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# Numerical Study of Combustion Characteristics, Performance and Emissions of SI Engine Fueled with Different Hydrocarbons Fuels

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**Abstract.** A numerical approach has been designed and modified with Advanced Simulation Technologies Boost to examine the impact of the piston face temperature on the performance of the spark ignition engine, combustion characteristics and emissions when using liquefied petroleum gas (LPG) and petrol fuels at an engine speed of 2500 rpm with a constant throttle position. In this work, a four-cylinder four-stroke spark ignition engine was used. The results show that when the piston face temperature increased, the brake power and the effective torque were reduced. No alteration in the specific brake fuel consumption for both fuels selected at higher piston face temperature has been observed. The peak fire pressure decreases while the peak fire temperature grows slightly when moving from lower to higher temperatures on the piston face. Liquid petroleum gas produced lower effective power and an effective torque compared to the gasoline fuel at all the selected piston face temperature. For both fuels, carbon monoxide and NOx emissions increased, while unburned hydrocarbon emissions decreased dramatically when the temperature of the piston face increased. The LPG emitted lower exhaust gas emissions than the gasoline hydrocarbon fuel at all piston temperatures.

## 1. Introduction

The depletion of oil resources has been a popular problem among other countries recently. Excessive use of fossil fuels exhausts reserves and also increases air pollution [1]. Researchers and car manufacturers are forced to concentrate on finding alternatives to conventional oil fuels. An alternative fuel shall be technically feasible, economically competitive, environmentally acceptable and readily available [2]. Multiple potential renewable resources, such as natural gas, biodiesel, methanol, ethanol, hydrogen and liquefied petroleum gas (LPG) have been planned [3]. Among alternative fuels, as environmentally and economically friendly fuels, LPG can help keep planetary people moving by reducing the effect of road transport on climate, weather, natural resources and public health [4].



For many purposes, such as cooking, heat, energy production, transportation and various other applications, LPG fuel is used as a fuel around the world. The LPG appears in gaseous form at ambient pressure, but with moderate pressure it will become a liquid that has a high power that is useful for transport and storage. The LPG is also largely constituted as a by product for the production and refining of natural gas and crude oil, but can also be constituted as a by-product of processing and some other biofuels manufacturing processes. There is an indication of the use of LPG as fuel for combustion engines shortly after its extensive development in the early 20th century as cooking and lighting fuel [5].

A significant increase in LPG fuelled vehicles was driven by the oil crisis of the 1970s and rising oil prices [6]. Most of these vehicles were originally designed to operate on gasoline and were subsequently modified to operate on LPG. The LPG conversion systems for road vehicles follow the example as charging systems and pollution control technologies advance and become more complicated and compatible with existing vehicle equipment. The LPG (also known as "Autogas") is an oil refining gas consisting primarily of propane, propylene, butane and other light hydrocarbons [7].

About 60% of the total quantity of LPG produced is naturally derived from oil resources, in the event that no real refining is required. The resulting 40% is produced as by-product from the distillation stage or after treatment processes along the refining of crude oil [8]. Due to the high number of Octane and therefore a low number of Cetane identical to 105 and also having a high calorific value compared to other gaseous fuels, the LPG is acceptable and efficient as fuel for the combustion engine [9]. The benefits in terms of efficiency and efficiency can be attributed by the higher octane of LPG octane compared to gasoline. In contrast to gasoline available at most fuel stations, it is possible to use higher ignition times and a higher compression ratio with less sensitivity to the pre-ignition or knock can be used [10].

At reduced pressure, with an amount of 0.7 to 0.8 MPa and low environmental temperatures, LPG can be liquefied. The higher self-ignition temperature, higher flame speed and higher flammability limits make LPG a better fuel for spark-ignition engines (SI) than gasoline [11]. Gasoline is a transparent flammable liquid derived from petroleum that is mainly used for most internal combustion engines as a fuel. Initially, it contains organic molecules, integrated into a variety of additives, generated by fractional distillation of the oil. On average, up to 72 liters (19 liters) of crude oil will produce a 160-liter (42 gallons) barrel. On average, after processing into an oil refinery, a 160-liter barrel of crude oil (42-U.S. Gallon) will produce about 72 liters (19 liters US) of petrol, based on the analysis of crude oil and on which other refined products are also processed [12]. Based on the literature [13] the use of LPG instead of traditional gasoline would mean a 7 % reduction in the BP engine, a 30 percent reduction in the CFSB, where the engine was converted to work in gasoline or LPG when it used the fuel injection into the four-stroke spark ignition engine.

According to [14], LPG fuel was found to have the capacity to reduce emissions; CO (-30%), CO<sub>2</sub> (-10%), HC (-30%) and NO<sub>x</sub> (-41%) for the urban test cycle process (ECE 15) compared to gasoline. Meanwhile, the extra-urban cycle, the LPG lowered the vehicles emissions; CO (-10 %), CO<sub>2</sub> (-11 %), HC (-51%) and NO<sub>x</sub> (-51%) (-77%). The contrast occurred when the Opel Zafira 1800cc four-cylinder engine was used as a test vehicle with a Landi Renzo package.

The experimental work was carried out by [15] and noted that, in the case of the LPG engine, the brake power is higher while the heat carried by sheltered water is covered by the exhaust gas and, in the case of the gasoline engine, the unacceptable losses are greater. They also noted that, unlike petrol, LPG has higher fuel consumption.

The influence of the difference in ignition time with the efficiency of a four-cylinder multipoint diesel engine that was rethought to operate with the LPG injection was analyzed in [16]. A better output was obtained when the ignition time is adjusted to 6 ° BTDC when LPG is used as fuel. Progress in idle time has also resulted in a decrease in CO (-1%) and HC (-50 ppm). But an increase (+1400 ppm) in NO<sub>x</sub> emissions is demonstrated by the ignition time developed.

In the form of a statistical study conducted by [17] the coding of the environment using Matlab has been produced and experimental results are used to verify its results. The author observed

that the calculation engine model could be applied with a useful model to assess the efficiency and emission of a fuel used for the SI engine by alternative fuels such as hydrogen, ethanol, methane and methanol. Finally, it has been reported that gasoline generates a high resistance than the renewable fuel that is all being studied. The effective power provided by propane is 10% lower than gasoline. The BSFC of the propane-powered engine is about 9% lower than the petrol engines. The work of [18] organized a calculation cycle model comprising propane and gasoline as part of a parameter estimation code that was created using this model. The comparison indicates that significant changes in vehicle emissions can be achieved if LPG-powered S.I. Engines are operated in cases similar to those fuelled with petrol. The LPG has reduced volumetric efficiency, thus reducing engine efficiency and thus increasing the actual fuel consumption. The objective of this work is to study numerically the influence of piston face temperature on the performance of the SI engine, combustion characteristics and emissions when using liquefied petroleum gas (LPG) and gasoline fuels at an engine speed of 2500 rpm with a constant acceleration position.

## 2. Simulation Procedure

### 2.1 Fuels

In this investigation, the impact of the piston face temperature on SI engine output, combustion characteristics and emissions at an engine speed of 2500 rpm and constant throttle position is investigated by two types of hydrocarbon fuel. The forms are presented as follows:

#### (A) Gasoline Fuel

A combination of a wide range of different hydrocarbons is industrial gasoline. Gasoline is produced by approaching a number of requirements for engine efficiency and various formulations are achievable. As a result, the precise molecular structure of the gasoline is unknown. Because it is allowed to start with the coldest engine, the output specifications often differ across the stations, within additional unstable compounds (additional butane) at the coldest time. The content of the refinery differs according to the raw oils it produces, the type of transformers present throughout the refinery, the operation of those units and the hydrocarbon flows that the refinery prefers to apply when mixing the final production [19].

A uniform composition of thin and relatively light hydrocarbons between 4 and 12 carbon atoms per molecule ( popularly known as C4-C12) contains most of the standard gasoline [20]. This is a combination of paraffin, olefin and cyclo-alkane (naftene). For the oil industry, the use of paraffin and olefin instead of the usual alkane and alkene chemical nomenclatures is unique, respectively. All gasoline fuel properties are measured in the AL-Doura Refinery Laboratories, as shown in Table (1) [21].

Table (1) Gasoline Properties by AL-Doura Refinery Laboratories [21]

Stoichiometric AFR	14.98
Density (kg/l)	0.731
Gravimetric LHV (MJ/kg)	43.12
Volumetric LHV (MJ/l)	31.52
Carbon intensity (gCO <sub>2</sub> /l)	2297.3

Carbon Intensity (gCO <sub>2</sub> /MJ)	72.88
RON (to ASTM D2699)	82
MON (to ASTM D2700)	75.0

### (B) Liquefied Petroleum Gas (LPG)

A mixture of various types of hydrocarbons is defined as a liquefied petroleum gas (ethane, propane, butane and Pentane). The percentage volume of LPG compositions as shown in Table (2). The analysis of the components of a LPG fuel was carried out at the Al-Hillah gas plant, as shown in Table (3) [22].

Table (2): Compositions of LPG [22]

Items	C <sub>2</sub> H <sub>6</sub>	C <sub>3</sub> H <sub>8</sub>	C <sub>4</sub> H <sub>10</sub>	C <sub>5</sub> H <sub>12</sub>
Volumetric Fractions (%) by Volume	0.9	36.3	62.3	0.5

Table (3) LPG Fuel Component Analysis by Al-Hillah Gas Factory [22]

Material	Analysis by Volume	Molecular Weight (Kg/Kmol)
C <sub>2</sub> H <sub>6</sub>	0.9	30
C <sub>3</sub> H <sub>8</sub>	36.3	44
C <sub>4</sub> H <sub>10</sub>	62.3	58
C <sub>5</sub> H <sub>12</sub>	0.5	72

## 2.2 Injection System Technology

LPG-fuelling technologies have been very adapted to those of gasoline-fuelled engines. Port Fuel Injection (PFI) indicates the most important LPG power technologies at present with regard to spark ignited engines.

The port fuel injection LPG has advantages over single-point power systems. The PFI methods represent quasi-imitation in multi-port electronic control injection systems that have been commonly used over the last two decades for petrol engines. In fact, most vehicles equipped with LPG port injection were structured specifically for gasoline and later transformed for LPG operating. In addition, there is a range of LPG offerings from original equipment manufacturers (OEMs), especially in Asiatic and European. Two variable types of conversions like bi-fuel, enable users to change the LPG and gasoline, and dedicated, allowing only the operation of LPG. The two-fuel system needs additional fuel injectors for LPG to be mounted, whereas dedicated systems substitute LPG injectors for gasoline injectors. This is important due to the lower energy per LPG volume. Based on air flow variations between the cylinders, individual injectors can operate on a sequential PFI system to obtain more or less fuel for particular cylinders. This allows the engine as a whole to better control the ratio

of air fuel and therefore a more effective three-way catalyst (TWC) activity to minimize hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOX) in production at the same time output. In addition, these injectors are generally installed relatively close to the suction valve in the suction manifold, providing a faster response to the engine's transient operation and controlled adjustments in the A:F ratio. Compared to gasoline engines, more than injection of LPG can appear lower controlled and uncontrolled emissions. Similarly, due to the fact that the engines were originally built for gasoline, LPG modifications and even OEM LPG offerings are always at a disadvantage. In relation to conventional fuel, a higher octane number of LPG enables more improved ignition time and increase compression ratios. Without adjusting the OEM petrol ignition time guides or the compression ratio, combustion efficiency will eventually decreased by generating higher HC and CO emissions, with the significant difference in lower NOx emissions from the exhaust gas. Therefore, it is necessary to identify the technology used current gasoline just after analyzing emissions converted to apply it to LPG in relation to gasoline vehicles [5].

### *2.3 Numerical setup*

A model was developed by AVL Boost to predict engine efficiency, combustion characteristics, and exhaust emissions to achieve this project and collect data. To complete this search, a four-cylinder SI engine was identified. The Vibe 2 zone combustion model and the Woschni 1990 heat transfer model were selected as submodels for more detailed results. All tests were conducted at the engine speed of 2500 revolutions/min, the piston face temperature (300, 320, 340, 360 and 380 °C) and the LPG and gasoline fuel constant throttle. The components of the test engine, including the cylinder configuration, the input and output manifolds, the air filter, the unit boundaries, the catalyst used on the basis of the actual values, were taken from the test engine and connected by pipelines (Figure 1). Major engine specifications are given in Table 4.

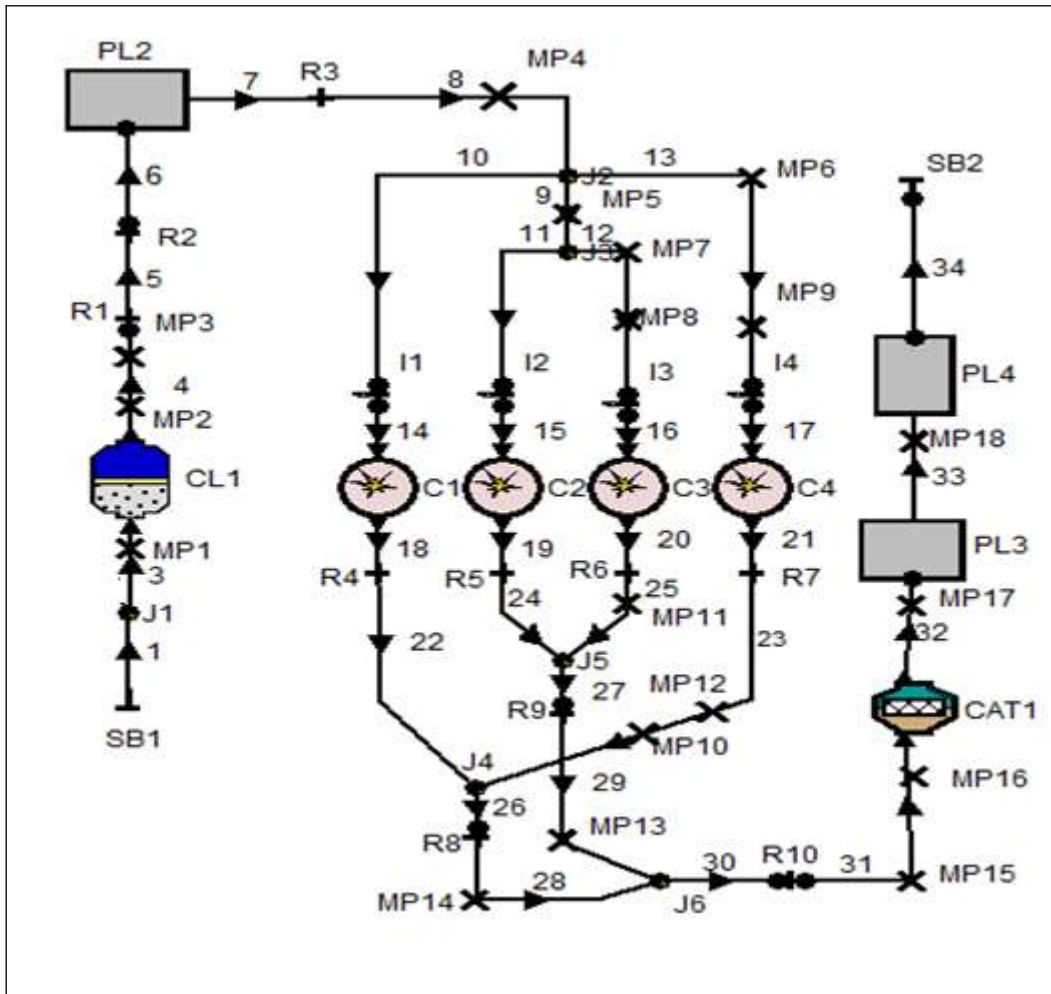


Figure 1. Schematic of the Engine Symbolic Model (AVL BOOST)

Table 4. 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

### 3. Result and Discussion

This section explains all interactions between the combustion properties, efficiency and emissions of the spark ignition engine driven by two different types of fuels (gasoline, LPG) and the different temperatures on the piston face by applying a numerical analysis.

#### 3.1 Cylinder Pressure

Figure (2) shows the variations in cylinder pressure (bar) with the position of the crank angle [CA deg], the experimental and simulation outputs of SIE engine at 2500 rpm with a constant position of the accelerator. There is a clear correlation between simulation and experimental trace.

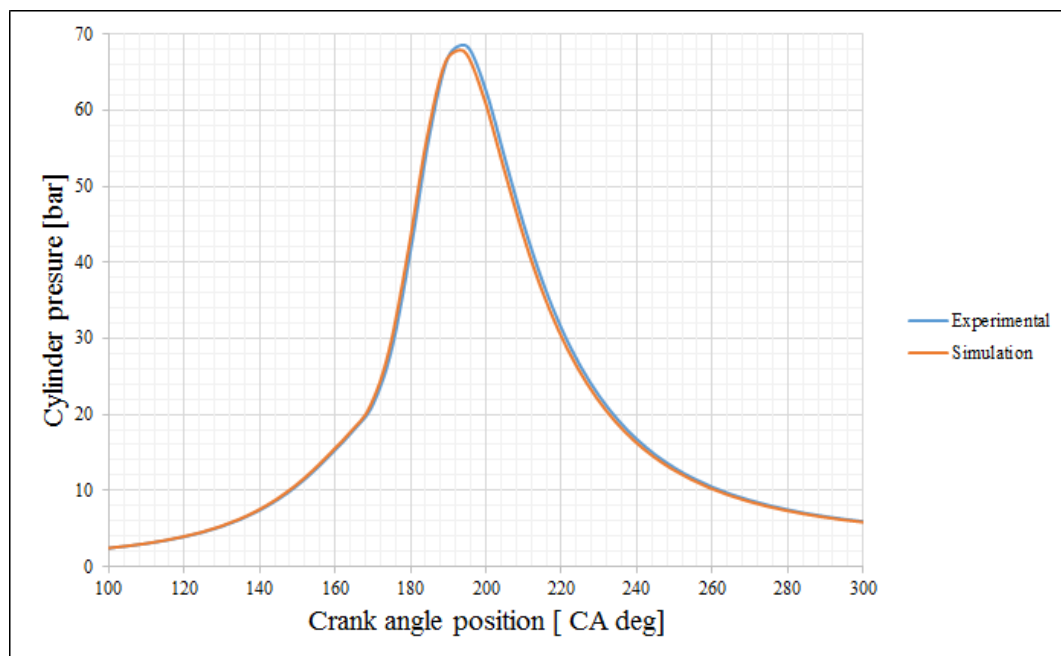


Figure 2. Comparison Between Experimental and Simulation Pressure Traces for Engine Speed 2500 rpm



### 3.2 Effective Power

The variation in effective power according to the temperatures of the piston face for petrol and LPG fuels tested is shown in Figure (3). It can be observed that effective power decreases with increased piston face temperature for the LPG or gasoline due to the reduction in the volumetric efficiency.

In addition, at the same piston face temperature, LPG fueled engine produces less efficient power than its value in the gasoline-powered engine due to lower heating value and lower LPG volumetric efficiency. The reason for the decrease in volumetric efficiency of a gaseous fuel such as LPG is, at room temperature, that the gaseous fuels are vapors, so there will be no cooling effect on intake charge while vaporizing so that the density of the suction mixture will be reduced and, moreover, the decrease in volumetric efficiency is also due to a higher volume of fuel in intake mixture.

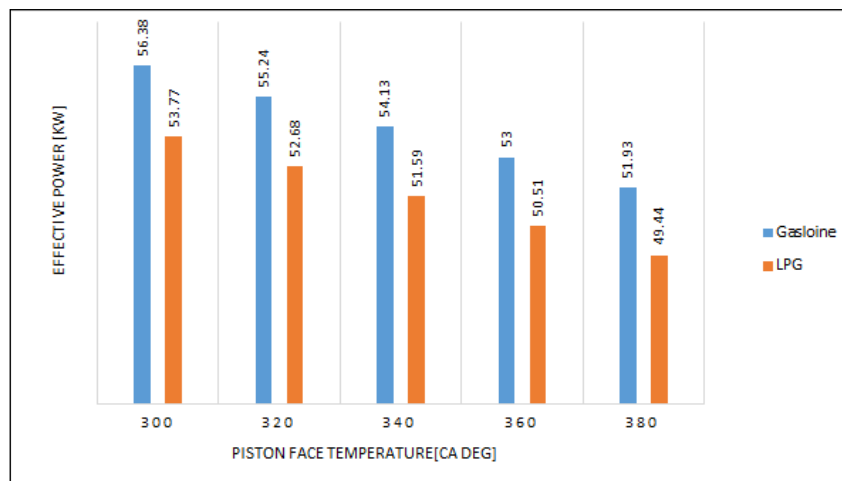


Figure 3. Effective Power of Gasoline and LPG Fueled Engine at 2500 rpm with Piston Face Temperature.

### 3.3. Effective Torque

The variation of the actual torque according to the temperatures of the piston face for tested petrol and LPG fuels. It can be observed that the actual torque decreases with the increase of the piston face temperature for LPG or petrol fuel due to the reduction of volumetric efficiency. Furthermore, at the same piston face temperature, LPG fueled engine produces a less effective torque of its value in the petrol-powered engine due to the lower density and volumetric efficiency of the LPG.

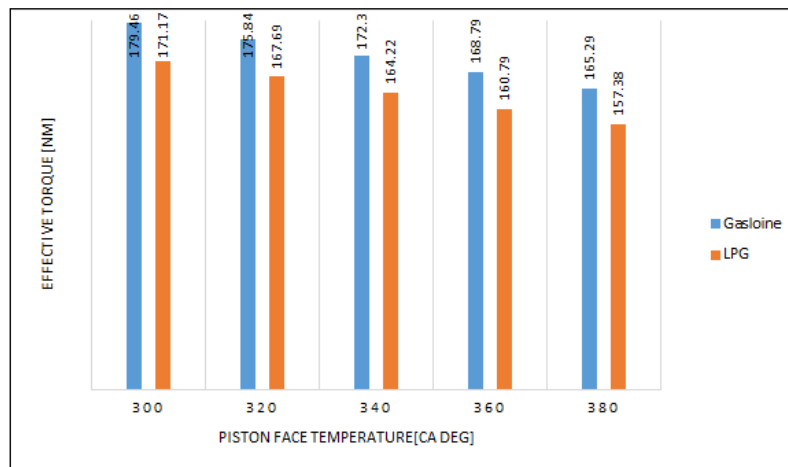


Figure 4. Effective Torque of Gasoline and LPG Fueled Engine at 2500 rpm vs. Piston Face Temperature

### 3.4. Brake Specific Fuel Consumption (BSFC)

Brake Specific Fuel Consumption presents an analysis of how fuel can be used and converted in particular energy efficiency. Fig.(5) shows the effects of the different piston temperatures on LPG or the performance of the indirect injection engine fuelled to the supply of a specific fuel consumption (g/kWh). Fig. (5) also shows that the specific fuel consumption of the LPG or gasoline engine BSFC is increased with the increase in the temperature of the piston face. This is due to the fact that as more fuel is burned, the temperature of the gases inside the cylinder increases so the temperature of the piston face. Also, it can be observed that the specific fuel consumption of the LPG-fueled engine is higher than the value of gasoline fueled engine at the same piston face temperature due to the reduction in volumetric efficiency.

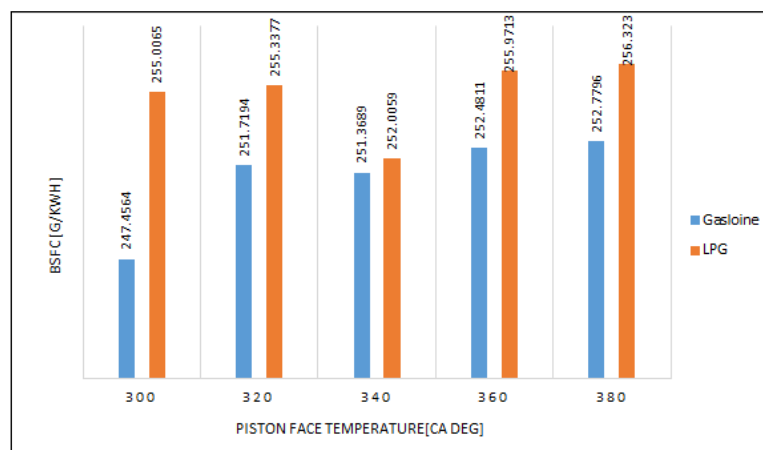


Figure 5. BSFC of Gasoline and LPG Fueled Engine at 2500 rpm vs. Piston Face Temperature.

### 3.5. Peak Fire Pressure

The maximum fire pressure can be defined as the highest pressure on an engine cylinder during combustion. Figure (6) shows the effect of various piston face temperatures on LPG or gasoline fueled indirect injection SI engine.

As shown in below figure that the peak fire pressure is reduced by increasing the temperature of the piston face temperature of an LPG or gasoline due to reduced volumetric efficiency. Also, it can be noted that the maximum fire pressure of LPG fueled engine is higher than its value in gasoline-powered engines according to lower volumetric efficiency. This means that we need to burn more fuel in LPG fueled engine compared with gasoline at the same temperature face piston.

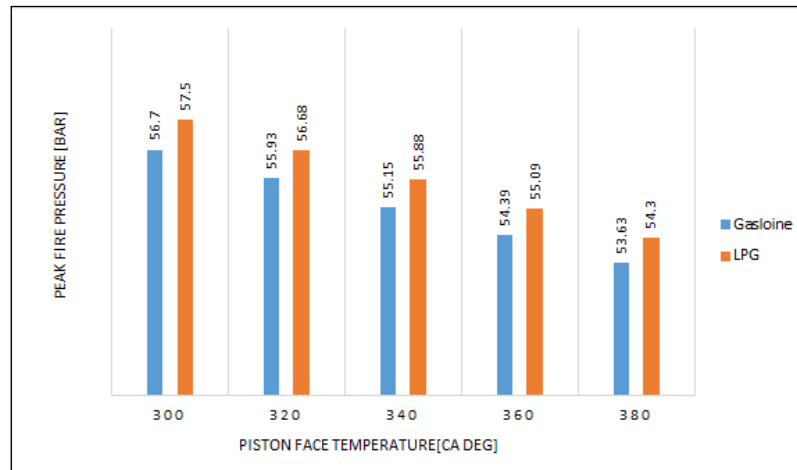


Figure 6. Peak Fire Pressure of Gasoline and LPG Fueled Engine at 2500 rpm vs. Piston Face Temperature.

### 3.6. Peak Fire Temperature

The maximum fire temperature can be defined as the maximum temperature of an engine cylinder during combustion. Figure 7 shows the effects of different piston temperatures on the performance of the LPG and petrol fuelled indirect injection engine SI. From this figure it is clear that the maximum fire temperature is increased by increasing the temperature of the piston face for both test fuels. In addition, it can be noted that, at the same piston face temperature, the peak fire temperature of the LPG fuelled engine is higher than its value in a gasoline-fueled engine according to lower volumetric efficiency. In addition, to achieve the same power for two engines, it is necessary to burn more fuel for the LPG needed to burn.

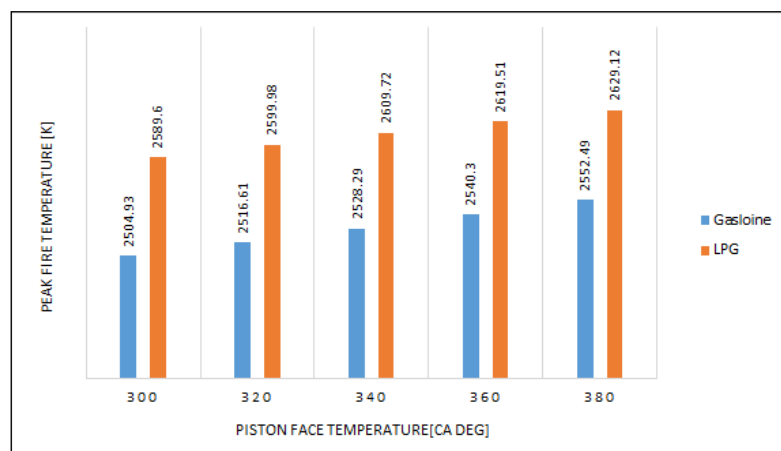


Figure 7. Peak Fire Temperature of Gasoline and LPG Fueled Engine at 2500 rpm vs. Piston Face Temperature.

### 3.7. Carbon Monoxide Emission (CO)

Carbon monoxide occurs when a fuel is not completely burned. Effect of the various temperatures of the piston face on the indirect injection engine SI fuelled with LPG and gasoline shown in Figure 8. This figure shows that carbon monoxide emission increases with the increase in the temperature of the piston face for both LPG or gasoline fueled. This behavior due to the increasing in the dissociation of  $\text{CO}_2$ . Also, it can be noted that, at the same piston temperature, the emission of carbon monoxide from engine-powered LPG is lower than that of petrol fuel due to the lower ratio of carbon to hydrogen in LPG compared to petrol fuel.

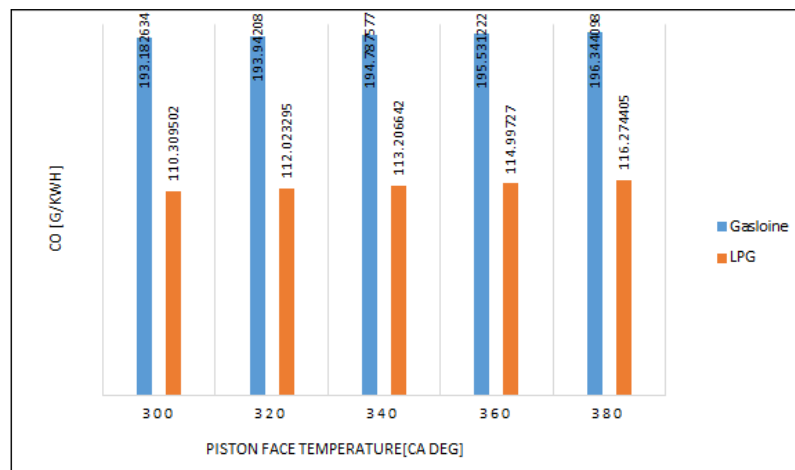


Figure 8. Co of Gasoline and LPG Fueled Engine at 2500 rpm vs. Piston Face Temperature.

### 3.8. Unburnt hydrocarbon UHC

Hydrocarbons are produced by the incomplete combustion of fuels and the evaporation of fuels. HC is an essential component of photochemical smog and HC is considered to be a serious atmospheric pollutant, especially in urban areas. Figure 9 shows the effect of different temperatures of the piston face on the performance of the indirect injection engine fuelled with LPG or petrol.

Fig.(9) shows that unburn hydrocarbons have decreased by increasing the piston face temperature of an LPG or gasoline fueled SI engine. This return to the high piston face temperature enhances the combustion.

Also, it can be noted that, at the same piston face temperature, the unburned hydrocarbon of the LPG is lower than that of gasoline. This can be due to the better mixing process of LPG than gasoline and this leads to better combustion.

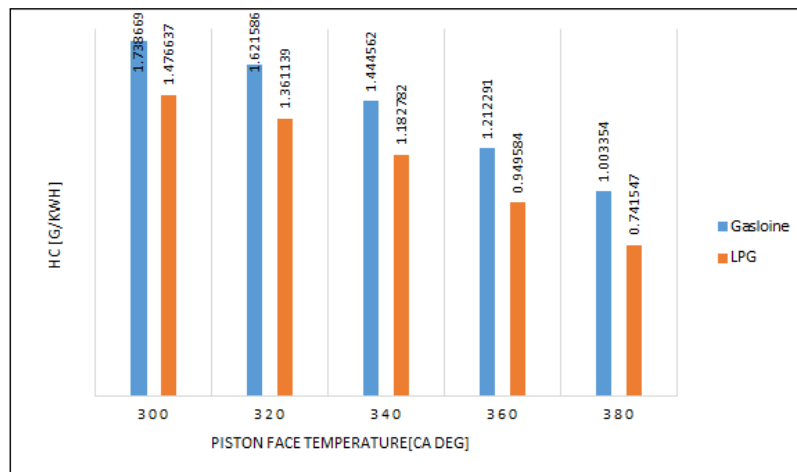


Figure 9. UHC of Gasoline and LPG at 2500 rpm vs. Piston Face Temperature.

### 3.9 Oxide of Nitrogen NO<sub>x</sub>

Oxides of nitrogen (NO, NO<sub>2</sub>, N<sub>2</sub>O, etc.) are the compounds of N<sub>2</sub> and O<sub>2</sub>. NO<sub>x</sub> produces when fuels are burned at high temperatures, high pressures and excess oxygen in the engine combustion chamber. The effect of various piston face temperatures on SI engine emission operating on LPG or gasoline fuels is shown in figure 10. This figure shows that NO<sub>x</sub> emission has increased by increasing the temperature of the piston face when used both fuels. Also, it can be noted that, at the same piston face temperature, the oxide of nitrogen of engine fueled LPG is less than that of gasoline.

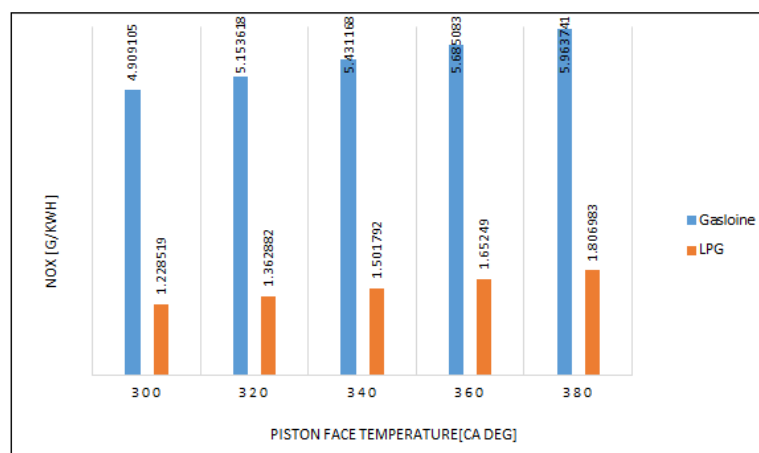


Figure 10. Nox of Gasoline and LPG at 2500 rpm vs. Piston Face Temperature.

## 4. Conclusions

The present study analyzed exhaust emissions, performance and combustion characteristics of a four-cylinder SI engine when using LPG and gasoline. The engine speed was fixed at 2,500 rotations per minute. However, the temperatures on the piston face were different. It was concluded on the basis of the numerical results that:

- 1- At all piston face temperatures, the LPG fuel produces a lower effective torque and an effective power compared to a gasoline.

- 2- Liquefied petroleum gas fueled engine produces greater brake specific fuel consumption than that of gasoline fuel at the same piston face temperature.
- 3- The LPG-powered engine produces peak fire temperature and peak fire pressure higher than its gasoline at all operating conditions.
- 4- Liquefied petroleum gas fueled engine produces lower CO, unburnt hydrocarbon and oxide of nitrogen emissions compared to the gasoline for the various piston face temperature.

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