure inside the chamber using gasoline with additive is slightly higher than pure gasoline. This is due to the lower heating value (LHV) of gasoline with butene, homopolymer is higher than conventional gasoline.

Therefore, the pressure inside the cylinder is directly related to the engine power. Ozsezen and Canakci [17] derived that as the chamber pressure increases, the engine power increased.

The percentage of changes in engine performance parameters for gasoline with the additive at different engine speeds is compared to conventional gasoline and data reported in Table 3.

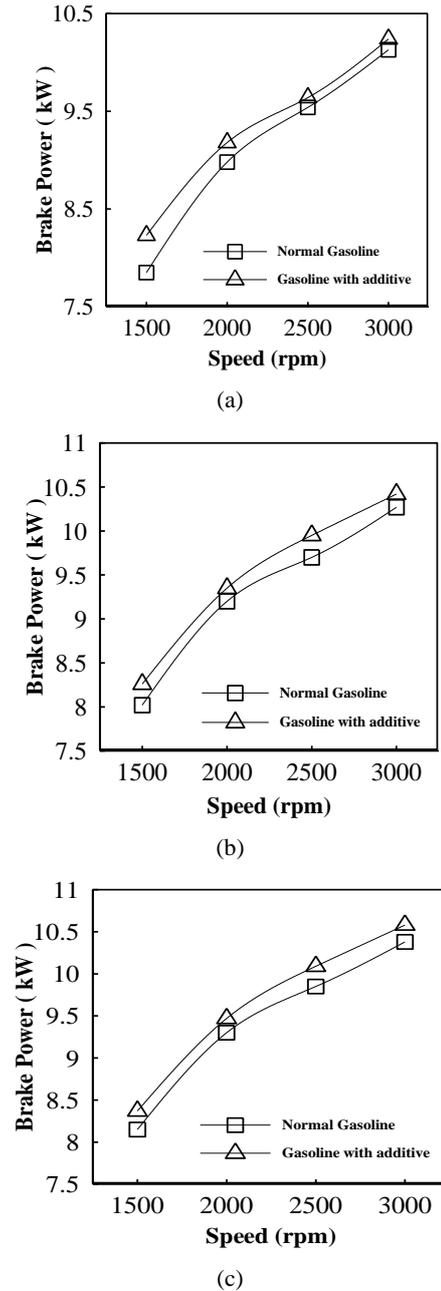


Figure 5. Experimental results of brake power for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

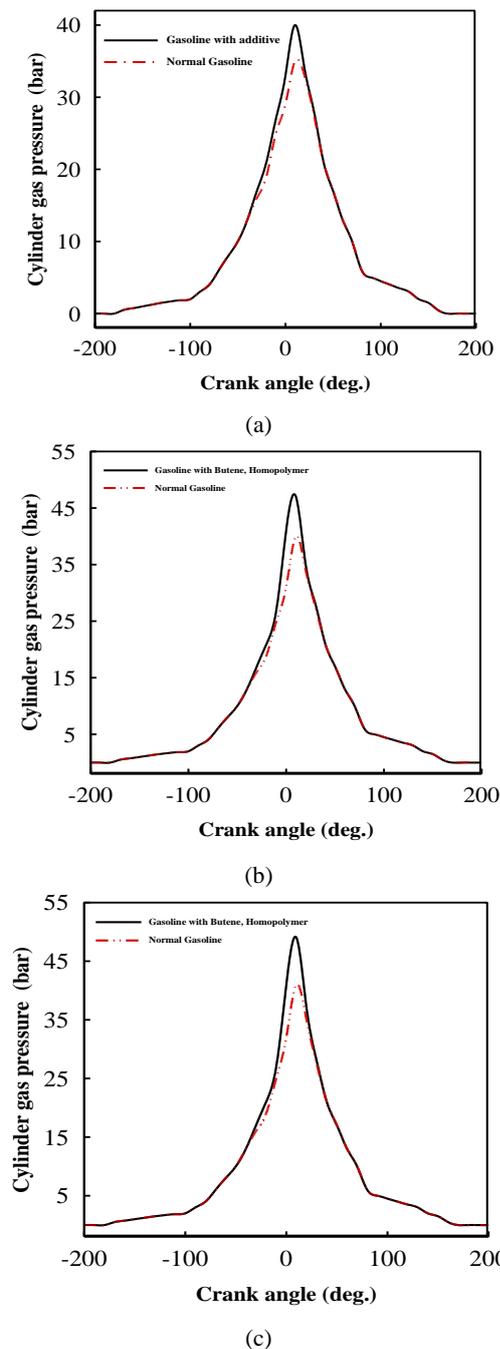


Figure 6. Effect of fuel blends on indicated pressure (IMEP) at engine speed 2500 rpm for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug

As can be seen, spark plug replacement has little effect on engine performance parameters and the performance of all three types is almost identical.

Figure 7 shows the ignition delay changes at different engine speeds for different types of spark plugs using pure gasoline. As shown in Figure 7, changing the spark plugs slightly reduces the ignition delay.

TABLE 3. Percentage increase of engine performance parameters when using gasoline with additive compared to conventional gasoline

Type of spark plug	Engine speed	Percentage increase of brake torque	Percentage increase of brake power
Single Electrode Spark Plug	1500	5.42	4.84
	2000	2.54	2.23
	2500	2.13	1.05
	3000	4.66	1.08
	Average Values		3.69
Dual Electrode Spark Plug	1500	4.94	2.99
	2000	4.77	1.63
	2500	0.94	2.58
	3000	5.11	1.46
	Average Values		3.94
Platinum+4 Spark Plug	1500	5.03	2.61
	2000	4.85	1.70
	2500	1.92	2.42
	3000	4.78	1.90
	Average Values		4.14

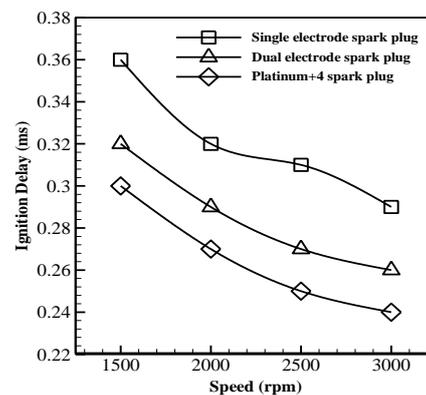


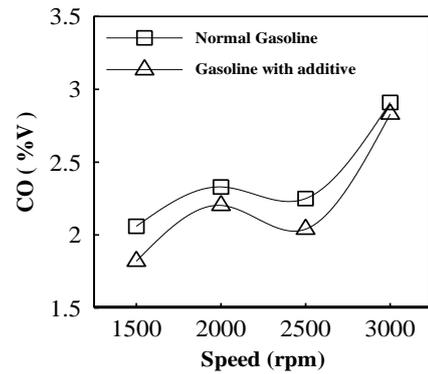
Figure 7. Variations of ignition delay according to different engine speeds for different types of spark plugs using pure gasoline

3. 2. Engine Exhaust Emissions

In this section, the effects of the addition of fuel additive on pollutant emissions were investigated. As shown in Figure 8, the amount of carbon monoxide released by the engine decreases by adding the additive to gasoline. The main contributor to controlling carbon monoxide is the excess

air ratio, which was considered to be fixed in this study. As it was stated, the combustion process improves with the use of this additive. This means that the fuel burns more slowly and more time is required to complete the combustion reaction. Consequently, carbon monoxide emissions are reduced. Also, as the engine speed rises, the amount of carbon monoxide emissions increases. The reason is that, by increasing the engine speed, combustion reactions do not have enough time to form, and therefore incomplete combustion occurs. The main cause of carbon monoxide emissions is incomplete combustion [10]. In Figure 8, at 2000 rpm, the amount of carbon monoxide emissions first increased and then decreased at 2500 rpm (the opposite is shown in Figure 9 for carbon dioxide emissions) due to combustion fluctuations in the combustion chamber that dumps over time.

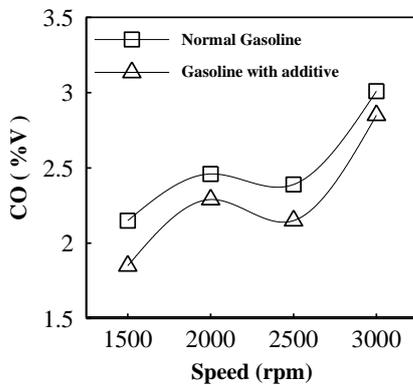
The effect of adding additive to gasoline on the amount of carbon dioxide emissions released from the engine is shown in Figure 9. The results showed that carbon dioxide emissions increased by adding additive to gasoline. As previously mentioned, due to the combustion improvement and the completion of the combustion process, the amount of carbon dioxide increases and the amount of carbon monoxide decreases.



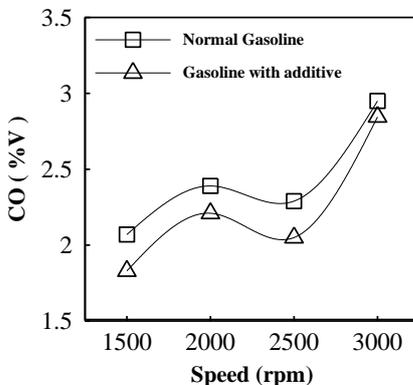
(C)

Figure 8. Experimental results of carbon monoxide for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

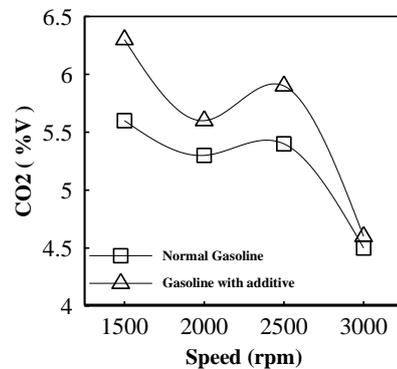
It is also apperceived that with increasing engine speeds, carbon dioxide emissions are reduced due to incomplete combustion. The reason that there is less time for combustion reactions in the engine. Carbon dioxide emissions display various conduct than carbon monoxide emissions [18].



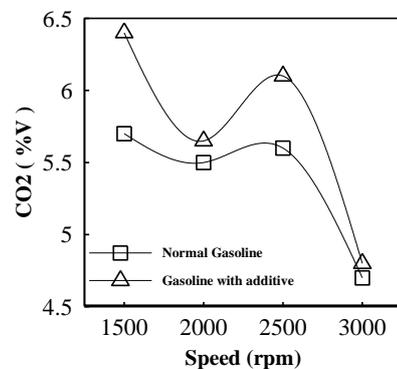
(a)



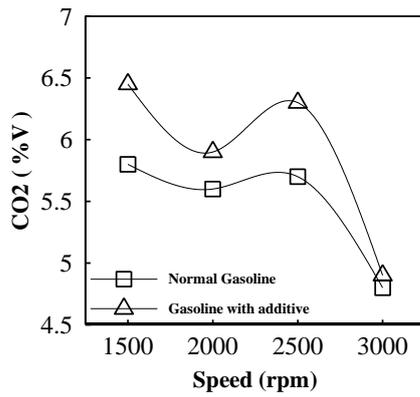
(b)



(a)



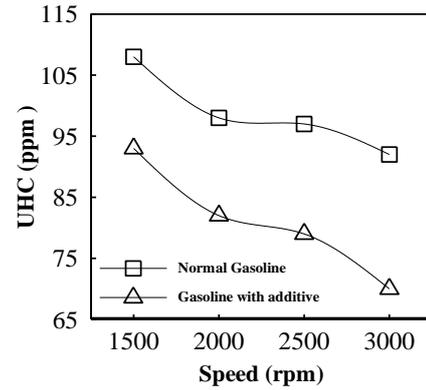
(b)



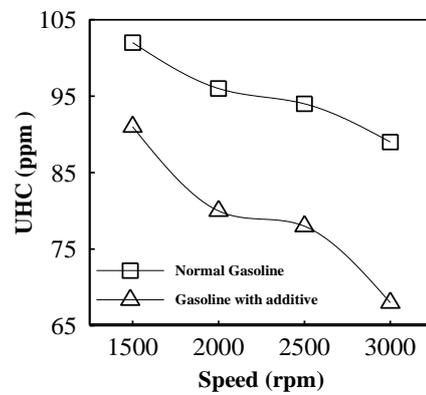
(c)

Figure 9. Experimental results of carbon dioxide for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

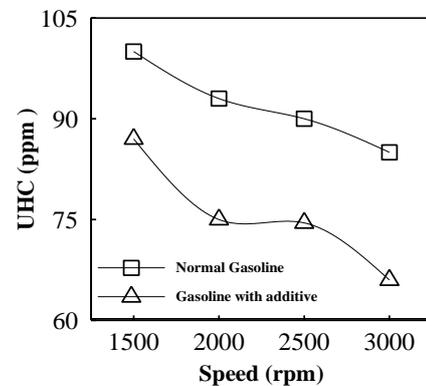
The effect of adding additive to gasoline on the amount of unburned hydrocarbons (UHCs) emissions produced by combustion is shown in Figure 10. The amount of UHC emissions increased if the fuel is not burned or incomplete combustion inside the chamber [10]. As can be seen from the figure, the increase in engine speed reduces the amount of unburned hydrocarbons emissions. As the engine speed rises, the opportunity for heat transfer from the engine is reduced, and thus the temperature of the combustion chamber wall increases, which consequently leads to decrease the thickness of the flame silencing layer near the wall. By adding the additive to the fuel, the amount of unburned hydrocarbons emissions decreases. The reasons for this decrease are: 1) Increasing the temperature of the combustion chamber, which causes the flame silencing to be delayed when it reaches the cylinder wall. This is because one of the main causes of the formation of unburned hydrocarbons emissions is the occurrence of flame silencing phenomenon in the adjacent of the cylinder wall. 2) Increasing the temperature of the combustion gases, which causes post-reactivity in exhaust gases and these hydrocarbons are oxidized at high temperatures. The fuel containing the additive has a higher octane number than conventional gasoline. The high octane number is one of the factors that increases the velocity of the flame. As a result, the flame does not turn off when it reaches the grooves inside the cylinder and unburned hydrocarbons emissions are reduced. UHC emissions were more reduced than other emissions. The UHC emissions decreased with the addition of the butene, homopolymer to the fuel. Increasing the temperature of the combustion gases caused post-reactivity in the exhaust gases. UHC emissions are more sensitive to temperature than other emissions. As a result, UHC emissions were decreased with increasing temperature.



(a)



(b)



(c)

Figure 10. Experimental results of unburned hydrocarbons for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

Figure 11 shows the exhaust gas temperature (EGT) trend for different fuels. EGT changes proportionally with the maximum cylinder temperature [19]. Exhaust gas temperature is higher when using gasoline with butene, homopolymer. Pure gasoline has greater latent heat than fuel with additive, as stated formerly. As a result, vaporization of conventional gasoline reasons a higher temperature drop in combustion chamber.

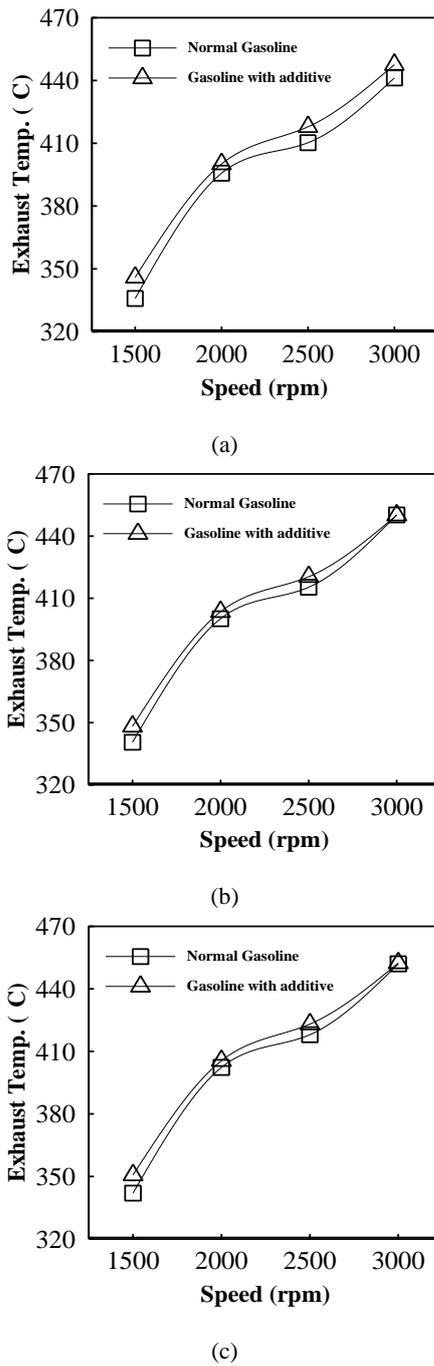


Figure 11. Experimental results of temperature of the exhaust gases for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

The effect of adding additive to gasoline on the amount of nitrogen oxides emissions produced by combustion is illustrated in Figure 12. The formation of NOx emissions is influenced by the combustion temperature [20]. As the engine speed increases and the additive is used, the amount of nitrogen oxides emissions

increases, because at high engine speeds the number of work cycles increases over a given time, and as a result the heat transfer decreases and the maximum combustion temperature in the cylinder increases. It should be noted that the highest amount of nitrogen oxides emissions produced in the internal combustion engines is from the thermal path (Zeldovich). The Zeldovich mechanism

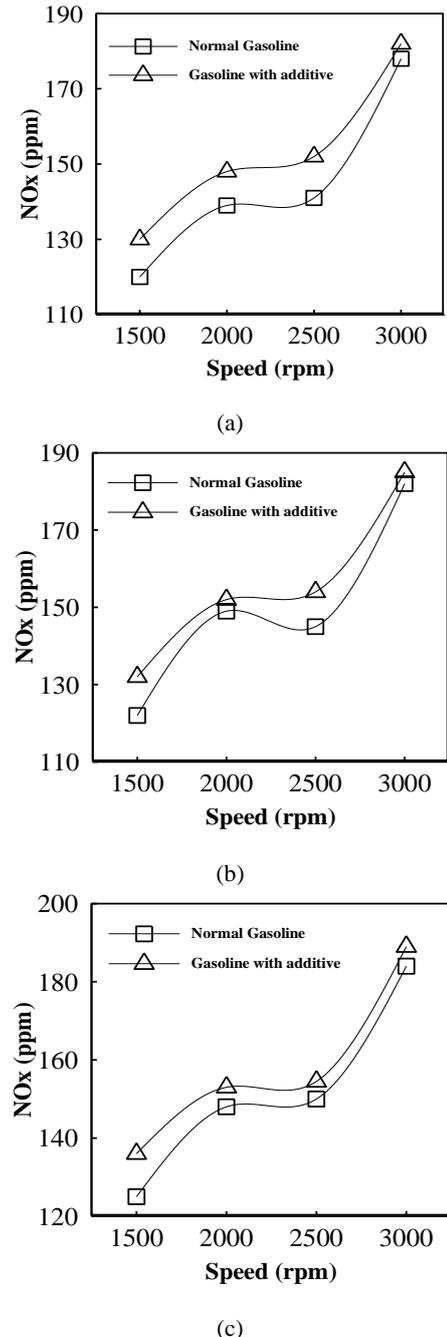


Figure 12. Experimental results of nitrogen oxides for (a) Engine with single electrode spark plug, (b) Engine with dual electrode spark plug, (c) Engine with platinum+4 spark plug at different fuel blends and engine speeds

explicates the formation of thermal NOx [21]. Therefore, the production rate of this pollutant has a direct relation with the highest combustion temperature. The thermal path of nitrogen oxide production increases exponentially with increasing temperature, and is very sensitive to temperature. In other words, nitrogen and oxygen react at high temperatures, so the high temperature is the significant factor for the formation of nitrogen oxides emissions [22]. Using fuel with the additive, more complete combustion is formed inside the cylinder, which increases the temperature of the cylinder by complete combustion, and therefore the amount of nitrogen oxides emissions increases as temperature rises. NOx emissions increased with increasing engine speed due to increased temperature and pressure inside the combustion chamber. Therefore, NOx emissions are directly related to the temperature of the combustion chamber [16, 23, 24].

Percentage increase or decrease of pollutants in the case of using gasoline with the additive compared to the use of ordinary gasoline in different engine speed is reported in Table 4.

TABLE 4. Percentage changes in engine exhaust emissions when using gasoline with additive compared to conventional gasoline

Type of spark plug	Engine speed	Percentage reduction of CO	Percentage increase of CO ₂	Percentage reduction of UHCs	Percentage increase of NOx
Single Electrode Spark Plug	1500	13.95	12.5	13.88	8.33
	2000	6.91	5.66	16.33	6.47
	2500	10.04	9.26	18.56	7.80
	3000	5.31	2.22	23.91	2.25
	Average Values	9.05	7.41	18.17	6.21
Dual Electrode Spark Plug	1500	11.59	12.28	10.78	8.19
	2000	7.53	2.72	16.66	2.01
	2500	10.48	8.93	17.02	6.21
	3000	3.56	2.13	23.59	1.65
	Average Values	8.29	6.52	17.02	4.52
Platinum +4 Spark Plug	1500	11.65	11.21	13.01	8.80
	2000	5.45	5.36	19.35	3.38
	2500	9.33	10.53	17.22	3.00
	3000	2.75	2.08	22.35	2.71
	Average Values	7.29	7.29	17.98	4.47

4. CONCLUSIONS

The use of fuel additives is one of the main strategies for improving engine performance and reducing the amount of pollutants. In this research, the effects of adding a non-oxygenated additive to gasoline on engine performance and pollutant emissions was investigated. Also, engine spark plugs were replaced and tests were repeated using each of the spark plugs. The results of experimental tests showed that by adding the butene, homopolymer to gasoline, brake torque, and brake power were increased by an average of 4% and 2%, respectively. Also, with increasing the engine speed up to 2500 rpm, the brake torque was increased, while its amount was decreased at higher speeds. On the other hand, brake power was increased with increasing engine speed.

By using the additive, the amount of carbon monoxide (CO) and unburned hydrocarbons (UHCs) emissions were decreased by an average of 8% and 18%, respectively. Also, with increasing engine speed, the carbon monoxide emission was increased, but on the other hand, the amount of unburned hydrocarbons emission was decreased.

By adding the additive to fuel, carbon dioxide (CO₂) and nitrogen oxides (NOx) emissions were increased by an average of 7% and 6%, respectively. Also, the results revealed that with increasing engine speed, carbon dioxide emission was decreased, but on the contrary, nitrogen oxides emission was increased.

As previously mentioned, in this study, three types of spark plugs were used, which include single electrode, dual electrode and Platinum+4. As a result, according to experimental tests, spark plug replacement had little effect on the values of performance parameters and pollutant emissions of engine, and their values remained almost constant. The effect of multi-electrode spark is long-term and the short-term effect is not significant. Because erosion occurs over time and ignition by the spark plug is not done well, on the other hand, multi-electrode spark plugs are more resistant to this phenomenon and therefore have better performance in a long time operation.

5. REFERENCES

- Huang, Y.-H. and Wu, J.-H., "Analysis of biodiesel promotion in taiwan", *Renewable and Sustainable Energy Reviews*, Vol. 12, No. 4, (2008), 1176-1186. doi: 10.1016/j.rser.2007.01.009
- Wiesenthal, T., Leduc, G., Christidis, P., Schade, B., Pelkmans, L., Govaerts, L. and Georgopoulos, P., "Biofuel support policies in europe: Lessons learnt for the long way ahead", *Renewable and Sustainable Energy Reviews*, Vol. 13, No. 4, (2009), 789-800. doi: 10.1016/j.rser.2008.01.011
- Demirbas, A., Balubaid, M., Basahel, A., Ahmad, W. and Sheikh, M., "Octane rating of gasoline and octane booster additives", *Petroleum Science and Technology*, Vol. 33, No. 11, (2015), 1190-1197. doi: 10.1080/10916466.2015.1050506

4. Stratiev, D. and Kirilov, K., "Opportunities for gasoline octane increase by use of iron containing octane booster", *Petroleum & Coal*, Vol. 51, No. 4, (2009), 244-248.
5. Rashid, A.K., Abu Mansor, M.R., Ghopa, W.A.W., Harun, Z. and Mahmood, W.M.F.W., "An experimental study of the performance and emissions of spark ignition gasoline engine", *International Journal of Automotive & Mechanical Engineering*, Vol. 13, No. 3, (2016). doi: 10.15282/ijame.13.3.2016.1.0291
6. Ebrahimi, R. and Mercier, M., "Experimental study of performance of spark ignition engine with gasoline and natural gas", Vol. 24, No. 1, (2011), 65-74.
7. Pan, M., Wei, H., Feng, D., Pan, J., Huang, R. and Liao, J., "Experimental study on combustion characteristics and emission performance of 2-phenylethanol addition in a downsized gasoline engine", *Energy*, Vol. 163, (2018), 894-904. doi: 10.1016/j.energy.2018.08.130
8. Okoronkwo, A., Igbokwe, J., Ezurike, B. and Oguoma, O., "The emission characteristics of a petrol-ethanol-diethyl-ether blend as a carbon monoxide reduction additive in spark ignition engine", *International Journal of Ambient Energy*, Vol. 39, No. 4, (2018), 360-364. doi: 10.1080/01430750.2017.1303627
9. Srinivasan, C.A. and Saravanan, C., "Emission reduction on ethanol-gasoline blend using fuel additives for an si engine", *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, Vol. 35, No. 12, (2013), 1093-1101. doi:10.1080/15567036.2011.584114
10. Zaharin, M.S.M., Abdullah, N.R., Masjuki, H.H., Ali, O.M., Najafi, G. and Yusaf, T., "Evaluation on physicochemical properties of iso-butanol additives in ethanol-gasoline blend on performance and emission characteristics of a spark-ignition engine", *Applied Thermal Engineering*, Vol. 144, (2018), 960-971. doi: 10.1016/j.applthermaleng.2018.08.057
11. Zamankhan, F., Pirouzfard, V., Ommi, F. and Valihsari, M., "Investigating the effect of mgo and ceo 2 metal nanoparticle on the gasoline fuel properties: Empirical modeling and process optimization by surface methodology", *Environmental Science and Pollution Research*, Vol. 25, No. 23, (2018), 22889-22902.
12. Valihsari, M., Pirouzfard, V., Ommi, F. and Zamankhan, F., "Investigating the effect of fe2o3 and tio2 nanoparticle and engine variables on the gasoline engine performance through statistical analysis", *Fuel*, Vol. 254, (2019), 115618. doi: 10.1016/j.applthermaleng.2018.08.057
13. Amirabedia, M., Jafarmadar, S., Khalilarya, S. and Kheyrollahi, J., "Experimental comparison the effect of mn2o3 and co3o4 nano additives on the performance and emission of si gasoline fueled with mixture of ethanol and gasoline", *International Journal of Engineering*, Vol. 32, No. 5, (2019), 769-776. doi: 10.5829/ije.2019.32.05b.19
14. Patil, A.R., Yerrawar, R., Nigade, S., Chavan, O., Rathod, H. and Hiran, B., "Literature review on need of composite additives for si engine", *International Journal for Research and Development in Technology*, Vol. 2, (2014), 8-12.
15. He, B.-Q., Liu, M.-B. and Zhao, H., "Comparison of combustion characteristics of n-butanol/ethanol-gasoline blends in a hcci engine", *Energy Conversion and Management*, Vol. 95, (2015), 101-109. doi: 10.1016/j.enconman.2015.02.019
16. Thangavel, V., Momula, S.Y., Gosala, D.B. and Asvathanarayanan, R., "Experimental studies on simultaneous injection of ethanol-gasoline and n-butanol-gasoline in the intake port of a four stroke si engine", *Renewable Energy*, Vol. 91, (2016), 347-360. doi: 10.1016/j.renene.2016.01.074
17. Ozsezen, A.N. and Canakci, M., "Performance and combustion characteristics of alcohol-gasoline blends at wide-open throttle", *Energy*, Vol. 36, No. 5, (2011), 2747-2752. doi: 10.1016/j.energy.2011.02.014
18. Li, Y., Ning, Z., Chia-fon, F.L., Yan, J. and Lee, T.H., "Effect of acetone-butanol-ethanol (abe)-gasoline blends on regulated and unregulated emissions in spark-ignition engine", *Energy*, Vol. 168, (2019), 1157-1167. doi: 10.1016/j.energy.2018.12.022
19. Eyidogan, M., Ozsezen, A.N., Canakci, M. and Turkcan, A., "Impact of alcohol-gasoline fuel blends on the performance and combustion characteristics of an si engine", *Fuel*, Vol. 89, No. 10, (2010), 2713-2720. doi: 10.1016/j.fuel.2010.01.032
20. Deng, B., Fu, J., Zhang, D., Yang, J., Feng, R., Liu, J., Li, K. and Liu, X., "The heat release analysis of bio-butanol/gasoline blends on a high speed si (spark ignition) engine", *Energy*, Vol. 60, (2013), 230-241. doi: 10.1016/j.energy.2013.07.055
21. Miller, J.A. and Bowman, C.T., "Mechanism and modeling of nitrogen chemistry in combustion", *Progress in Energy and Combustion Science*, Vol. 15, No. 4, (1989), 287-338. doi: 10.1016/0360-1285(89)90017-8
22. Varatharajan, K. and Cheralathan, M., "Influence of fuel properties and composition on nox emissions from biodiesel powered diesel engines: A review", *Renewable and Sustainable Energy Reviews*, Vol. 16, No. 6, (2012), 3702-3710. doi: 10.1016/j.rser.2012.03.056
23. Gonca, G., "Influences of different fuel kinds and engine design parameters on the performance characteristics and no formation of a spark ignition (si) engine", *Applied Thermal Engineering*, Vol. 127, (2017), 194-202. doi: 10.1016/j.applthermaleng.2017.08.002
24. Elfasakhany, A., "Experimental investigation on si engine using gasoline and a hybrid iso-butanol/gasoline fuel", *Energy Conversion and Management*, Vol. 95, (2015), 398-405. doi: 10.1016/j.enconman.2015.02.022

Persian Abstract

چکیده

در این پژوهش، تاثیر افزودن بوتن، هموپلیمر به بنزین بر پارامترهای عملکردی و انتشار آلاینده‌ها از یک موتور اشتعال جرقه‌ای بررسی شده است. این افزودنی موجب افزایش عدد اکتان سوخت شد. همچنین در این پژوهش علاوه بر سوخت، شمع‌های موتور نیز تعویض گردید. شمع‌های مصرفی شامل شمع تک، دو و چهار الکترودی بودند. نتایج آزمون‌های تجربی نشان داد که با افزودن بوتن، هموپلیمر به سوخت، مقادیر گشتاور ترمزی، توان ترمزی، آلاینده دی اکسید کربن و آلاینده اکسیدهای نیتروژن با استفاده از تمامی شمع‌ها افزایش می‌یابند. همچنین در نقطه مقابل انتشار آلاینده‌های هیدروکربن‌های نسوخته و مونواکسید کربن کاهش یافت. علاوه بر این، این نتیجه حاصل شد که تغییر شمع‌ها تأثیر اندکی بر عملکرد موتور و انتشار آلاینده‌ها دارد و نتایج آزمون‌های تجربی آن با استفاده از هر سه نوع شمع تقریباً یکسان است.
