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EFFECT OF IGNITION TIMINGS ON THE SI ENGINE PERFORMANCE AND EMISSIONS FUELED WITH GASOLINE, ETHANOL AND LPG

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Abstract

The engine performance, combustion characteristics and exhaust gas emissions of a four-cylinder, four-stroke indirect injection spark ignition engine has been numerically investigated at constant engine speed and different ignition timings when using gasoline, ethanol and LPG fuels. For this purpose, a model has been suggested by using a two-zone burnt and unburnt gas for in-cylinder combustion. The experimental data related to the cylinder pressures have been carried out to validate the engine model. The optimal effective power and effective torque were shown at advanced crank angle degrees before the top dead center. It is observed that the brake specific fuel consumption decreases if the ignition timings increase. The ethanol fuel exhausted a minimum level of carbon monoxide, unburnt hydrocarbon and oxide nitrogen emissions when compared with the gasoline fuel at all operating conditions. LPG fuel produced promising good emission results than that obtains from gasoline fuel.

Keywords: LPG and Ethanol fuels, SI engine, Engine performance, Emissions.

I. Introduction

In the last two decades, many studies have been carried out to discover a suitable alternative fuel for spark ignition engines to lowest the toxic emissions yet maintaining the same performance as that of conventional fuel, [II], [III], [VI], [X], [XX]. Alcohols could offer a promising solution to resolve the above problem [V], [IX], [XV], [XVII],[XXI]. The effect of spark ignition timing on SI engine performance fueled with hydrogen-ethanol fuel (0 to 80% with an increment of 20%, by volume) at different compression ratios (7:1, 9:1,11:1) and an engine speed of 1500 rpm was carried out by [XI]. The results show that the brake means effective pressure and the brake thermal efficiency increased, while the brake specific fuel consumption decreased when the hydrogen fraction increases in the ethanol fuel. Tunka and Polcar [XIV] experimentally studied the effect of ignition timing on engine performance (effective power and effective torque), combustion characteristics (cylinder pressure, heat burn rate, combustion duration, combustion stability) of a four-cylinder AUDI spark ignition engine at an engine speed of 2500 rpm and constant load. The results showed that the effective power and torque increase, while the pressure in the cylinder decreases, as the ignition timing increases. Moreover, the combustion is more stable at advanced ignition timing, whereas no significant difference was observed in the combustion duration.

An experimental investigation of the brake power, brake fuel consumption, brake thermal efficiency and exhaust gas emissions of a single cylinder SI engine operating gasoline and LPG fuels under various load conditions and different compression ratios was carried out by [XII]. The result showed that the LPG fuel produced almost a similar engine performance compared to gasoline fuel. Moreover, the LPG fuel improved the brake specific energy consumption, carbon monoxide and unburnt hydrocarbon better than the gasoline fuel at the same selected operating conditions.

Several studies on LPG fuel have been conducted by different researchers [I], [VIII], [XVI],[XVIII]. The effective power and torque produced by the engines when using these fuels were lower than that of the gasoline fuel in most of the testing conditions. They observed that the LPG produced lower volumetric efficiency, CO, HC, and NOx emissions than that of conventional fuel. They explain this reduction due to the fact that LPG has a lower carbon-hydrogen ratio and a high octane number which resulting in a homogeneous mixture in the combustion chamber than the gasoline fuel.

The Iraqi government in 2019 starts to apply a new rule on the taxi company by using LPG fuel in their cars instead of gasoline fuel. Therefore, it's very important to take in the consideration of the Iraq humidity and temperature during the summer as well as several operating conditionsin any future studies. According to the literature, the drawback of using alcohol in spark-ignition engines is the negative impact on engine performance. However, changing the spark timing could have a significant influence on the combustion mechanism. Therefore, the aim of this study is to investigate the effect of spark ignition timings on engine performance, combustion characteristics and emissions of a four-cylinder, four-stroke, SI engine running at a constant engine speed of 2500 rpm fueled with gasoline, ethanol and LPG fuels.

II. Numerical Procedure

For the current work an engine combustion model was created and developed by used AVL Boost to predict the combustion characteristics, engine performance and exhaust gas emissions. AVL Boost is multi-purpose thermo-fluid dynamics software using to simulate the compression or spark ignition of an internal combustion engine. Hence, the combustion chamber is divided into two zones consisting of unburnt and burnt gas described by a Vibe function. The Woschni 1978 heat transfer model was selected for this simulation. All engine components such as intake and exhaust pipes, air cleaner filter, cylinder geometry, catalyst geometry, and others were taken from the real test engine and linked together by pipes in the program as shown in figure 1. The main specifications of the test engine are listed in Table1 and the diagram shown in figure 2. The results of gasoline were collected at different ignition timings (15 BTDC, 10 BTDC, 5 BTDC, TDC, and 5 ATDC) at a constant engine speed of 2500 rpm under constant load and lambda equal to 1.2. Then, the model was run by used ethanol and LPG fuels at the same operating conditions; the results were collected and compared with that obtained of gasoline. The humidity was 10%, the temperature was 45 °C were selected as input in the simulations (the average Iraq summer climate).

Table 1: Engine Specification.

Particulars	Specifications
Manufacturer	Hyundai
Model	2.0 L, L4 DOHC 16 Valves
Type	Regular Unleaded
Combustion	Indirect Injection
Number of cylinders	4
Bore x stroke (mm)	81 x 97
Compression ratio	12.5:1
Maximum power (Net @ RPM)	108 kW @ 6200
Maximum torque (Net @ RPM)	132 Nm @ 4500

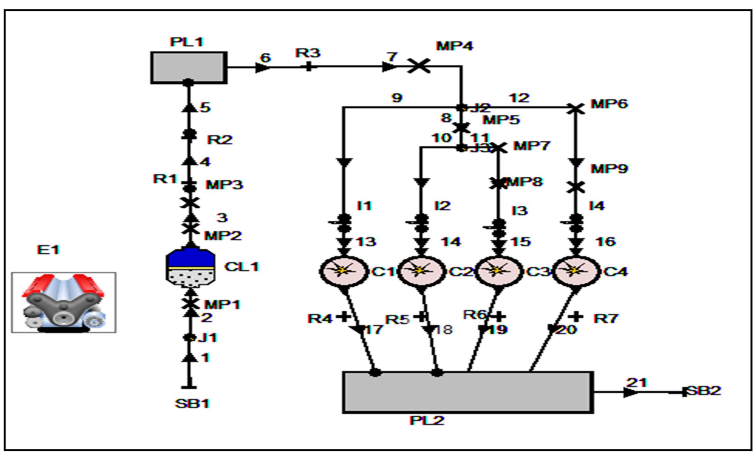

Fig. 1: Schematic of the engine symbolic model (AVL BOOST).

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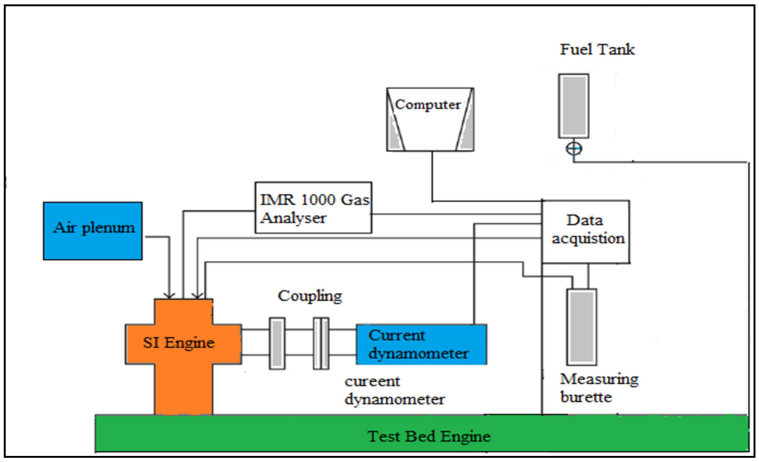

Fig. 2: The schematic of the engine.

III. Results and Discussion

Cylinder Pressure

In order to obtained accuracy results from the model, the cylinder pressure numerically produced compared to the experimental data and, for the spark ignition engine fueled with gasoline fuel at full load and engine speed 2500 rpm as shown in Figure 3. This figure presents the best approach between the experimental and simulation pressures traces was found in the peak cylinder pressure with a relative deviation was 0.8 %.

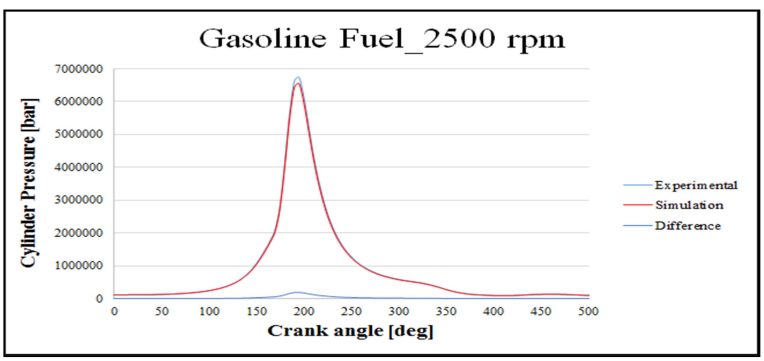

Fig. 3: Comparison between experimental and simulation pressure traces 2500 rpm speed.

Effective Power

Figure 4 presents the effective power that was predicted by the model as a function of ignition timing when using gasoline, ethanol, and LPG fuels. The results have been collected at a constant engine speed of 2500 rpm, constant load, and a variety of ignition timings. It can be seen that the effective power decreases with rising ignition timings regarding the selected fuels at all operating conditions. This reduction was due to the increase in friction power, which leads to a reduction in the network. Ethanol fuel exhibit lower effective power at all selected ignition timings compared to that of gasoline fuel. Essentially, this behavior is logical because ethanol fuel has lower heating values than those of gasoline. As shown in this figure, the LPG fuel produced lower effective power at all operating conditions in comparison to this of gasoline fuel; this may be to the fact that LPG fuel reduces the engine volumetric efficiency. There are similarities between the results expressed in this part of the study and those described by [XII], [XIV].

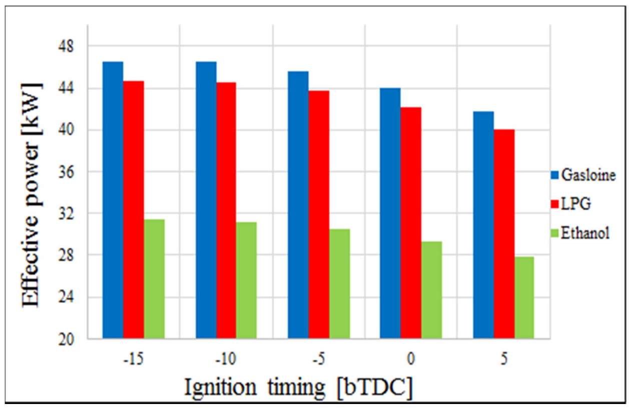

Fig. 4: Variation of effective power with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Effective Torque

The variation of effective torque as a function of ignition timing (15, 10, 5 BTDC, 0, 5 ATDC deg CA) for gasoline, ethanol and LPG fuels presented in Figure 5.As is evident in this figure, the effective torque decreases when increasing ignition retarding. This is due to a decrease in the in-cylinder pressure in the compression stroke, and consequently, less network is produced. Moreover, with further spark retarding, the torque slightly decreases because the in-cylinder peak pressure shifts to the expansion stroke. As known, the effective torque is depending on the in-cylinder mixture mass. It is clear from this figure that the LPG and ethanol fuels produced slightly lower effective torque than the gasoline fuel at the same ignition timing, since ethanol has lower calorific value compared to gasoline, while LPG reduced the engine volumetric efficiency. These results seem to be consistent with [III], [XXI].

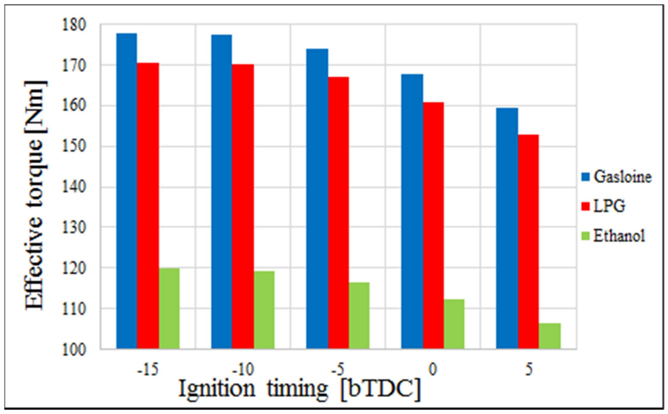

Fig. 5: Variation of effective torque with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Brake Specific Fuel Consumption (BSFC)

Figure 6 shows the variation of brake specific fuel consumption (BSFC) with respect to ignition timing at an engine speed of 2500 rpm for gasoline, ethanol and LPG fuels under constant engine speed. As shown in this figure, the BSFC of ethanol and LPG fuels was higher compared to gasoline at all selected ignition timings. The minimum BSFC value was obtained for all types of fuels at 15 crank angle degrees before top dead center (BTDC), while the maximum values were registered at 5 crank angle degrees after top dead center (ATDC). At all selected ignition timings, the engine consumed a greater amount of ethanol fuel to predict the same effective power due to the lower heating values of ethanol fuel compared to gasoline. The increases in BSFC of LPG fuel is related to the decreases in engine effective efficiency and it's due to lower volumetric efficiency. These results are in agreement with the findings of [XII], [XX], [XXI].

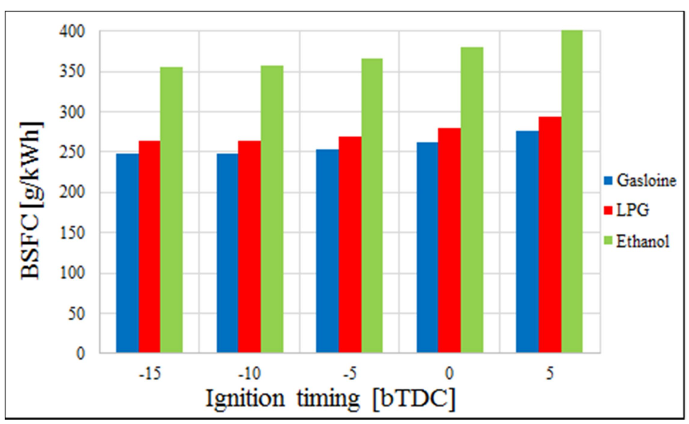

Fig. 6: Variation of brake specific fuel consumption with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Peak Fire Temperature

Figure 7 shows the effect of ignition timing (15, 10, 5 BTDC, TDC, and 5 ATDC degrees) on peak fire temperature of the spark-ignition engine when operating on gasoline, ethanol and LPG fuels at a constant engine speed of 2500 rpm under constant load. Peak fire temperature of the SI engine with LPG is observed to be greater than that of the gasoline and ethanol fuels. This may be due to the burning rate of LPG was higher which leads to decreased combustion duration resulting in an increased in the cylinder gas temperature. A slight change in peak fire temperature of the gasoline, ethanol and LPG fuels was observed when changing the ignition timing from advance to retarding.

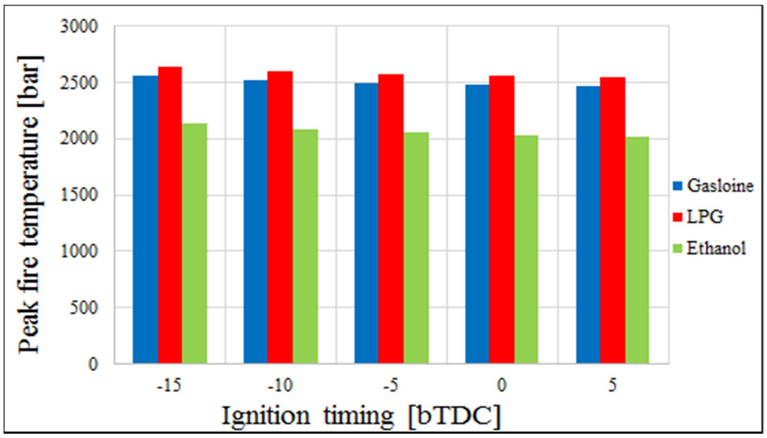

Fig. 7: Variation of peak fire temperature with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Peak Fire Pressure

Figure 8 represents the peak fire pressure the was created inside the cylinder for the three types of fuels at a variety of ignition timings and a constant engine speed. Numerical results show that the peak fire pressure developed inside the cylinder at all the ignition timings for the different fuels gasoline, ethanol and LPG in the same trend. The peak fire pressure for the gasoline and LPG fuels was observed to be slightly higher compared to the ethanol fuel. Regarding to the LPG fuel, the variation compared to the gasoline fuel was slightly lower.

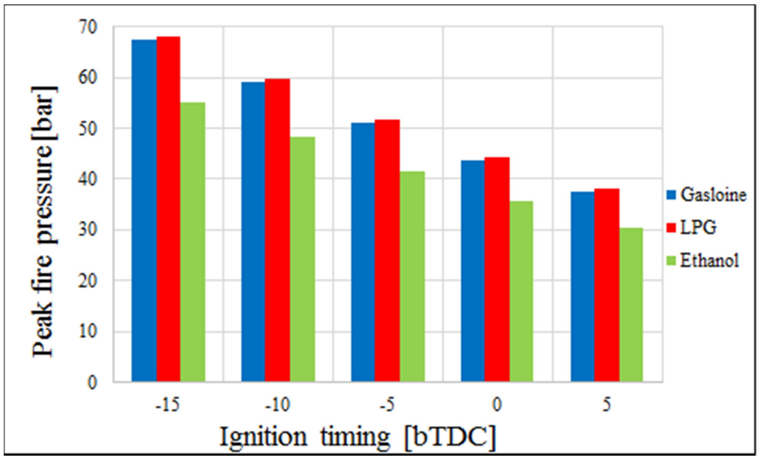

Fig. 8: Variation of peak fire pressure with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Carbon Monoxide (CO)

Figure 9 shows the carbon monoxide emissions of the SI engine for the gasoline, ethanol, and LPG fuels at different ignition timings (15, 10, 5 BTDC, 0, 5 ATDC deg CA). It is observed from the figure that the carbon monoxide of the LPG lower than that of the gasoline fuel. In addition, ethanol fuel has the lowest carbon monoxide compared to the gasoline and LPG fuels, since the latent heat of vaporization is higher for ethanol, which leads to the perfect mixture which improves the fuel combustion process. The CO emission of LPG was lower when compared to the gasoline fuel, this reduction related to the octane number of the fuel. This definition is similar to that found in [XIV].

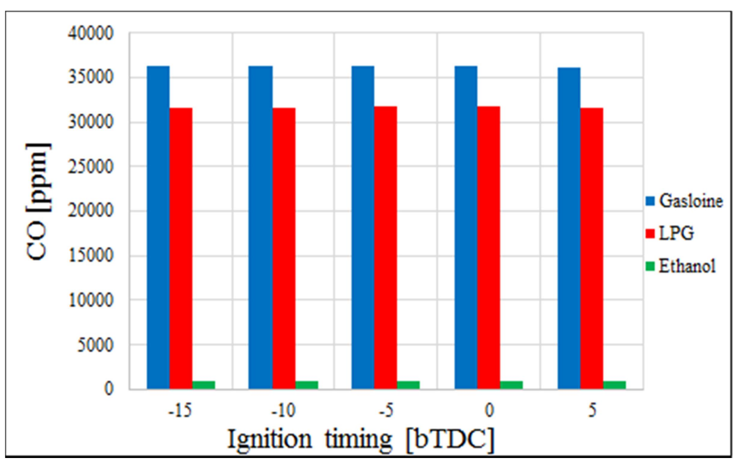

Fig. 9: Variation of CO with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Unburned Hydrocarbon (HC)

Figure 10 provides the predicted unburnt hydrocarbon emissions for different spark timings (15, 10, 5 BTDC, 0, 5 ATDC deg CA) and different fuel types (gasoline, ethanol and LPG) corresponding to an engine speed of 2500 rpm and constant engine load. It was observed that the unburnt hydrocarbon emission numerically predicted was slightly varied when altering the ignition timings. The ethanol fuel exhausted lower unburnt hydrocarbon than that of gasoline fuel. The LPG fuel emitted lower unburnt hydrocarbon when compared to that of gasoline fuel at all operating conditions. These results are similar to those reported by [IV], [VIII].

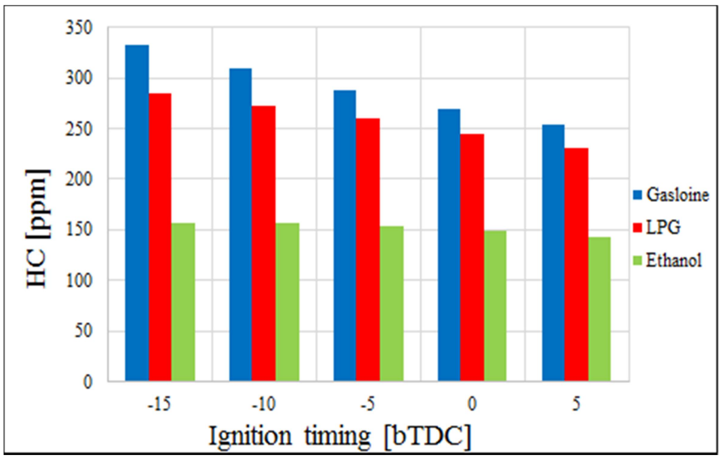

Fig. 10: Variation of HC with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

Oxide Nitrogen (NOx)

The variations of oxide nitrogen with respect to the ignition timings at an engine speed of 2500 rpm for gasoline, ethanol and LPG fuels are presented in Figure 11. The ethanol fuel exhaust dramatically lower values of NOx, while LPG produced higher NOx when compared to gasoline fuel at all operating conditions.This behavior was due to reduces the rate of the cylinder charge temperature during the start stages of the combustion process. As shown in this figure that the gasoline, ethanol and LPG fuels exhausted dramatically lower values of NOx when retarding the spark timing relative to the TDC. However, these results were very encouraging. These results are similar to those of comparable studies [VII], [XIII].

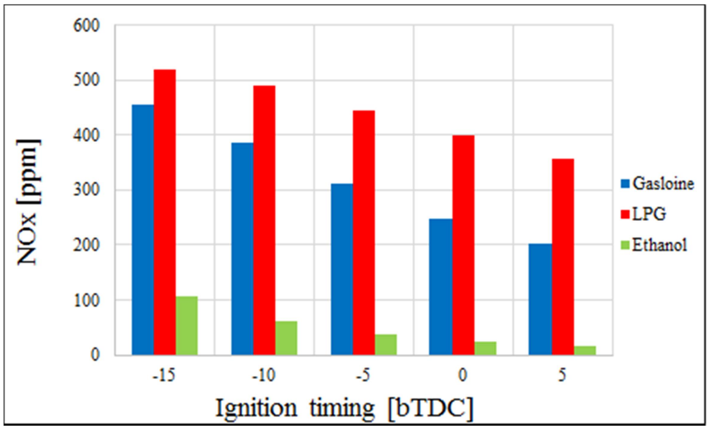

Fig. 11: Variation of NOx with ignition timings for gasoline, ethanol and LPG fuels at 2500 rpm.

IV. Conclusion

In the present work, the effect of ignition timings on the combustion characteristics, performance and exhaust gas emissions of a four-cylinder, four-stroke indirect injection SI engine running on gasoline, ethanol and LPG fuels. The numerical results were calculated at an engine speed of 2500 rpm, constant load under different ignition timings (15, 10, 5 BTDC, TDC, 5 ATDC deg CA). For this reason, an existing two-zone burnt and unburnt model was created. The main conclusions of this work are the following:

- The effective torque and effective power of the engine was lower when using ethanol and LPG in compared to those of gasoline for all ignition timings.
- The BSFC of the ethanol and LPG fuels were higher than that of gasoline fuel at the same ignition timing.
- LPG fuel produced higher peak fire pressure and higher peak temperature to those of gasoline, while ethanol produced slightly lower.
- A slight decrease in CO and HC emissions was observed when using LPG and ethanol fuels at the same ignition timing in comparison to gasoline fuel.
- Regarding NOx emissions, the LPG fuel emitted higher, while the ethanol emitted lower than the gasoline fuel at the same ignition timing.
- Ethanol and LPG fuels slightly reduce the engine performance, fuel economy and then lead to improvements in exhaust gas emissions which means could be used safely in the SI engine at different ignition timings.

V. Acknowledgement

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