TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 3559 - 3565

Numerical study of combustion characteristic, performance and emissions of a SI engine running on gasoline, ethanol and LPG

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Article Info
Volume 82
Page Number: 3559 - 3565
Publication Issue:
January-February 2020

Article History
Article Received: *18 May 2019*
Revised: *14 July 2019*
Accepted: *22 December 2019*
Publication: *20 January 2020*

Abstract:
A numerical study has been carried out to determine the combustion characteristics, engine performance and emissions of a spark ignition engine. In this work, a four-cylinder,four-stroke indirect injection engine fueled with gasoline, LPG and ethanol was used. The results were collected at a constant engine speed of 2500 rpm with variable compression ratios of 8.5:1, 10.5:1, 12.5:1 (original), 14.5:1 and 16.5:1. Calculations focused on how the parameter of compression ratio could affect variables such as emissions, peak fire temperature, peak fire pressure, specific fuel consumption, effective torque, and brake power. In the findings, it was established that under various compression ratios, LPG and ethanol exhibit superior or better combustion and performance characteristics. It was established further that on all the selected compression ratios, when ethanol is used as the engine fuel, there tends to be a notable decrease in the emissions of unburned hydrocarbon, nitrogen oxide, and carbon monoxide.

Keywords: *ethanol, LPG, performance, combustion, numerical*

I. INTRODUCTION

It is necessary to reduce undesirable emissions from internal combustion engines that have a negative influence on the environment causing various problems such as respiratory hazards, acid precipitation, global warming and ozone depletion. Several studies have reported that passenger car emissions using fossil fuels contribute around 18% of CO, 20% of CO_2, 14% of black carbon and 37% of NOx [1-5]. Therefore, it is very important to use clean alternative fuels, such as Natural Gas (NG), biodiesel, ethanol, Liquefied Petroleum Gas (LPG) and Hydrogen. Moreover, these types of fuels have several advantages including, but not limited to, their high octane number, clean combustion, high availability and attractive price compared to fossil fuels [6,7].

In the study by Warade and Lawankar [8], the objective was to examine how blends of LPG and ethanol affect the emissions and performance of engines. The experimental conditions involved different engine loads and a constant speed. In the findings, it was avowed that when the blends are employed, there tends to be a reduction in the emission of unburned hydrocarbons and carbon monoxide while yielding an improvement in thermal efficiency. Thus, the blends were found to outperform gasoline fuel. In a similar study, Chaichan et al. [9] strived to investigate the impact posed by liquefied petroleum and natural gas usage on the brake power of engines, as well as the thermal efficiency and fuel-consumption of

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systems at various spark timings, compression ratios, and speeds. In the findings, it was reported that the exhaust gas temperature, specific fuel consumption, and brake power are reduced, outperforming the case of gasoline.

It is also notable that various investigations have reported that alternative fuel for SI engines could be beneficial by reducing the CO and HC levels, outperforming conventional fuels [10-12]. However, it is important to acknowledge that for experimental studies, such investigations are cost-intensive regarding the examination of the impact posed by alternative fuels on the system emissions, combustion characteristics, and the performance of engines – under different operating conditions. Hence, simulating engines is a demanding procedure because the investigation comes with complex mechanics and physics.

In the study by Shetti et al. [13], a computational fluid dynamics (CFD) framework was proposed in relation to the examination of the outcomes that could be obtained after using gas fuel. Variables that were investigated included nitrogen oxide, carbon monoxide, cylinder pressure, and cylinder temperature under various spark times. In another study, Bayraktar and Orhan [14] focused on a quasi-dimensional framework for spark ignition engines. The researchers targeted two thermodynamic areas constituting unburned and burned gases. The motivation was to predict the level of exhaust emission and the performance of the engine for LPG and fueled gasoline at various operating conditions. In the findings, the proposed model demonstrated that when LPG is used, it tends to improve outcomes regarding the emission of exhaust compared to the case of gasoline, with the operating conditions being similar. In this study, the central purpose lies in the numerical investigation of the impact posed by ethanol and LPG on the parameters of emission, combustion, and spark ignition engine performance, with compression ratios varied[18-23]. Also, the study strives to proposed a framework and analyze the results regarding the proposed model's performance.

II. SIMULATION PROCEDURE

In this study, the base constitutes gasoline and will be used for the purpose of comparing the outcomes for LPG, ethanol, and gasoline fuel. Table 1 demonstrates the specific features of the SI engine under investigation. Indeed, the engine's compression ratios include 16.5:1, 14.5:1, 12.5:1 (original), 10.5:1, and 8.5:1. The speed of the engine is also kept constant at 2500 rotations per minute. Similarly, the study is implemented by using the AVL-Boost program, with the test engine used to obtain real values. Initially, gasoline fuel is used to run the model before comparing the findings with company data. This procedure and comparison seeks to discern the model's feasibility. Later, ethanol and LPG fuels are used to run the model before comparing the results regarding the performance of the three selected fuels.

Table 1
Main engine specifications

Particulars	Specifications
Engine make	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

III. RESULTS AND DISCUSSION

This section presents the study's findings that were obtained after examining the impact of various compression ratios on the parameters of unburned nitrogen oxide and hydrocarbon, carbon monoxide, peak fire temperature, peak fire pressure, brake-specific fuel consumption, effective torque, and effective power. Notably, the speed of the engine was kept constant and was set at 2,500 rotations per minute.

3.1. Effective Power

Figure 1 reveals that the effective power of LPG, ethanol, and gasoline becomes higher when the compression ratio increases. Essentially, this is because the more pressure that is applied results in a greater temperature created as the compression ratio increases, more effective power is produced. However, LPG and the ethanol-fueled engine produce less effective power than that of gasoline due to the fact that their heating value content is lower. Some studies have also confirmed that when LPG and ethanol as used as engine fuels, the resultant systems experience reduced effective power [16, 17]. For these studies, the objective has been to determine various LPG and ethanol-powered engines' emissions, combustion, and performance under different compression ratios.

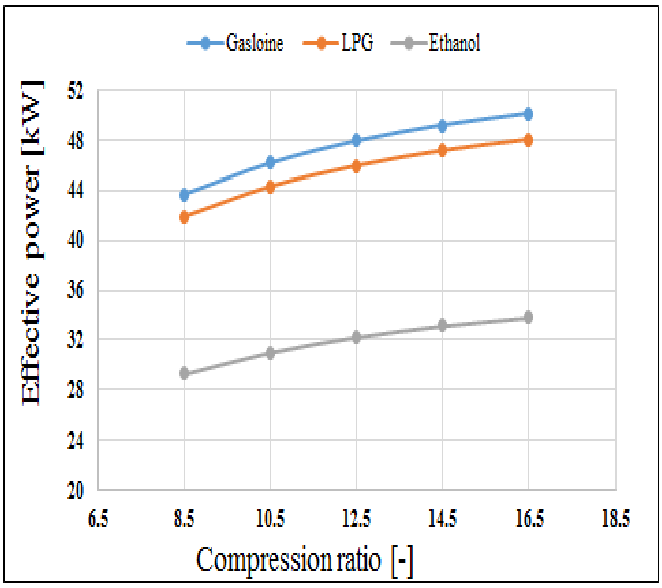

Fig.1. Variation of effective power_ Gasoline_ LPG_ Ethanol at 2500 rpm vs. compression ratio.

3.2. Effective Torque

The variation of effective torque according to compression ratio for the tested gasoline, ethanol and LPG fuels is shown in Figure 2. It can be observed that the effective torque for ethanol and LPG fuels decrease when compared to gasoline fuel at all compression ratios. The augmentation in compression ratio increased the effective torque for all test fuels up to 15.7%. The reason for the higher effective torque for fuels is due to the higher cylinder pressure. In the same vein, Norrizal and others [2] in their work note that LPG fuel shaped slightly lower effective torque than gasoline fuel.

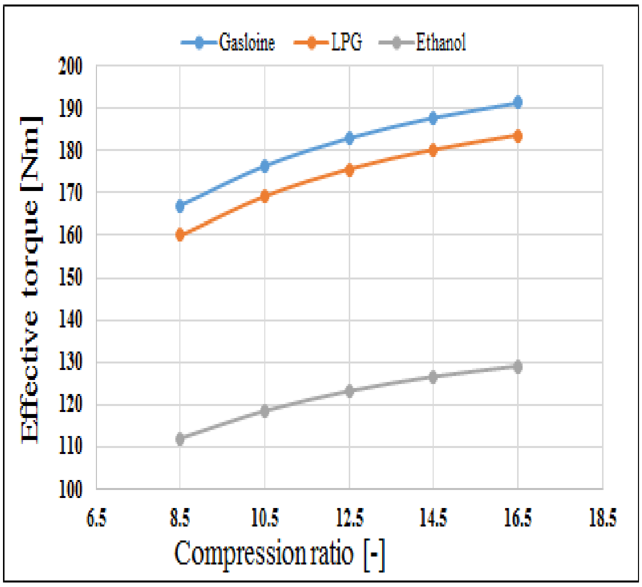

Fig.2. Variation of effective torque_ Gasoline_ LPG_ Ethanol at 2500 rpm vs. compression ratio

3.3. Brake Specific Fuel Consumption (BSFC)

As shown in Figure 3, gasoline, LPG and ethanol fuels appear to exhibit similar brake-specific fuel consumption trends at all compression ratios. The LPG fuel has a slightly higher fuel consumption rate, while ethanol has a dramatically higher consumption rate than gasoline for all compression ratios. As shown in the figure below, the BSFC of all selected fuels decreases when the compression ratio increases. The ethanol fuel produced a higher BSFC than the other fuels due to its lower heating value, which means that a greater amount of fuel is consumed to produce similar effective power. Similarly, Mustafa and Gitano-Briggs [15] found that LPG produced slightly higher BSFC than gasoline at all operating conditions.

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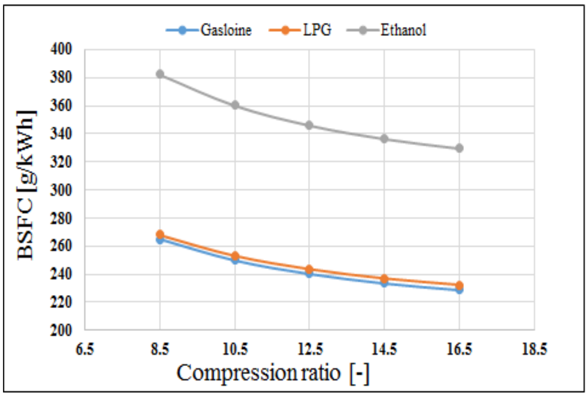

Fig.3. Variation of BSFC _ Gasoline _ LPG _Ethanol at 2500 rpm vs. compression ratio

3.4. Peak Fire TemperatureProfiles

Figure 4 shows the peak fire temperature of gases inside the combustion chamber as a function of compression ratio predicted by the model at an engine speed of 2500 rpm for gasoline, ethanol and LPG fuels, respectively. In all compression ratios, a maximum peak fire temperature of 2600K is reached when using gasoline. As shown in the figure below`, the ethanol fuel registered the lowest peak fire temperature at all compression ratios compared with the gasoline and LPG fuels.This reduction was expected since ethanol has a lower heating value than the other fuels.

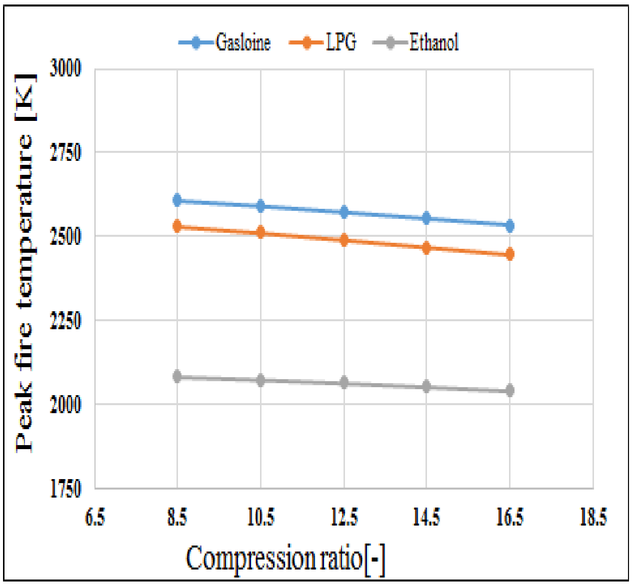

Fig.4. Variation of peak fire temperature_ Gasoline-LPG _Ethanol at 2500 rpm vs. compression ratio

3.5. Peak Fire Pressure

In Figure 5, the deviation in the predicted peak fire pressure is presented after using LPG, ethanol, and gasoline at different compression ratios. From the figure, this study's results demonstrate that for the three fuels that were used, there is a significant increase in peak fire pressure with an increase in the compression ratio. Ethanol produced the lowest peak fire pressure value of all three fuels. This behavior could be correlated to the gas temperature inside the cylinder that had already decreased as a result of the lower chemical energy related to the burned fuel mass.

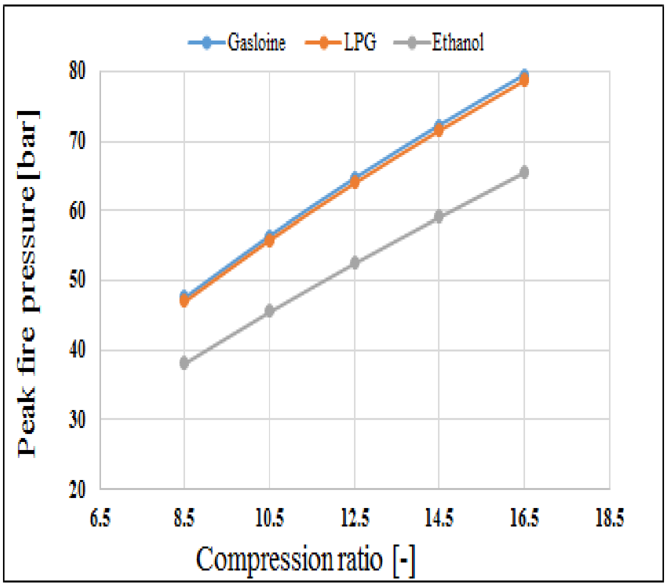

Fig.5. Variation of peak fire pressure_ Gasoline_ LPG_ Ethanol at 2500 rpm vs. compression ratio

3.6. Carbon Monoxide (CO)

The variation of carbon monoxide with respect to compression ratio for the engine-fueled gasoline, ethanol and LPG is shown in Figure 6. From this figure, it can be found that as the compression ratio increases, there is a slight amount of increase in carbon monoxidefor all test fuels. The CO emission decreases with complete combustion of the fuel and it is lower for ethanol than gasoline and LPG. Carbon monoxide emissions for ethanol decreased up to 93%, while the LPG produced a higher CO by 64.5% compared to the gasoline. The explanation for this variance in CO emission

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could be attributed to variations in chemical composition among the selected fuels. Indeed, the findings support those that were documented by Warade and Lawankar [8].

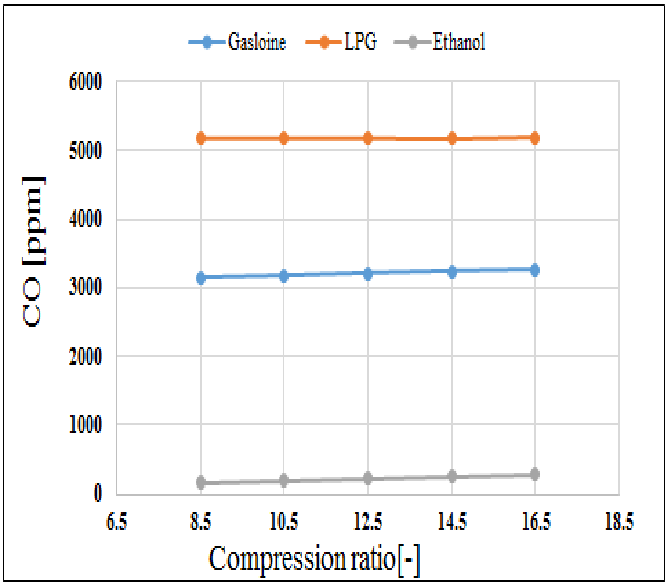

Fig.6. Variation of CO_ Gasoline _LPG _Ethanol at 2500 rpm vs. compression ratio

3.7. Unburned Hydrocarbon (HC)

The unburned hydrocarbon emission is a very important parameter that could be used to present the losses in indicator power. Figure 7 shows the unburned hydrocarbon as a function of compression ratio at an engine speed of 2500 rpm when using gasoline, ethanol and LPG fuels, respectively. From the below figure, it can be found that the HC emission decreases when using ethanol, while it increases when using LPG at all compression ratios compared with gasoline. Again, this behavior could be explained in the same way as previously mentioned above. Several studies have also reported similar HC trends when using LPG and ethanol as fuel for SI engines [10, 11].

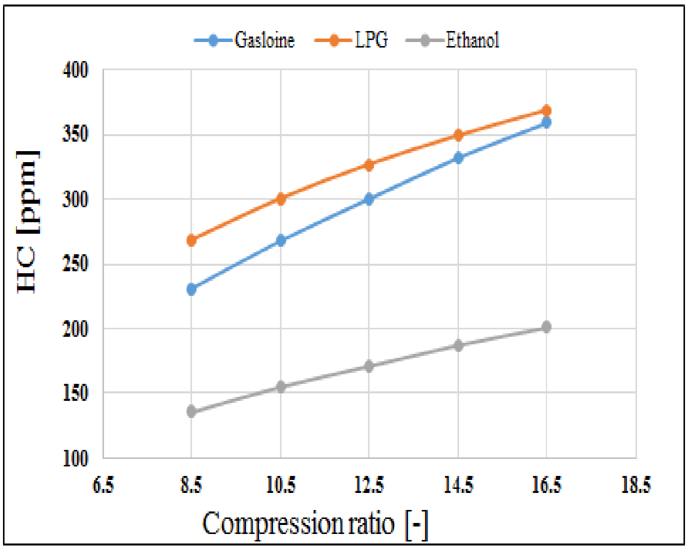

Fig.7. Variation of HC_ Gasoline_ LPG_ Ethanol at 2500 rpm vs. compression ratio

3.8. Nitrogen Oxide (NOx)

Nitrogen Oxide emissions are considered as one of the main toxic pollutants produced from spark ignition engines. Three factors influence NOx emissions. These factors include the residence time, the concentration of oxygen in the chamber, and the temperature of the gas inside the cylinder. From figure 8, it can be clearly seen that ethanol and LPG fuels release lower NOx emissions compared with the gasoline at all compression ratios. Ethanol has lower energy content than gasoline, thus enabling a lower local gas temperature and contributing to a significant reduction in the emission of nitrogen oxide. Similar outcomes have been documented in different scholarly investigations that have focused on the emission of nitrogen oxide when LPG and ethanol are used as spark ignition engine fuels [4, 5, 7].

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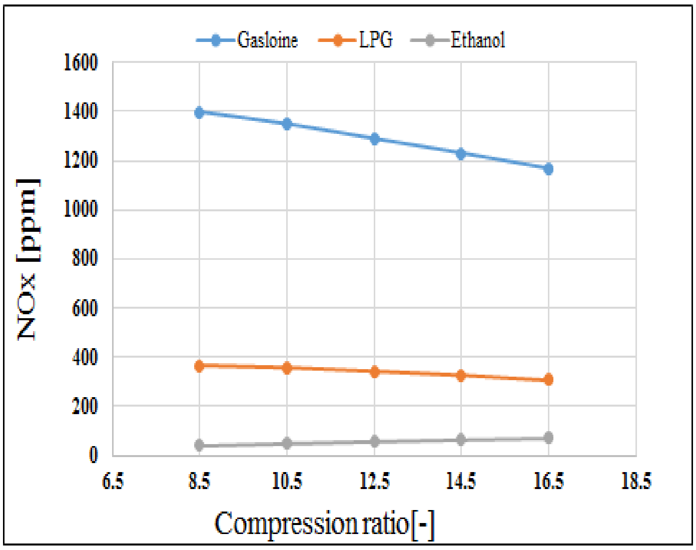

Fig.8. Variation of NOx_ Gasoline_ LPG_ Ethanol at 2500 rpm vs. compression ratio

IV. CONCLUSIONS

This study focused on a four-cylinder four-stroke SI engine and examined its exhaust gas emissions, performance, and combustion characteristics when using LPG, ethanol, and gasoline fuels. The speed of the engine was set at 2,500 rotations per minute. However, the compression ratios were varied. From the numerical outcomes, it was concluded that LPG and ethanol had lower effective torque and effective power than gasoline, with constant outcomes reported at all the compression ratios. It was also found that greater brake-specific fuel combustion is realized when LPG and ethanol are used, with similar results obtained at all the selected compression ratios. For LPG and ethanol, lower peak fire temperature and peak fire pressures were reported compared to situations where gasoline was used for the different compression ratios. In addition, ethanol fuel was found to emit less unburned hydrocarbon and carbon monoxide compared to the case of gasoline, with the highest emissions of these elements reported for the case of LPG. For LPG and ethanol, lower NOx emissions were established compared to gasoline. At a compression ratio of 8.5:1, the former fuels (LPG and ethanol) exhibited 71.4% and 97.4% emissions respectively.

V. ACKNOWLEDGEMENTS

The authors of this paper acknowledge the AVL Advanced Simulation Technologies team for their significant support.

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