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Original Research Article

Numerical Study of Combustion Characteristics, Performance and Emissions of an SI Engine Running on Gasoline, Ethanol and LPG

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Abstract

A numerical study has been carried out to determine the combustion characteristics, engine performance, and emissions of a spark-ignition (SI) 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. The influence of compression ratio on brake power, effective torque, specific fuel consumption, peak fire pressure, peak fire temperature, and emissions was calculated. It was found that when the engine operates with a different compression ratio, ethanol, and LPG produce better performance and combustion characteristics. On the other hand, carbon monoxide, NO_x, and unburned hydrocarbon emissions decrease when the engine is operated on ethanol fuel at all compression ratios.

Keywords: Numerical study, combustion, performance, LPG, ethanol.

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 NO_x globally [1-5]. Therefore, it is crucial to use cleaner 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].

Warade and Lawankar [8] studied the effect of using ethanol and LPG blends on engine performance and emissions at a constant speed and different engine loads. Their results show that these blends improve thermal efficiency and reduce carbon monoxide and unburned hydrocarbon compared to gasoline fuel. With the same objective, Chaichan *et al.*, [9] carried out an experimental study on the influence of using natural gas and liquefied petroleum gas on engine brake power, brake-specific fuel consumption and thermal efficiency at different speeds, compression ratios and spark timings. Their results showed that brake power, specific fuel consumption, and exhaust gas temperature for both fuels were lower than that for gasoline.

Different studies have found that alternative fuel for SI (spark-ignition) engines could result in the release of lower HC and CO compared to conventional fuel [10-12]. In the case of experimental studies, more money and effort must be invested to study the effects of alternative fuel on engine performance, combustion characteristics, and emissions when several operating conditions are selected. Therefore, simulation can offer a promising solution to reduce both cost and efforts. However, the simulation of an engine represents a big challenge for researchers due to its complex physics and mechanical operations.

Shetti and others [13] propose a computational fluid dynamics model to investigate the effect of using gas fuel on cylinder temperature, cylinder pressure, carbon monoxide, and nitrogen oxide at different spark times. Bayraktar and Durgun [14] have suggested a quasi-dimensional model for spark ignition engines by using two different thermodynamic regions, consisting of burned and unburned gases to predict engine performance and exhaust emission fueled gasoline and LPG at different operating conditions. The model's results show that LPG significantly improves exhaust emissions compared to gasoline under the same operating conditions. The objective of the current study is to investigate the effect of LPG and ethanol on spark-ignition engine performance, combustion, and emissions at different compression ratios numerically. For this purpose, a model is suggested, and the results are analyzed accordingly.

Simulation Procedure

Gasoline has been chosen as the base and compared with the values obtained from ethanol and LPG fuels. The specifications of the SI engine used are shown in Table-1. The compression ratio of the engine varied from 8.5:1, 10.5:1, 12.5:1 (original), 14.5:1 and 16.5:1, respectively, with a constant engine speed of 2500 rpm maintained for the engine performance test. The numerical study was carried out using the AVL-Boost program – after all the requirements were applied – based on the real values that were taken from the test engine. First, the model was run using gasoline fuel, and the results were compared with the available results provided by the manufacturing company to check the usefulness of the model. Next, the model was run using gasoline, ethanol, and LPG (considered to consist only of propane) fuels. Finally, a comparative study is carried out for the three tested fuels.

Table-1: 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

RESULTS AND DISCUSSION

This section presents the results of the engine simulations. It discusses the effects of critical parameters of effective power, effective torque, brake specific fuel consumption, peak fire pressure and temperature, carbon monoxide, unburned hydrocarbon, and nitrogen oxide at different compression ratios and the constant engine speed of 2500 rpm as explained above. The results are discussed according to these essential parameters:

Effective Power

Figure-1 reveals that the effective power of gasoline, ethanol, and LPG becomes higher when the compression ratio increases. Essentially, this is because the application of more pressure results in higher engine temperature. The study finds that LPG and ethanol-fueled engines produce less effective power than that of gasoline at all compression ratios because of their lower heating value content. The reduction of effective power by ethanol and LPG-fueled engine has also been demonstrated by several other studies [16, 17], which investigated the performance, combustion, and emissions of different ethanol and LPG-powered engines tested on the dynamometer with different compression ratios.

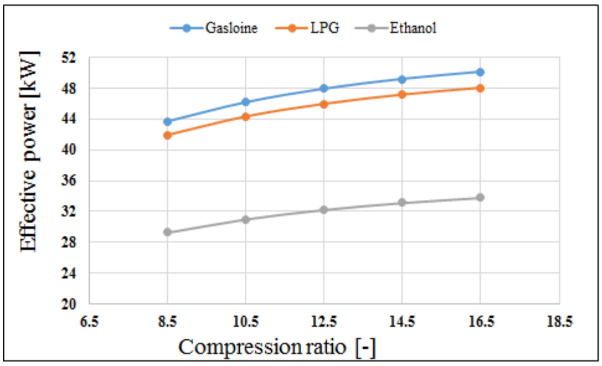

Fig-1: Variation of Effective power (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

Effective Torque

The variation of effective torque according to the 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 decreases 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 higher cylinder pressure. In the same vein, Mustafa and others [2] found in their work that LPG fuel shaped slightly lower effective torque than gasoline fuel.

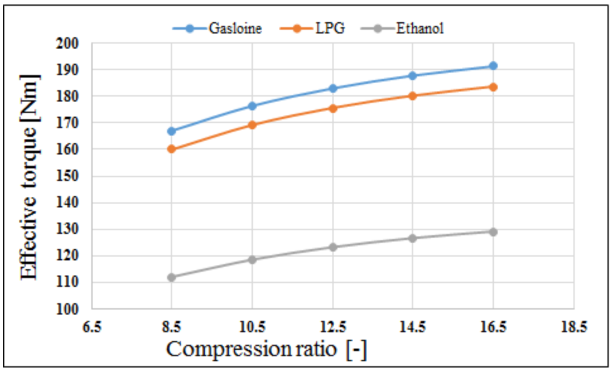

Fig-2: Variation of Effective Torque (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

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. Ethanol fuel produced a higher BSFC than the other fuels due to its lower heating value, which means that a considerable 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.

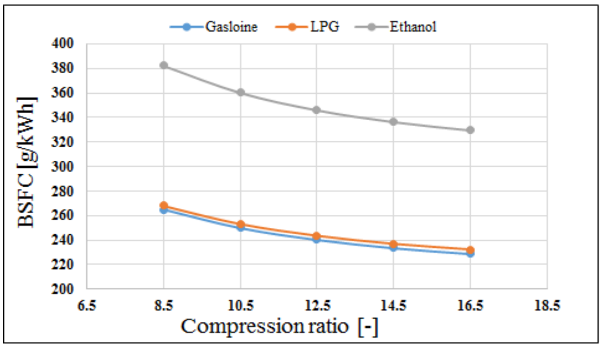

Fig-3: Variation of BSFC (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

Peak Fire Temperature Profiles

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 gasoline and LPG. This reduction was expected since ethanol has a lower heating value than other fuels.

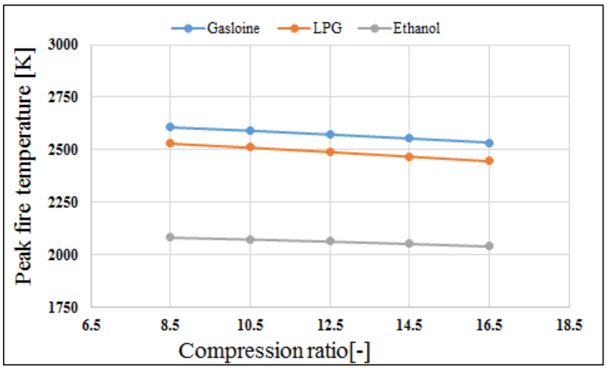

Fig-4: Variation of Peak Fire Temperature (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

Peak Fire Pressure

Figure-5 shows the predicted peak fire pressure deviation for gasoline, ethanol, and LPG at an engine speed of 2500 rpm. It can be observed that the peak fire pressure dramatically increases when the compression ratio increases for all test fuels. 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 has already decreased as a result of producing lower chemical energy with the same fuel mass.

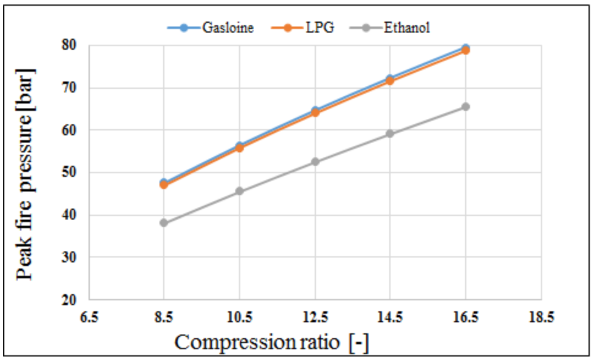

Fig-5: Variation of Peak Fire Pressure (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

Carbon Monoxide (CO)

The variation of carbon monoxide (CO) with respect to the compression ratio for the engine using gasoline, ethanol, and LPG is shown in Figure-6. From this representation, it can be found that as the compression ratio increases, there is a slight amount of increase in carbon monoxide for 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 may be associated with the difference in chemical properties of the test fuels. These results are similar to those reported by Warade and Lawankar [8].

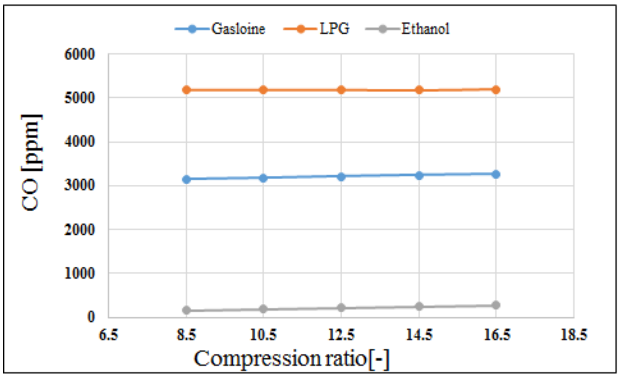

Fig-6: Variation of CO (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

Unburned Hydrocarbon (HC)

The unburned hydrocarbon emission is a very important parameter that can be used to present losses in indicated 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 pictorial presentation below, it can be found that HC emission decreases when using ethanol, while it increases when using LPG at all compression ratios when compared with gasoline. Again, this behavior can be explained in the same way as CO emissions. Several studies have also reported similar HC trends when using LPG and ethanol as a fuel for SI engines [10, 11].

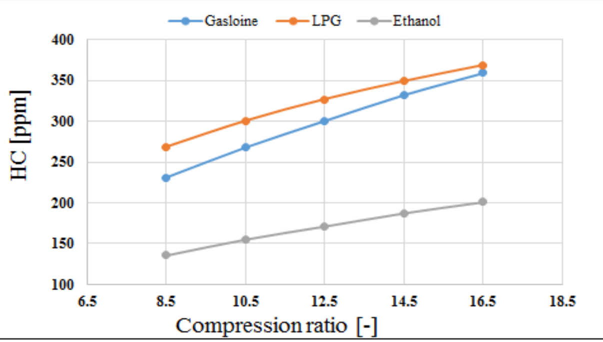

Fig-7: Variation of HC (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

Nitrogen Oxide (NO_x)

Nitrogen Oxide emissions are considered as one of the primary toxic pollutants produced by spark-ignition engines. NO_x emissions are influenced by three factors: inside cylinder gas temperature, chamber oxygen concentration, and residence time. From figure 8, it can be seen that ethanol and LPG fuels release lower NO_x emissions compared with gasoline at all compression ratios. Ethanol has a lower energy content than gasoline, thus enabling a lower local gas temperature, contributing to a dramatic decrease in NO_x emissions. Several studies have reached similar conclusions related to NO_x when using ethanol and LPG as fuel in spark-ignition engines [4, 5, 7].

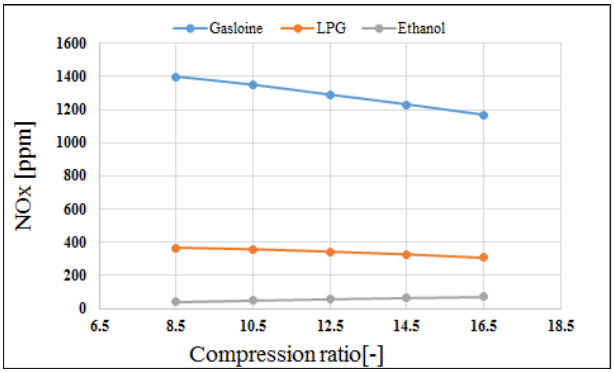

Fig- 8: Variation of NO_x (Gasoline, LPG, and Ethanol) at 2500 rpm vs. Compression Ratio

CONCLUSIONS

This research effort has studied the combustion characteristics, performance, and exhaust gas emissions of a four-cylinder, four-stroke SI engine fueled with gasoline, ethanol, and LPG fuels at an engine speed of 2500 rpm under different compression ratios. According to this numerical study, the following results are reported that support several previous research efforts:

- Effective power and effective torque for ethanol and LPG are lower compared to gasoline fuel at all compression ratios.
- Using ethanol and LPG produced higher brake-specific fuel consumption compared to gasoline at all compression ratios.
- The peak fire pressure and peak fire temperature for ethanol and LPG were lower than that of gasoline.
- Carbone monoxide and unburned hydrocarbon emissions emitted by ethanol fuel are lower than those of gasoline, while LPG emissions are higher.
- NO_x emissions for ethanol and LPG fuels are lower than gasoline reach up to 97.4% and 71.4%, respectively, at a compression ratio of 8.5:1.

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