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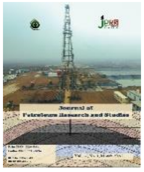

Combustion Performance and Emissions in Multipoint Port Fuel Injection Engines with Liquefied Petroleum Gas Fuel Injection

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Abstract

Fossil fuels used in internal combustion engines are some of the worst polluters and harm our environment and this fuel is the highest economic cost; hence the need to use other fuels with lower shared concern is reserved for the ecological impact and the least efficient cost. As such, the researchers have been able to use several other types of low-level fuels such as the Liquefied Petroleum Gas mixing 50, 75, and 100. This study is focused to performance of the liquefied petroleum gas as compared to gasoline and emissions from the four-stroke spark ignition at constant pressure ratio of 10:1, variable speed of 1000–2000 rpm. The indicated volumetric efficiency in this case has negative changes with increasing speed of the engine, and when using liquefied petroleum gas fuel. An improvement in volume efficiency, brake thermal efficiency, emission of gases such as HC, NOx, CO_2, CO and fuel consumption rates show that values have been raised and consumption rates by fuel optimized. The results show an improvement in the fuel consumption, combustion thermal efficiency and other aspects related to the combustion of the liquefied petroleum gas fuel compared to the pure gasoline. The HC, NOx, CO_2, and CO emissions are reduced while operating with liquefied petroleum gas as a fuel.

Keywords: Pre-chamber gas injection system, Combustion process, Emission control, Cranking timing, Engine fuel economy.

أداء الاحتراق والانبعاثات في محركات الحقن متعدد النقاط للوقود باستخدام حقن غاز البترول المسال

الخلاصة

تعد أنواع الوقود الأحفوري المستخدمة في محركات الاحتراق الداخلي من أسوأ الملوثات التي تُلحق الضرر بالبيئة، كما أنها تشكل أعلى تكلفة اقتصادية. لذا، يُفضّل استخدام أنواع وقود أخرى ذات تأثير بيئي أقل وتكلفة أقل. ولهذا، تمكن الباحثون من استخدام أنواع أخرى من الوقود منخفض الانبعاثات، مثل غاز البترول المسال بنسب خلط 50 و75 و100. تركز هذه الدراسة على أداء غاز البترول المسال مقارنةً بالبنزين، وعلى الانبعاثات الناتجة عن محرك رباعي الأشواط يعمل بالشرارة عند نسبة ضغط ثابتة 10:1 وسرعة متغيرة تتراوح بين 1000 و2000 دورة في الدقيقة. في هذه الحالة، تتغير الكفاءة الحجمية المشار إليها سلبًا مع زيادة سرعة المحرك، وعند استخدام غاز البترول المسال كوقود. ويُظهر تحسن الكفاءة الحجمية، والكفاءة الحرارية للمحرك، وانبعاثات الغازات مثل الهيدروكربونات، وأكاسيد

النيتروجين، وثاني أكسيد الكربون، وأول أكسيد الكربون، ومعدلات استهلاك الوقود، ارتفاعًا في القيم وتحسينًا في معدلات الاستهلاك. تظهر النتائج تحسناً في استهلاك الوقود، وكفاءة الاحتراق الحرارية، وجوانب أخرى متعلقة باحتراق غاز البترول المسال مقارنةً بالبنزين النقي. كما تنخفض انبعاثات الهيدروكربونات، وأكاسيد النيتروجين، وثاني أكسيد الكربون، وأول أكسيد الكربون عند استخدام غاز البترول المسال كوقود.

1. Introduction

The continuing increase in fuel prices globally has led to the interest of researchers in the field of energy economics in finding alternatives to automobile fuels. Air pollution is a problem faced by all industrialized countries, so there is a need to reduce the amount of pollution resulting from factory emissions and internal combustion engines, as car engine pollutants constitute the largest and most dangerous part due to their importance in daily use.

Depending on the type of fuel used, it can be classified as gaseous fuel and gasoline. Gaseous fuel is a new idea in the world of cars that can achieve possibilities and prospects for the next generation due to the high value of the octane number and the low economic value as well as the reduction of exhaust emissions.

Sustained reduction of exhaust emission is an attribute recognized by liquefied petroleum gas from the viewpoint of the second viewpoint. In terms of operating characteristics, the merits of liquefied petroleum gas petroleum gas fuel are sufficient supply infrastructure and comparatively higher heating value. It though has a somewhat higher-octane number and the exhaust HC emission of it is less than that of gasoline. In comparisons of the recent past, the ability of Liquefied petroleum gas (liquefied petroleum gas) has been compared often with the ability to replace gasoline. It is important to note that several works on the emissions of automobiles using liquefied petroleum gas as fuel have been reported in the literature.

The low carbon content of gaseous fuels makes this fuel superior to liquid fuels due to good combustion, low hydrogen and carbon emissions, and better thermal efficiency, which leads to fuel economy for car engines that use LPG instead of gasoline is also possible [1-3].

The first basic consideration for the choice of any of the alternatives is that the fuel must be either plentiful in availability or at best derived from renewable resources; it has to contain a lot of specific energy; the fuel has to be easy to store and transport; it has to have low impacts on the depletion of the resource base of the environment; and, lastly, it has to be a quality fuel that is safe and its handling characteristics [4–6].

liquefied petroleum gas is a gas that is primarily composed of propane and butane, although it may also include any number of hydrocarbons including propane and n-butane. Compression is only up to 520 bars, and it performs well and acts as an alternative fuel in SI engines [7-9] employed a single cylinder engine with four-stroke, in order to determine the liquefied petroleum gas compositions affected, butane and propane the mixing ratios show that blending of the two gases augments the engine performance. Moreover, liquefied petroleum gas composition as a fuel fraction slightly affects the efficiency of the engine yet it substantially influences the combustion noise. The objective of this research was to establish the performance of a small-scale SI engine utilizing exclusively liquefied petroleum gas fuel [10].

The implications of the two fuel supply methods, namely injection and carburetion on the Spark Ignition engine in relation to mean effective indications and volumetric legislations were analyzed empirically. They utilized an engine with four cylinder, 1581cc displacement volume, water cooled and compression ratio of 9.2:1. The findings endorsed the fact that engine performance with the sample of liquid petroleum gas injection control unit designed and developed by the researcher is relatively higher than with the prevailing LPG carburetion system and normal gasoline. The observations made were as follows: The volumetric efficiency was always maximum in gasoline carburetion than when liquefied petroleum gas alone is carbureted and the maximum volume efficiency observed was when liquefied petroleum gas is injected [11].

The position of an injector for liquefied petroleum gas is studied. A four-cylinder SI engine with a displacement volume of 982 cm^3 of engine was used for performing experimental work on ultra-lean combustion with direct injection and transportation, minimal pollution and depletion of the environment resources, and finally, it must be of good quality with a safe. It shows the results where, for brake torque between 0-20N.m, the BSFC has been lowered to a range of 0 - 9%. Nevertheless, lean combustion produced its benefits that are accompanied by the increase of order of magnitude higher particulate matter emission integrated with the particle number [12] that compared the exhaust emissions of gasoline and liquefied petroleum gas test using Kane Auto exhaust gas analyzer that records such as emissions of CO2, HC, O2, and CO2.

The test section is a single cylinder spark ignition engine with two carburetors that was studied by [13]. The emissions were captured for different load levels of (0 – 1200) W for both fuels. The HC emission of liquefied petroleum gas was observed to be very high, and the CO2 emission of gasoline was higher than liquefied petroleum gas experimentally investigated the impacts of compression ratio, SU stroke/bore ratio and equivalence ratio of gasoline and liquefied petroleum gas.

The Otto cycle engines were modeled using the finite-time thermodynamic method to obtain a simulation. Recall that in the use of liquefied petroleum gas it was found that a 10% reduction in volumetric efficiency leads to 12% reduction in energy density. From the previous formula while the specific fuel consumption of liquefied petroleum gas is greater than the gasoline-specific fuel consumption the liquefied petroleum gas specific fuel cost is less than that of gasoline because of the liquefied petroleum gas: Gasoline price ratio therefore utilizing the liquefied petroleum gas engine is more affordable compared to operating with gasoline. Very high performances are achieved for longer strokes and shorter bores and at lower compression ratios. The performance loss associated with the combustion of fuel also rises where the equivalence ratio is greater than the performance losses of liquefied petroleum gas can be alleviated by raising the volumetric efficiency or the compression ratio [13] studied the effects on performance and emissions of liquefied petroleum gas spark ignited gasoline-liquefied petroleum gas blend engine by using response surface methodology (RSM) and identifying the best operating liquefied petroleum gas ratio and engine load.

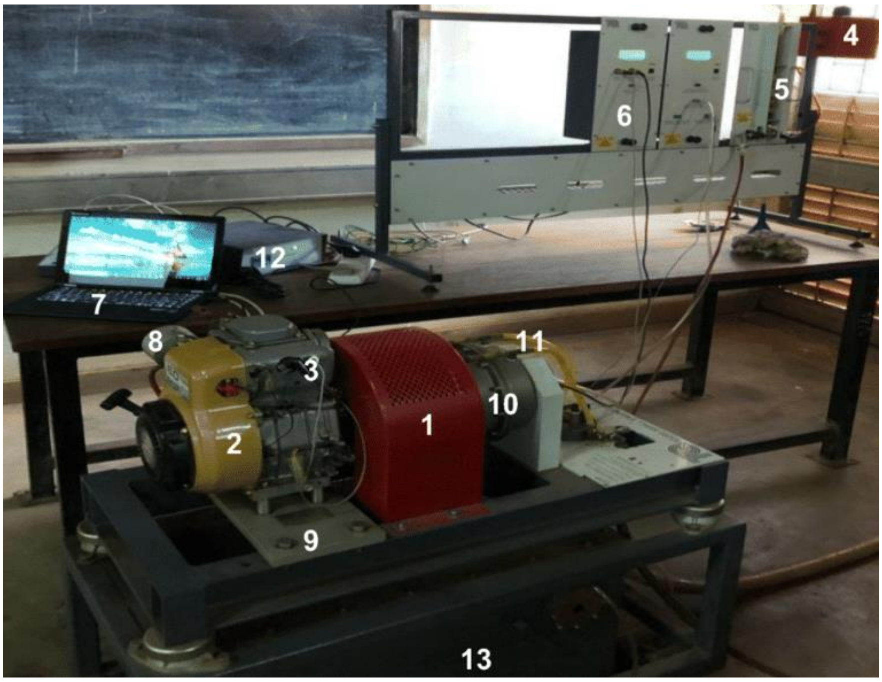
The RSM model data has been obtained from experiments done at four liquefied petroleum gas blends (25, 50, 75 and 100%) and at three loads (2000, 2500 and 3000W). From this study, it was realized that the best ratio of liquefied petroleum gas and engine load was 35 % and 2400W respectively. As mentioned, before it was stated and pointed out, increasing liquefied petroleum gas also cuts all emissions although detreating BTE and BSFC [14].

This study is focused to performance of the liquefied petroleum gas as compared to gasoline and emissions from the four-stroke spark ignition at constant pressure ratio of 10:1, variable speed of 1000–2000 rpm. The use of Liquefied Petroleum Gas will contribute to improving volume efficiency, brake thermal efficiency, emission of gases such as HC, NOx, CO_2, CO and fuel consumption rates. The originality of using LPG in cars stems from its unique combination of lower environmental impact, cost efficiency, and engine benefits, while also offering the flexibility of dual-fuel systems. These features make LPG an appealing alternative fuel choice in the automotive industry.

2. Method

The major ETU components include but are not limited to the dual fuel carburetor, exhaust gas analysis unit and hydraulic dynamometers as illustrated in Figure 1. The tests are carried out on both pure gasoline and then on liquefied petroleum gas only without the two combined. Compression ratio was constant (8.5:1) Due to stepped injection rate and variable engine speed; they range between 1000 and 2000 revolutions per minute. This interferes with a computer-based data acquisition system with VDAS which provides very high accuracy results on the screen for viewing in real time. The integration of various parameters relating to the performance of the drive on the computer making the act real and efficient [15]. The procedure for the experiment that involves the measurement of the exhaust gases' concentration using a Techno Test type device with the identification number of MOD488 to get the concentration of HC, CO, CO_2 and NOx was done in an experimental way based on the following steps:

1. The spark ignition motor speed is to reach 2000 rpm.
2. Thus, after stabilizing to a thermal equilibrium, the measurement of the torque quantity is realized. and Fuel consumption is recorded.
3. Often HC, CO, CO2, and NOx are used to determine the concentration of the exhaust gas after the exhaust. A gas analysis device has been heated for a time of 20 minutes.
4. When the speed is changing, the roll back is done, so that the process will start with the data collected in the necessary.



(1) dynamometer. (2) SI engine. (3) Transducer. (4) Fuel tank. (5) Automatic volumetric fuel gauge with DVF1. (6) Control panel. (7) CP (8) Air inlet. (9) Base plate. (10) Crank coder. (11) Water-cooled inlet. (12) Engine cycle analyzer. (13) Techno Test type device

Fig. (1): Schematic diagram of the experimental rig.

2.1. Data collection

2.1.1. Calculation and Mathematical Formulas

The brake power can be evaluated by the following equation as [16-21]:

$$BP = 2\pi NT \quad (1)$$

$$BSFC = mf\ BP \quad (2)$$

Efficiency by the brake power is estimated as:

$$\eta_{B,th} = BP\ (mf \times QHV \times 0.98) \quad (3)$$

$$m_f = v_f \times \rho_f\, 1000 \quad (4)$$

2.1.2. Error analysis

The error analysis is significant to evaluate the performance of LPG engine that comes from recording data and calculating emissions as in Table (1).

Table (1): Accuracy and error analysis.

Parameters	Errors %
Concentration Analyzers	1.5
Speed Chassis dynamometer	1
Distance Chassis dynamometer	0.5
Flow Exhaust dilution system	1.5

3. Results and Discussion

3.1. Brake power

Figure (2) demonstrates the changes of brake power depending on the variation of the engine speed at the large open of throttle. It was computed since deduction of the power provided by engine performance. The maximum brake power is not shown here; however, it should most likely be at 3000 rpm due to reduction in volumetric efficiency [19]. As seen through the various fuels analyzed, there was always an increase in the brake power with an increase in the engine speed. The blends of (6% ethanol) (86%gasoline) -(7% methanol) -(79%gasoline) - (13%methanol), and - (14%ethanol) (82%gasoline) responded positively to increased brake power by delivering 20%, 29% as well as 19% more brake power than straight gasoline at 2,000 rpm. The largest increase in brake power, 9.2, was observed for all the speeds. Although LPG has a lower energy density than gasoline, the higher thermal efficiency of LPG combustion (due to better ignition properties and faster combustion) can compensate for the lower energy content. This efficiency may be more pronounced at higher speeds, leading to an increase in brake power. The engine can extract more power per unit of fuel at the higher RPM range due to the quicker combustion process.

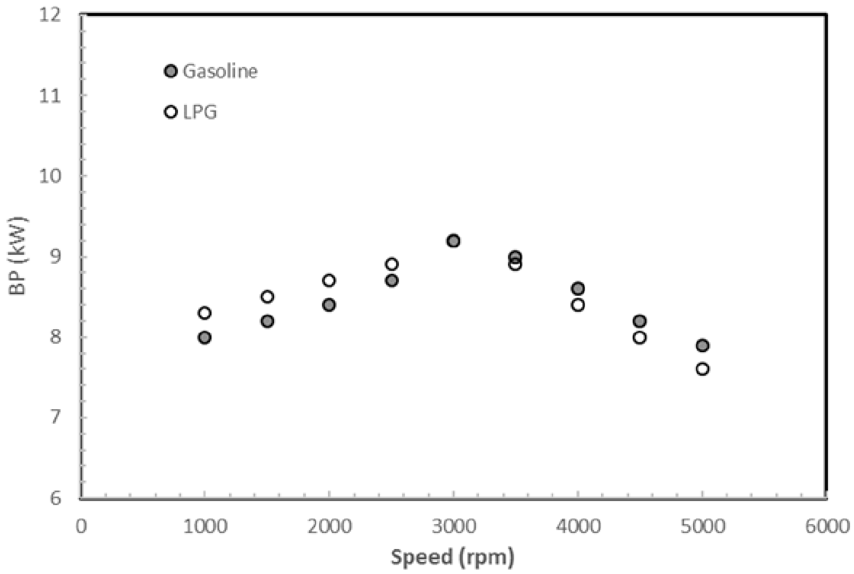


Fig. (2): Brake power with speed for LPG and gasoline engine.

3.2. Indicated power

So as discussed above the indicated mean effective pressure of an engine only depends on the position of the throttle valve. From the observed results as illustrated by Figure (3). It was observed that both gasoline engines and liquefied petroleum gas are a pattern that incipiently describes the fluctuation of the changes in the average IMEP with the increase in engine speed. The behavior of 5° TDC standard idle ignition timing is illustrated. It could, therefore, be deduced that while combustion of liquefied petroleum gas fuel causes slightly lower IMEP at low engine numbers, slightly higher IMEP is realized when the engine is operated at higher rpm numbers as opposed to combustion of gasoline fuel. However, the variability is not enormous, and this leaves us with a small range of variations. As such, the engine does not experience a large amount of power loss as often found in the standard power-to-weight ratio calculation.

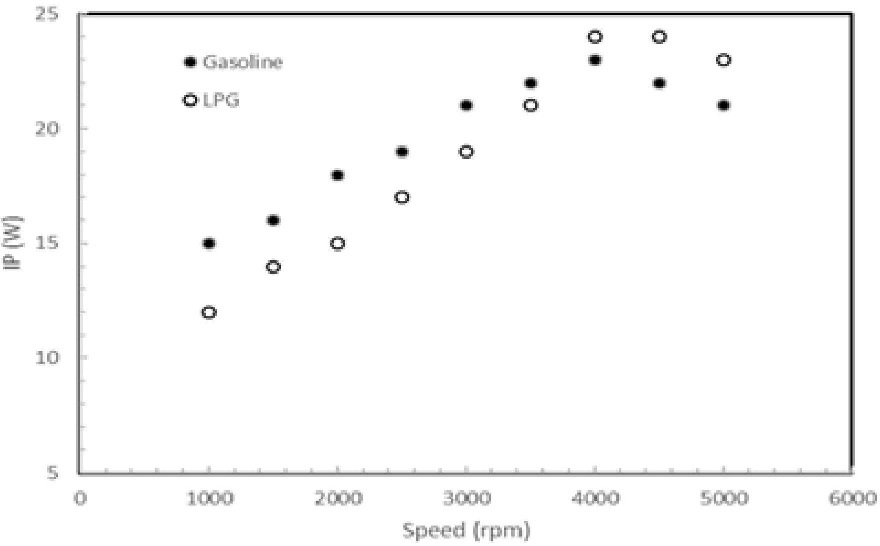


Fig. (3): Indicated power at different speeds for LPG and gasoline engines.

3.3. Emission

Figure (4) Here, it reveals the fluctuation of CO emission per horsepower per meter with BMEP. On the figure, it is seen how the level of CO emissions reduces when the amount of liquefied petroleum gas increases. This is because the burning of LPG fuel is rapidly gaseous state with a smaller atomic ratio of hydrogen to carbon [19]. The overall decrease of CO emissions was calculated as 26.8%, 26.2%, 40.7%, 53.3% if the fuel mixture containing 5%, 50%, 75% and 100% LPG was used.

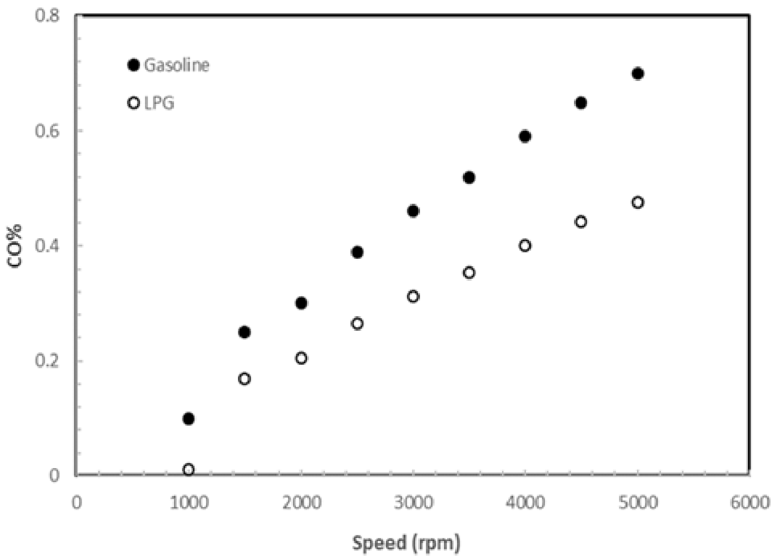


Fig. (4): CO emissions at different engine speeds for LPG and gasoline engines.

Prior to examining CO_2 emissions, the engine's real fuel injection time was verified. The fuel injection quantity and duration are displayed based on the propane content on Figure (5). The amount of injections and CO_2 emissions are directly correlated; that is, an increase in the amount and duration of fuel injection results in an increase in CO_2 emissions [19]. Carbon buildup in the engine port and valve can also result from excessive injection. The injection duration by fuel is displayed in Figure (5).

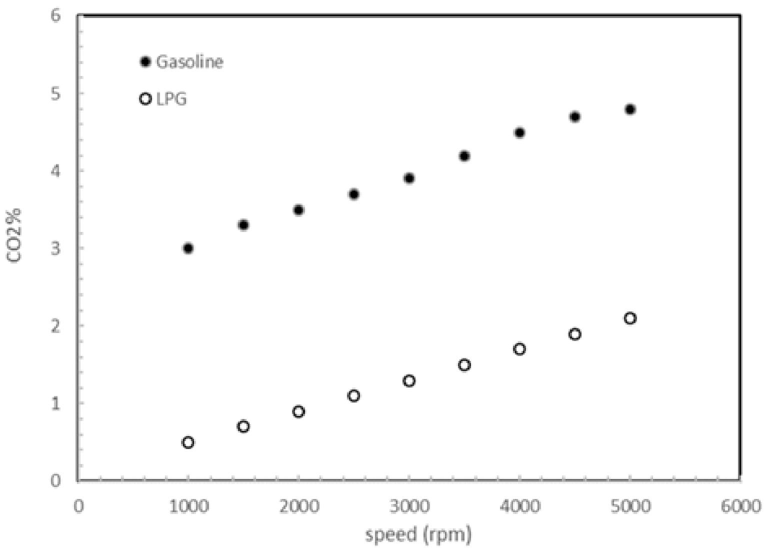


Fig. (5): CO_2 emissions at different speeds for LPG and gasoline engines.

The appearance of HC in the fumes suggests that there is rich combustion of fuel or in other words incomplete combustion. Incomplete combustion and the formation of HC are attributed by lower temperature, oxygen deficiency and the heterogeneity of the mixture [21]. The variation of HC emissions with BMEP is depicted in Figure (6). The figures show how HC emissions reduce as LPG usage increases. What is observed is that as the volume of the LPG increases the mixture becomes relatively more homogeneous which enhances the combustion process while also decreasing the levels of HC emissions. Due to this mix enrichment, HC emissions are directly proportional to engine BMEP. Emission reductions of HC were on average 26.0%, 40.0%, 52.0%, and 70.0% with 25 % LPG, 50 % LPG, 75 % LPG and 100 % LPG fuel blends respectively.

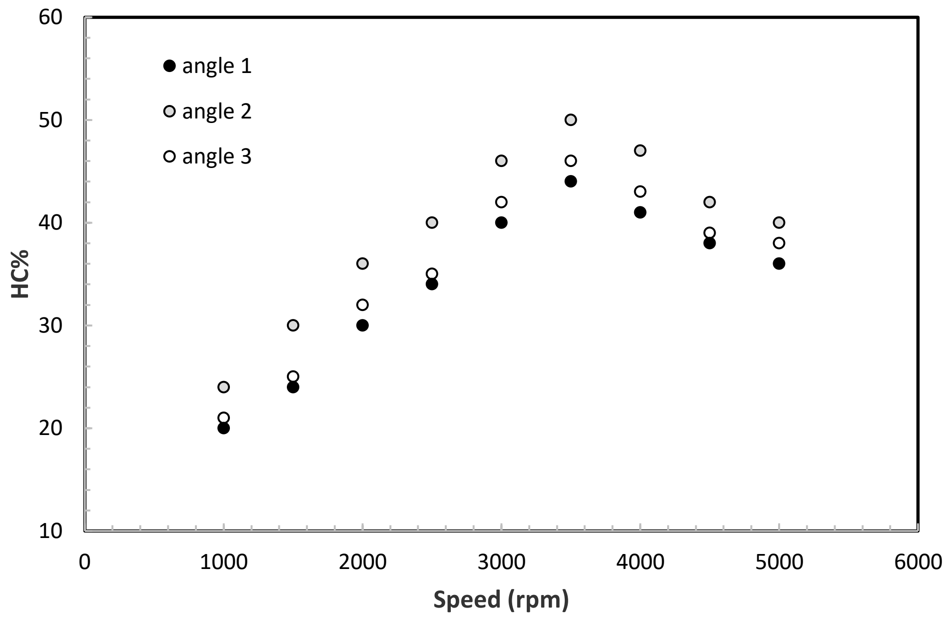


Fig. (6): HC emission at different sped for LPG and gasoline engine.

It also reveals that BSCF developed over some time in relation to the BMEP, as evidenced in Figure (7) above. Where there was high BMEP, there was low BSFC and the overall trend of BMEP and BSFC was inversely related. Compared to the baseline tests, the brake specific fuel consumption required for the ten blends tested with 25% liquefied petroleum gas was slightly higher. Two explanations come out clearly as we come to this conclusion: as for combustion efficiency, LPG is preferable because indicated power gas has better mass heat value. This then discovered that, relative to the subsequent level of LPG consumption, the BSFC was principally higher in all cases. The overall maximum fuel consumption was set under low engine loads where the ratio used was 50 percent petrol and 50 percent. liquefied petroleum gas was used while at higher loads 100% liquefied petroleum gas. On average the usage of 25% liquefied petroleum gas was established to improve the BSFC by on an average of 7.1 percent [21]. All the mixes containing 50, 75, and 100 liquefied petroleum gas produced betterment in the BSFC of 7.3, 0.4, and 1.8 percent, respectively.

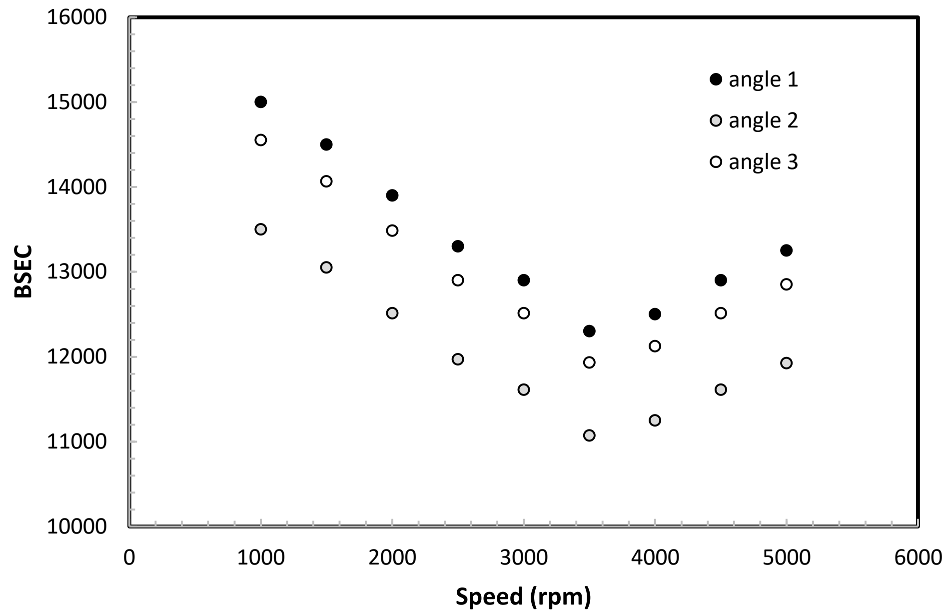


Fig. (7): BSEC at different speeds for Liquefied Petroleum Gas and gasoline engines.

It was discovered that understanding how different propane ratios effect CO_2 and PM emissions can aid in identifying solutions to reduce greenhouse gas emissions and particle pollution. Analyzing combustion efficiency is critical since more efficient combustion typically results in reduced emissions. This can help with fuel mixture modifications for improved performance. Findings can help to mitigate climate change and improve air quality, making them useful for regulatory compliance and sustainability programs. The study of how fuel mix affects engine performance (power output, fuel economy) is important for manufacturers and consumers seeking optimal operation. The findings may help authorities develop guidelines for liquefied petroleum gas engines and encourage cleaner fuel alternatives.

Gained knowledge can be used to create fuel formulas and liquefied petroleum gas engines, resulting in improvements that satisfy environmental and performance requirements. The study could improve general knowledge of combustion processes and emissions in other fuel types by offering insights that are applicable to other alternative fuels. The difference here could be due to the specific dual-fuel system technology used or the type of engine tuned for dual-fuel operation. Some papers might focus on the ease of retrofitting older engines, while others focus on more modern, optimized systems.

3.4. Validation of results

The comparison between the present results and other data available in the literature is conducted to be validated as in Table (2).

Table (2): Example Summary Table of Comparison.

Parameter	Present results	Yeom et al., [19]
Engine Performance	low RPMs, slightly lower torque at higher RPMs and IMEP.	Similar power output, less variation across RPMs.
Emissions	Lower CO, HC; higher NOx at high loads.	Similar CO, HC reduction; lower NOx emissions.
Combustion Speed	Faster combustion at high RPMs, advanced timing benefits.	Similar findings, more focus on temperature effects.

4. Conclusions

This paper evaluates the performance and emission characteristics of liquefied petroleum gas fuel in a single-cylinder SI gasoline engine at various engine speeds (1000-5000 rpm) that can complete the vehicle's driving cycle. Based on the outcomes of this study, the following conclusions were drawn. The thermal effectiveness of liquefied petroleum gas fuel was found to be higher than that of gasoline in a single cylinder SI combustion engine at various engines. The conclusions were summarized as:

1. The liquefied petroleum gas fuel appeared to be higher thermal efficiency than gasoline engines by 5%.
2. The indicated volumetric efficiency in this case has negative changes with increasing speed of the engine, and when using liquefied petroleum gas fuel.
3. The largest proportion of brake fuel consumption was recorded at 6% and is in liquefied petroleum gas, which indicated an elimination consumption than fuel of gasoline.
4. The HC is reduced from 0.30 to 0.16%, NOx from 0.14 to 0.09%, CO2 from 5275 to 4670 ppm and CO from 10 to 4 ppm when using liquefied petroleum gas fuel than the gasoline fuel.

Nomenclature

BSEC	Brake specific energy consumption (kJ/kW-hr)
CO	Carbon monoxide (% vol.)
HC	Hydrocarbon (PPM)
LPG	Liquefied petroleum gas
NOX	Oxides of nitrogen (PPM)
bTDC	Before TDC
ECU	Electronic control unit
IMEP	Indicated mean effective pressure (bar)
MPFI	Multipoint port fuel injection

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