IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Effect of LPG on Emission in a Single Cylinder Engine

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Abstract : An experimental investigation of the effect of liquefied petroleum gas (LPG) on emissions in a single cylinder electric generator has been carried out. Liquified petroleum gas is well developed for use in domestic cooking and is gaining recognition as a fuel for vehicle propulsion and portable electric generator. It is readily available, cost effective, low carbon and reduced emission compared to gasoline. The investigation was carried out to study the emission associated with using LPG and to present a proposal for the adoption of LPG which can aid in the reduction of toxic gas emissions from engines used for power-generating and for vehicle propulsion in the urban, peri-urban, and rural areas of the country. The low carbon content of LPG will also translate into highly reduced carbon dioxide (CO_2) emission which is the key global warming emission. This investigation involves the use of portable exhaust gas emission analyzer to sample and compare exhaust gases between gasoline and LPG emissions from a single cylinder 4-stroke 7KVA mobile power-generating set. This engine is the most popular among the low income earner in Nigeria and at the same it also dominate the propulsion system of the 2-and 3-wheel vehicle that are in millions across the country and other Sub Saharan Africa regions. The result of the investigation showed that LPG emissions and cost of fuel is lower than that of pure gasoline.

***IndexTerms* - Internal Combustion Engines; Liquefied Petroleum Gas; Gasoline; EmissionS.**

INTRODUCTION

The global concern on the use of fossil fuel effects on the environment and the effects on the air quality has reached an alarming rate, and Nigeria is not an exception. The air pollutants in the environment are mainly due to the emissions from automobile, mobile power generators, power plants, boilers, industries requiring crushing and grinding such as quarry, cement and steel industries. However, there is general believe that the transport sectors are responsible for over 70% of this pollutants in terms of energy demand locally and globally and this is confirmed by [1]. Fossil fuel derived diesel and gasoline are the main fuel used in fueling of stationary electric generator and transport engines and also the main source of toxic emissions.

In gasoline engines the main emissions generated are nitrogen oxides (NOx), carbon monoxide (CO), unburnt hydrocarbons (UHC), carbon dioxide (CO_2), particulate matter (PM), and volatile organic compounds (VOC). The oxides of nitrogen are formed in the engine when elemental nitrogen in the combustion air reacts with oxygen at high combustion temperature. The UHC is a result of incomplete combustion of the fuel in the engine, incylinder wall and piston crown wetting, and crevices are all contributors to this emission, it is also carcinogenic. The NOx emission is as a result of the in-cylinder combustion high temperature. The only control of NOx is to minimize the incylinder combustion temperature through varying strategies such as exhaust gas recirculation, and retarded spark timing. The NOx is also harmful to health and environment and is the key culprit for acid rain and smog. The particulate matter (PM) is a general term used to describe the mixture of solid particles and liquid droplets in the air. These particles, which are produced from diesel and mainly gasoline direct injection (GDI) engines, can affect the respiration system and can as well carry toxic substances into the lungs and bloodstream [2].

According to [3], the CO_2 emission which is the key enabler of global warming is not really a pollutant from the internal combustion engines. It is more of a factor that shows how complete the combustion is, but in recent decades it has been observed and confirmed that it was the key enabler of global warming. Currently effort is being made to decarbonize the reciprocating internal combustion engines. It is also widely known that the higher the carbon contents of the fuel the higher the level of CO_2 emissions. The CO emission is as a result of deficiency in oxygen supplied and this account for over 50% of CO emissions. For the UHC and PM emissions are as a result of incomplete combustion and cylinder wetting hence the needs for alternative and sustainable fuel characterized by zero or low carbon emission.

There is also the issue of limited availability of fossil fuel all these challenge has lead to many researcher proposing the adoption of alternative fuel. There is also an urgent need to source for an alternative fuel as the dependence on fossil fuel may no longer be sustainable for our energy demand in the next 50 years. The automotive industry and researcher have also made a fantastic improvement to see that emissions from the internal combustion engines are reduced to the possible minimum through engine downsizing, advanced combustion mode (such as variable valve timing and controlled autoignition), use of biofuel such as pure ethanol, ethanol gasoline blends [4].

The alternative fuels are becoming popular due to their perceived environmental and energy security benefits. Studies have shown that their use can reduce emissions of harmful pollutants and greenhouse gases. Since alternative fuels are largely produced domestically, increased use of these fuels would reduce dependence on foreign energy sources and could benefit local economies [5].

In recent time the Nigerian government has also mandated vehicle owners to retrofit their vehicle with LPG system, but very little number of motorists had so far complied. This low compliance was due the non sensitization of the vehicle owners the advantages of using LPG fuel and some form of incentives. According to investigations by [6] who carried an investigation on the adoption of liquefied petroleum gas and compressed natural gas into the Nigerian Transportation system he listed the countries that currently dominate the autogas. They also discussed what the government should do to actualize the policy that had been in place since 2007 but was never implemented. In addition, they listed emission mitigation and the low cost of LPG compared to gasoline as the key driver of autogas fuel.

Taoju Zhang [7], carried out a research on Possibilities of alternative vehicle fuel, he observed that the energy consumption has been increasing continually since urbanization. The global energy demand is continuously increasing due to the growth in global population and the rapid development of transportation, which is the highest consumer of world oil supply. About 70% of oil production is consumed in transport, it is also the second largest emitter of greenhouse gas. About 20% of CO_2 emissions are from the transportation sectors. Alternative energy solutions may shift energy consumption to low carbon fuel and this will lead to reduced pollutions and provide more energy diversity. The alternative fuel may be used in a dedicated system that burns a single fuel, or in a flexible fuel system designed for different class of blends of other fuel including traditional gasoline or diesel, such as in hybrid-electric or flexible fuel vehicles. Currently some vehicles and and production engines are designed for alternative fuel by the manufacturer. Others are converted to run on an alternative fuel by modifying the engine control unit and fueling system for optimal efficiency [9].

According to a study by Strumberger Nada, Bradvica Renata and Vlakic Sasa (2001) on LPG as automotive fuel in environmental protection, their study revealed that the use of LPG as propelling fuel is based on its physical and chemical properties which are more favourable compared to gasoline. In particular, the higher heating-energy content, high octane number, high latent heat of evaporation, and easy formation of homogeneous mixture are key advantages over gasoline fuel. They further stated that of all the fuel obtained by petroleum processing and in use today to power vehicles LPG is the most environmental friendly. The use of LPG helps to reduce acid rain, global warming and local air pollutions, thereby improving the quality of life. In addition it contains no lead, sulphur and particulates.

In many parts of Nigeria especially in the urban areas such as Lagos, Abuja, Kano, Ibadan, and Port Harcourt, air pollution is a major public health concerns. Several studies have examined the impact that alternative fuels, hybrids and battery electric propulsion have on the reduction of these harmful pollutants. The most common emissions are CO, NOx, UHC, and PM. But in recent time the CO_2 has been added due its contribution to the global warming effect. The CO emission is as a result of rich mixture and incomplete combustion due to lack of oxygen that would have completely oxidized the CO to CO_2, it is a poisonous gas because when inhaled in excess it builds up in the blood stream and thereby replacing the oxygen in the blood. Without oxygen or even lack of it, the cells throughout the body die, and the organs stop working, this has caused many deaths among Nigerian households using portable generators. The NOx and UHC can form ground level ozone, a principal component of smog. Alternative fuel engines have been found to produce fewer emissions and cleaner than conventional gasoline and diesel because they do not contain toxins such as benzene. LPG is an exceptional fuel that is readily available and the production cost is low.

A study carried out by Maciej Paczuski and Marcin Marchwiany (2016) on LPG as a Fuel for internal combustion engines showed that the costs or energy needed to produced gasoline and diesel fuel is far higher. LPG is rightly treated as an environmentally friendly fuel because of the low carbon properties and ecological benefits.

According to an experimental study carried out by Kaira Dheeraj, Babu Veeresh and Kumar Megavath (2014) on the effects of LPG on the performance and emission characteristics of SI engine. They concluded that the power output can be increased by advancing the ignition timing, employing an electronically controlled LPG injectors, and increasing the compression ratio. They also stated that advancing the ignition timing and increasing the compression ratio has an unfavorable effect on the NOx emission. In addition, they observed that the brake thermal efficiency increased with the LPG fuel.

One concern in considering alternative fuels is the performance and reliability of those systems using them. An experiment lead by Nagoro I H A, Eddy Suryono, and R D Prasetyo (2020) on the performance and emission characteristics of LPG in a spark-ignition engine, they observed that gasoline fueled engines attained better performance than LPG fueled engines. However, LPG fueled engines resulted in the lowest emissions benefit over a wide range of engine operating condition.

According to a country-by-country analysis carried out by the World Liquified Petroleum gas Association (WLPGA) in 2014 on Autogas Incentive Policies, engine life was claimed to be typically 50% longer as a result of reduced cylinder bore wear during cold starting, since LPG does not wash oil off the cylinder walls and the lubricating oil has a longer effective life due to almost complete absence of dilution. Combustion chamber and spark plug deposits are reduced, although spark plug life is not necessarily extended. The exhaust system durability is extended when operating solely on LPG fuel. Because LPG has a simple chemical composition, improved complete combustion occurs leading to lower CO and HC emission into the environment.

Adegoriola Adewale and Suleiman Ibrahim (2020), carried out an investigation on the adoption of gas automobile fuels (LPG and CNG) into the Nigerian transportation system. They observed from their studies that Nigeria with her abundant natural gas reserves can use the gas in place of the imported fuel in order to reduce expenses on imports. This is because the use of domestic natural gas as a vehicle fuel can have positive effects on economy and employment of the teaming youths. A data from Central Bank of Nigeria (CBN) revealed that from 2013 - 2017, the foreign exchange (FOREX) commitment to imports into the country stood at $119.409 billion. While the total FOREX committed to imports in the oil sector stood at $36.371 billion which is about 13.5% of all imports made by the country.

According to Macmillan Encyclopedia of Energy (2021), The first major government investment in an alternative fuel was for the purpose of energy security and oil import independence. Beginning in the late 1970s, billions of dollars were spent on synthetic fuels (converting coal and shale oil into gasoline and diesel). When oil prices began to fall in the early 1980s, and it became apparent that the costs of producing synthetic fuels would remain well above that of petroleum fuels, the program was abandoned.

In 2018 the World Liquefied Petroleum Gas Association (WLPGA) reported at least 136 new vehicle types from 45 car manufacturers producing vehicles with LPG fuel as their OEM products marketed in Europe, Asia, and the United States. The passenger car is the highest with 65.4% followed by trucks and buses with 12.5% and 4.4%. In Europe LPG are used in Light Duty Vehicles (LDV) that include passenger cars, vans, and wagons with engine capacities ranging between 0.9 to 2.5 liters. In Asia (South Korea, Japan, and India) the characteristics are similar to those in Europe except for Bajaj threewheelers with 0.2 liter. Meanwhile, in the United States, they are widely used as High Duty Vehicles (HDV) with engine capacities of 2.5 to 8.8 liters.

In addition, almost all the LPG vehicles in Europe are produced to use bi-fuel systems, while in Asia and the United States there are bi-fuel or mono LPG (fully-dedicated) options. A more sophisticated option is observed in Asia with Toyota JPN Taxi produced as a hybrid vehicle.

In the study carried out by Kivevele Thomas., Raja Thirunavukkarasu. Pirouzfar Vahid., Waluyo Budi and Setiyo, and Muji (2020) on Technology and Market Trend of LPG fueled vehicles. They concluded from their study that LPG vehicles were found to be growing in developing countries but tend to decline in developed ones.

The liquefied hydrocarbon gases, contain the mixture of C3-C4 hydrocarbons, and can serve as an alternative important source of energy for internal combustion engines. Currently on a global scale about 270 million tonnes of this fuel is produced, which the motor vehicle consumes about 26 million tonnes (~10%) [6].

NEED OF THE STUDY

In Nigeria currently few auto conversion centers are in operation in Benin, Lagos, and Abuja. However, there is little awareness and infrastructure supporting this mode of fuelled vehicle. But if the policy is properly implemented, the existing fuel stations can easily install the LPG infrastructure in their station. The key advantage of LPG as an alternative engine fuel is from the low investment cost for the production and low energy consumption are needed to produce high-quality by processing of natural gas or crude oil. LPG is produced as a byproduct in numerous petroleum refining processes, and the quality is similar to the conventional fuel, hence little or no modification to the engine fueling hardware requirements.

This experimental work is set to develop an understanding of the advantages of using LPG fuel over the conventional gasoline engines from the emission side and to produce a working document that will be shared to the policy makers especially the National Automotive Design and Development Council Nigeria so as to further accelerate the use of LPG as a fuel during this energy transition period. In addition, to further create citizen awareness platform on why it's better to retrofit gasoline fuelled internal combustion engines be it for domestic power-generating or vehicle propulsion. This analysis focused on the measurements and comparison of the exhaust gas emissions of CO, CO_2, NO and UHC under varying loads.
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EXPERIMENTAL SET UP

The engine used in this study is a single cylinder spark ignition (SI) four-stroke MAXI alternating current generator. The loading was done using halogen lamps and other loading devices. A Nanhua model NH4-506ENG 5 gas analyzer was connected to the engine exhaust to trap sample exhaust products so as to measure the UHC, NOx, CO, CO_2, and Lambda value. Pure gasoline was used as baseline fuel for this experiment, and the engine was retrofitted with dual fuel type carburetor that can use gasoline and LPG.. The reading from the Analyser was taken and recorded in every 5 minutes, and five readings were taken for each load and the average was taken. This process was also repeated using LPG as fuel, the engine specifications are listed in Table 1, and the engine set up in Figure 1. Table 2 is the experimental data for the gasoline fuel, and Table 3 is the LPG fuel data.

Table 1: Specification of the single cylinder generator used for the experiment

ITEM	SPECIFICATION
Engine type and model	Spark ignition SPE420E
Number of cylinder	1
Engine compression ratio	8.5:1
Engine displacement	459cc
Maximum output	16hp
Maximum start/run Watts	8.0/7.5KW
Method of loading	AC Generator with Load
Speed	3600rpm

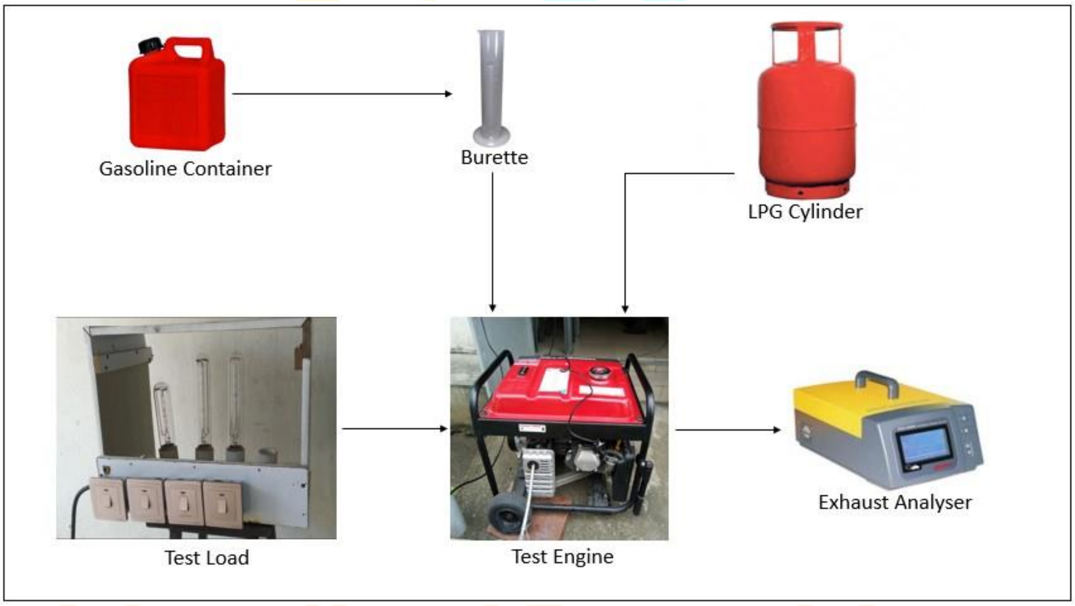

Figure 1: Experimental setup

Table 2: Experimental data for gasoline emissions

S/N	**Load (Watts)**	**HC (ppm)**	**NOx (ppm)**	**CO (%)**	**CO_2 (%)**	**O_2 (%)**	**λ (Lambda)**
1	60	0242	0008	03.74	02.33	14.44	2.094
2	200	0233	0006	04.05	02.35	14.08	1.980
3	1,000	0311	0007	05.31	02.39	13.14	1.640
4	2,400	0313	0009	05.37	02.41	13.09	1.620
5	3,200	0412	0010	05.71	02.84	10.11	1.610
6	4,600	0503	0013	07.08	03.44	19.36	1.160

Table 3: Experimental data for LPG emissions

S/N	**Load (Watts)**	**HC (ppm)**	**NOx (ppm)**	**CO (%)**	**CO_2 (%)**	**O_2 (%)**	**λ (Lambda)**
1	60	0127	0015	02.52	02.26	14.83	2.600
2	200	0122	0013	02.51	02.12	15.05	2.680

3	1,000	0130	0023	02.42	02.43	14.66	2.570
4	2,400	0154	0026	02.28	02.68	14.43	2.510
5	3,200	0216	0059	02.22	03.27	13.56	2.270
6	4,600	0207	0059	02.19	03.31	13.45	2.260

RESULTS AND DISCUSSION

EMISSION CHARACTERISTICS OF GASOLINE

Emissions of CO_2, CO, and O_2 in Percentages

The CO_2 is formed as a result of combustion in the engine and a sign of complete combustion, and CO is a product of incomplete combustion of fuel, the emission characteristics of gasoline fuel for CO, CO_2 and O_2 in Figure 2.

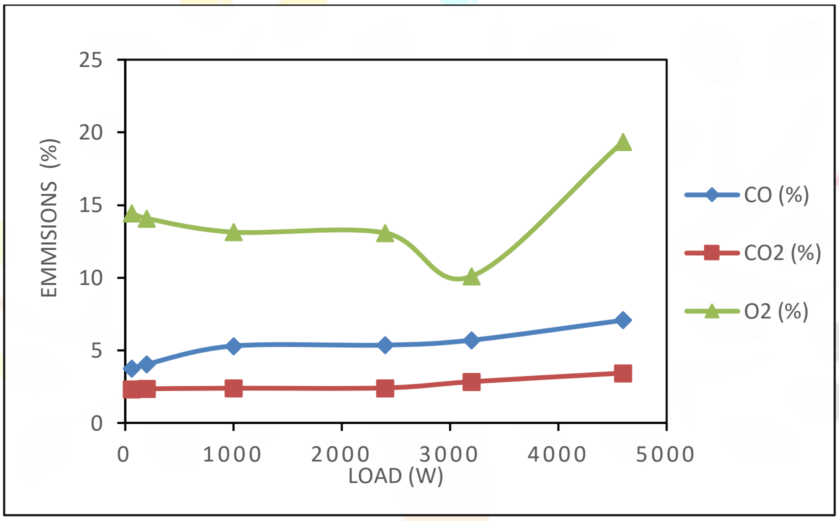

Figure 2: Effects of increasing load on CO_2, CO and O_2 emission using gasoline

From figure 2, it was observed that as the load increases the percentage of CO_2 was relatively constant within the range of 5% for all operating loads, but it starts to increase when the load reached 2,500Watts, this was likely as a result of increase in load and wider open throttle which may have lead to a reduced pumping losses, which resulted in an improved combuustion. The percentage of CO is within 2.5-7.5% in the emission, but there was steady increment as the load increases. This was due to the fact that as the load increases more fuel was added, but the increase was low.

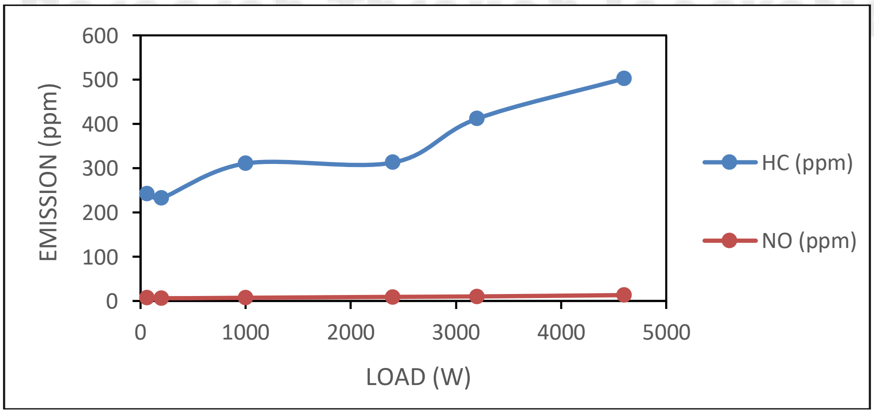

Figure 3: Effect of increasing load on UHC and NO_X emission using gasoline

From figure 3, the UHC emissions was seen to be increasing as the load increases, this may likely be due to increasing load with an increase in fuel addition. This may have resulted in increased fuel impingement on the piston crown and cylinder wall, and this is also common in carburetor engines, thereby leading to an increase in fuel consumption. But the formation of NOx was very low for all the operational loads applied. This may likely be due to the low temperature of combustion in this small engine and the maximum load used was just about 70% rated loading of the engine.

EMISSION CHARACTERISTICS OF LPG

Here the emissions resulting from the use of LPG for UHC, NO, CO and CO_2 as the load increases are shown and discussed.

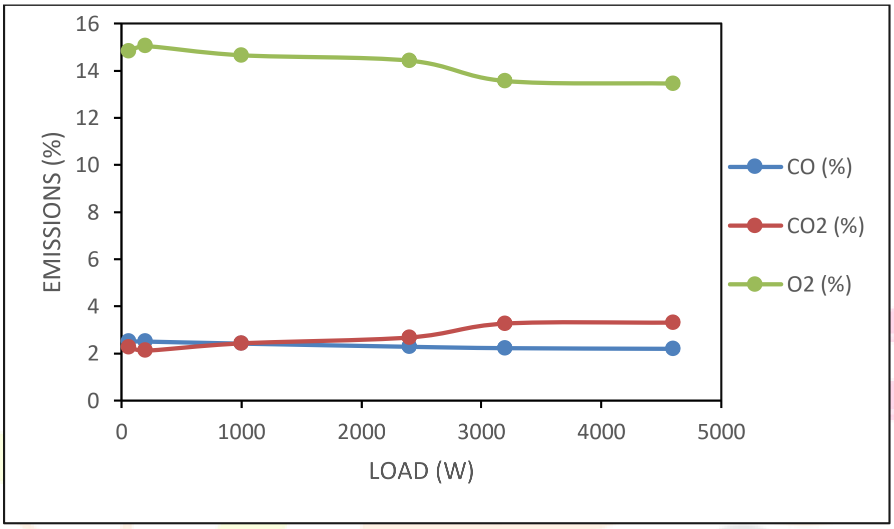

Figure 4: Effects of increasing load on CO, CO_2, and O_2 emissions using LPG

Figure 4 above shows the emission characteristics of LPG for CO and CO_2. As the load increases, the percentage of CO decreases, but the CO_2 emission increases but remains within 2% to 4%, this was likely due to the reduced carbon atom in LPG and the leaner mixture preparation of the LPG fuel as characterized by the value of lambda. In addition, the factors responsible for high formation rate of CO is reduced in using LPG.

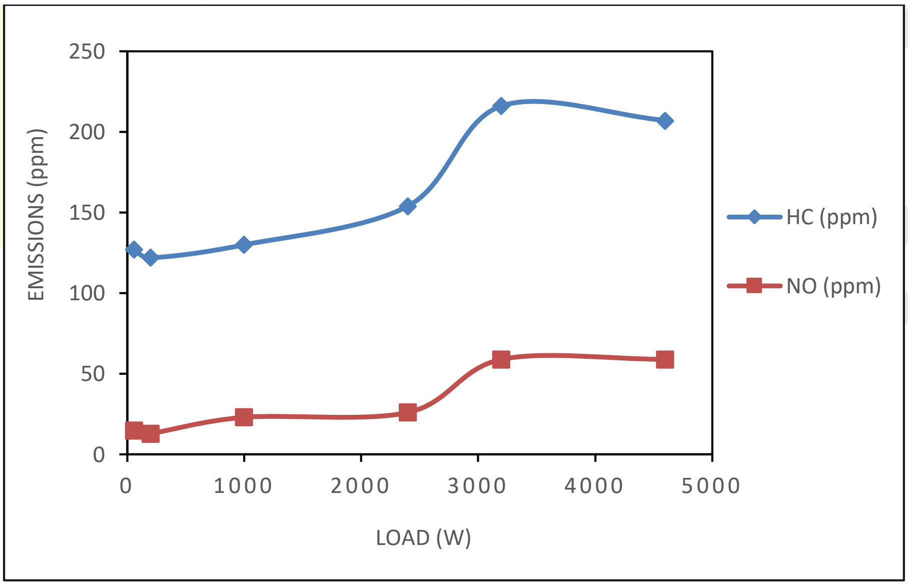

Figure 5: Effects of increasing load on UHC and NOx emissions using LPG

Figure 5 is the display of the emission of UHC and that of NOx. The two emissions shows similar trends, but that of UHC varies between 22 and 216ppm, and that of NOx varies between 13 and 59ppm. The increased in loads are the key factors to UHC and NOx emission increments.

COMPARISON OF EMISSIONS IN USING GASOLINE AND LPG FUEL

Unburnt hydeocarbon (UHC) Emissions

In Figure 6 there is an increase unburnt hydrocarbon emission with increase in load for both fuel. Unburnt hydrocarbon is also a product of incomplete combustion of fuel. The formation of hydrocarbon is due to lack of proper mixture preparation, and the type of fuel supply system be it carburetor, port fuel injector or direct injection system. However, it was observed that at low load the UHC emission of gasoline was 100% greater than for LPG and at high load this was about 200% greater than in LPG. This is in agreement with other literature and is also an evidence that using LPG is a better and environmental friendly compared to gasoline.

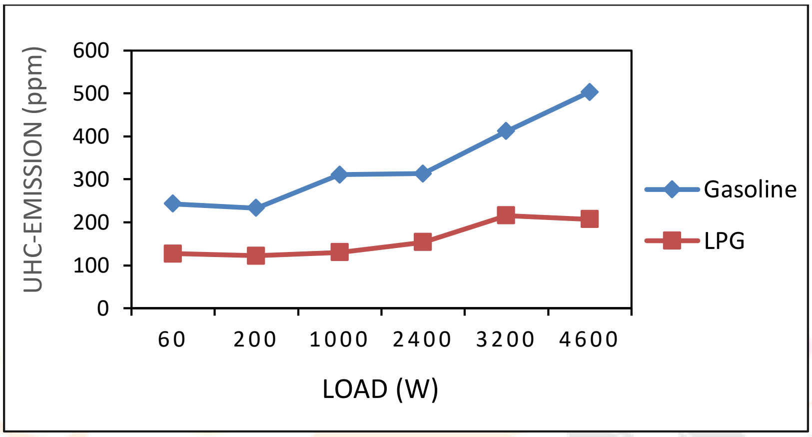

Figure 6: Effects of increasing load on HC emission using Gasoline and LPG

Nitric Oxide (NOx) Emissions

From Figure 7, it was observed that NOx emission increases with increase in load. Nitrogen oxides are generated from oxygen and nitrogen under high pressure and temperature conditions in the engine cylinder. NOx emission for LPG is higher than gasoline by up to 70%, and this is in agreement with some literature, but in some the NOx was higher for gasoline. Though in the experiment the values of lambda for LPG for all operational load was greater than 2.0 which was leaner compared to gasoline which was less than 2.0.

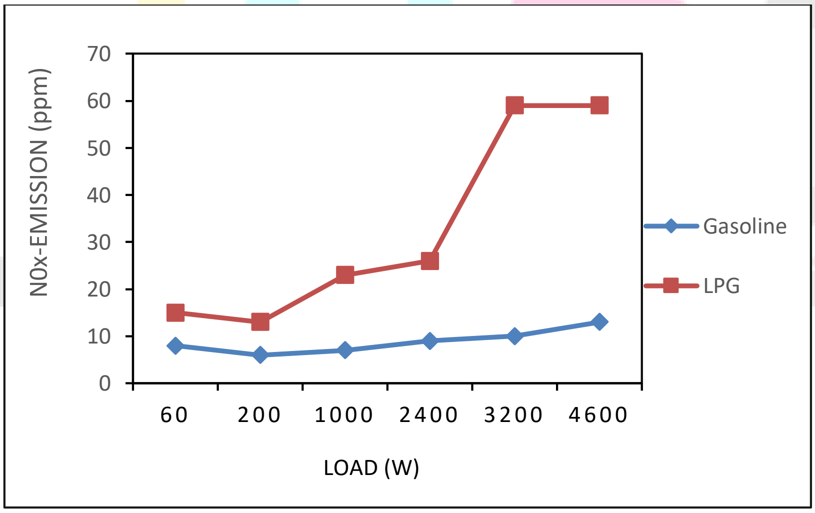

Figure 7: Effect of increasing load on NOx emission using Gasoline and LPG

Carbon Monoxide (CO) Emissions

Figure 8 is the display of the formation of carbon monoxide emissions from the engine. The CO emission is as a result of incomplete combustion of fuel, and it is higher for petrol compared with LPG, this can result from incylinder wall wetting, oil finding its way into the combustion chamber, and fuel impingement on the piston crown, and poor mixture preparation systems. The increment of CO at the lowest load was about 150% higher in gasoline than in LPG, and this increased to about 320% at highest load. This was likely due to increased amount of mixture admitted into the cylinder at highest load. It was also observed in figure 8, that as the CO emission keeps increasing for increasing load in using gasoline, that of LPG keeps decreasing.

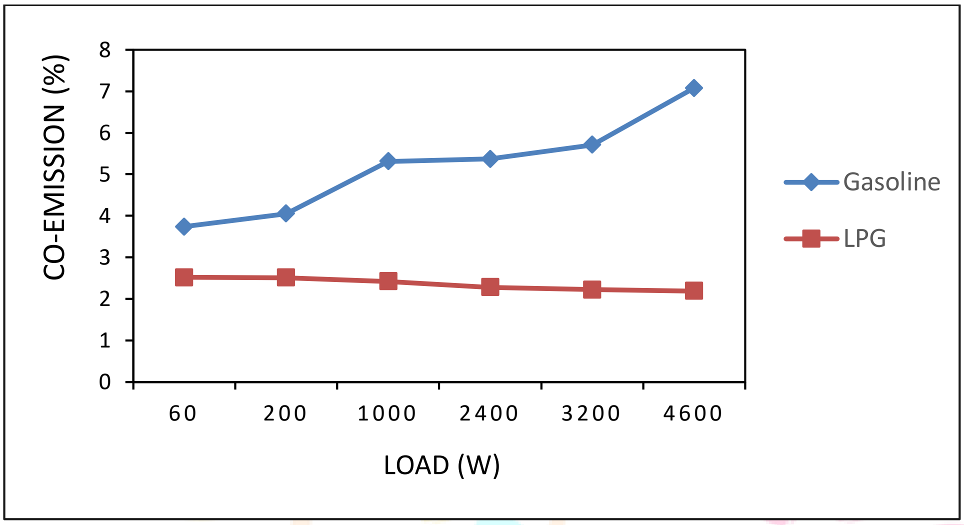

Figure 8: Effect of increasing load on CO emission using Gasoline and LPG

Carbon Dioxide (CO_2) Emissions

From figure 9, it was observed that CO_2 emission for both gasoline and LPG increases with increase in load, an increased in CO_2 is a sign better combustion processes. But the increasing CO_2 as the load increases is an indication that we had better combustion.

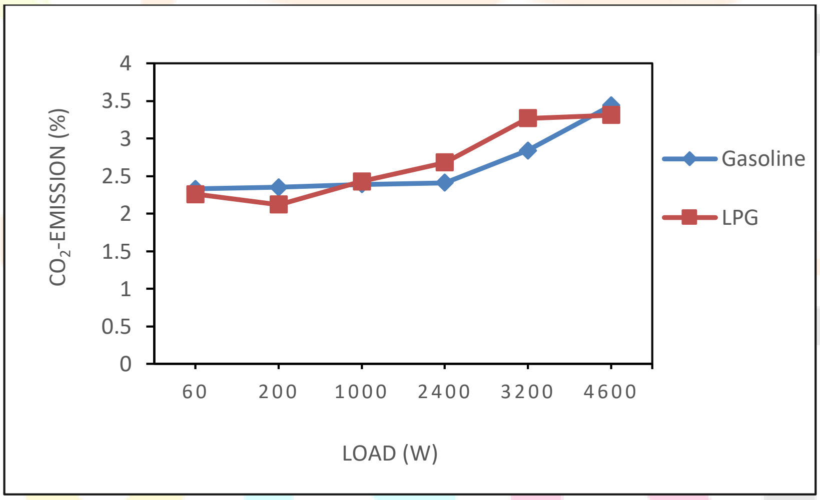

Figure 9: Effects of increasing load on CO_2 emission using Gasoline and LPG

Gasoline and LPG Fuel Mixture Comparison

One way of expressing the air/fuel ratio is by comparing the excessive air coefficient (lambda), which is the ratio of the total amount of air used in the combustion to the amount of stoichiometric air. The excess air controls the volume and the enthalpy of the energy of the working fluids, which are the determinant for the engine efficiency. As more excess air enters the combustion chamber, more of the fuel is burned until it finally reaches complete combustion.

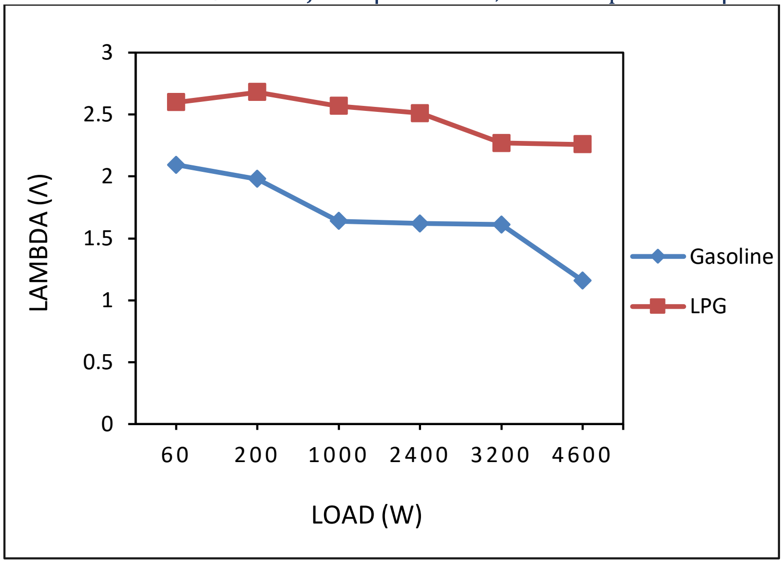

Figure 10: Effects of increasing load on Lambda using Gasoline and LPG

From Figure 10, the excessive air coefficient (Lambda) decreases with increase in engine load, and it is higher for the LPG fuel compared to gasoline. In all the engine operational load the LPG display a leaner mixture.

EFFECT OF LAMBDA ON EMISSIONS

Gasoline Emissions

Figure 11, shows the behavior of O_2, CO and CO_2 emissions as Lambda increases due to the variation in load.

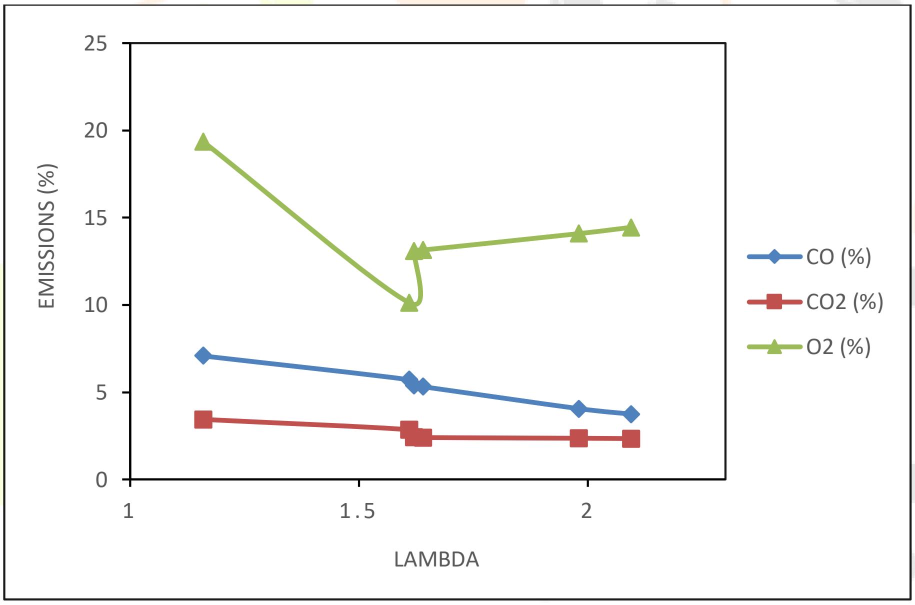

Figure 11: Effects of increasing Lambda on CO, CO_2 and O_2 emissions using Gasoline.

From figure 11, the values of O_2, CO_2 and CO decreases as lambda increases. However, as lambda increases above 1.6 the value of O_2 increases. The decreasing value is expected since as lambda increases the amount of injected fuel also reduces thereby leading to reduced CO and CO_2. However, making the mixture excessively ultra-lean can also lead to misfiring.

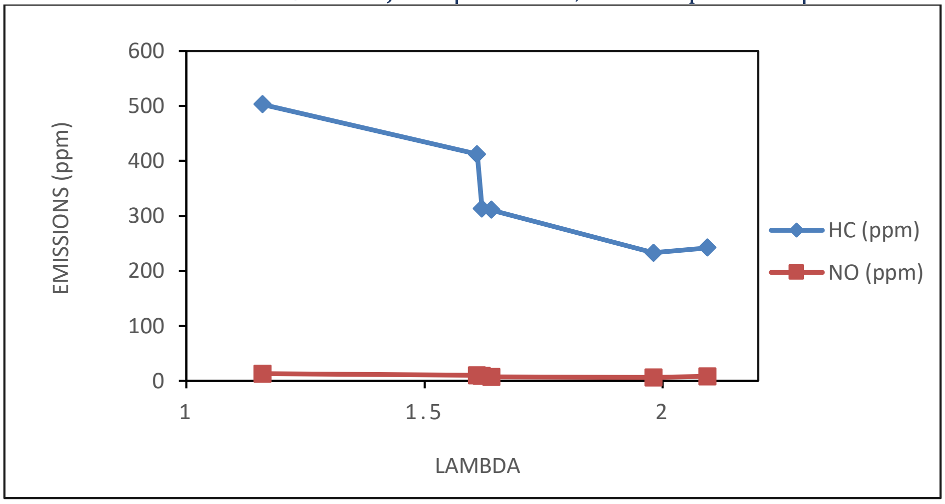

Figure 12: Effects of increasing Lambda on UHC and NOx emissions using Gasoline.

Figure 12 shows the display of UHC and NOx emissions as lamda increases. As indicated in the display UHC emissions was observed to decrease with increasing lambda and this is expected because as the mixture becomes leaner there is reduced amount of fuel contained in the mixture but NOx emission remains relatively constant with a value of 13ppm at lowest value of lambda and 8ppm at highest value of Lambda.

LPG Emission

Figure 13 for LPG fuel as the value of Lambda increases, the emitted CO_2 was observed to be decreasing, and that of CO was seen to be increasing. Hence, one key observation here was that as the value of O_2 was increasing for increasing Lambda, the CO_2 emissions was decreasing though in a small percentage, this may be an indication for the ultra-lean mixture in the LPG, characterized by reduced combustion efficiency compared to pure gasoline. In addition when the mixture is ultralean, it may lead to misfiring. This can further be confirmed by the observed increasing value of the CO emissions as lambda values increases, this indicates increase in incomplete combustion in the engine as the air to fuel ratio increases.

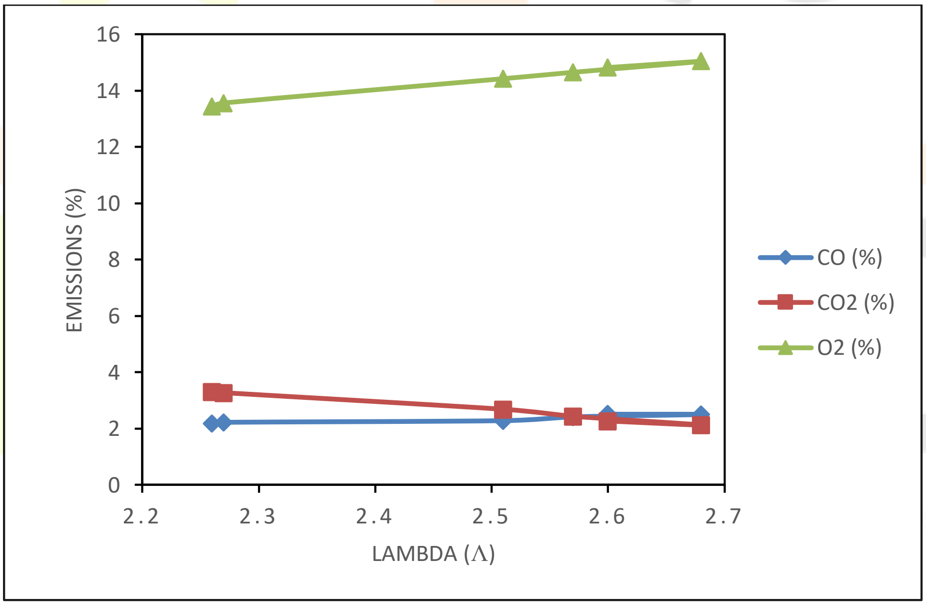

Figure 13: Effects of increasing Lambda on CO, CO_2 and O_2 emissions using LPG.

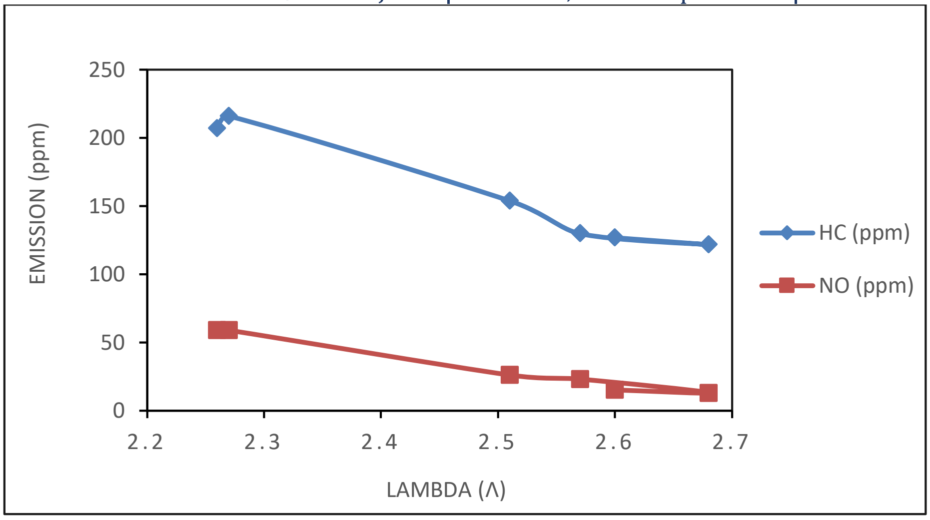

Figure 14: Effects of increasing Lambda on UHC and NOx using LPG.

Figure 14 show that both UHC and NO decreases as the air-fuel ratio increases and this implied that as that lean mixture lead to lower emissions of both gases.

Conclusion

In this study, performance of a single cylinder spark ignition engine fueled with LPG and gasoline was studied, and from the obtained results discussed we can conclude that the CO and UHC emissions for LPG are far less compared to that of gasoline. But the CO_2 emission for the two fuels are similar. The NO emission for LPG was higher than gasoline at all operating loads. The lambda values was leaner in LPG compared to gasoline which indicates a reduced fuel consumption in using LPG in all operating engine loads. In conclusion compared to gasoline, the LPG is a cleaner burning fuel, that can prolong engine life, and with the octane number of LPG over 100, means it eliminates knocking combustion that can damage the engine. Hence, the adoption of LPG is highly recommended because in overall it offers reduced Carbon emissions and reduces atmospheric green house gas pollutions compared to petrol in engines which contribute significantly to air pollution. The engine used for this experimental work was the carburetor type, there is need to further investigate this experiment with a standard engine test-bed coupled to dynamometer using port fuel injection and direct injection system. In addition, we recommend further investigation of this work using the positive valve overlap (PVO) SI combustion mode. This will involve modifying the existing engine valve timing for PVO configuration.

Acknowledgements

We would like to acknowledge the support of the **Royal Academy of Engineering UK** through the **HEPSSA Project** in procuring the research engine and the emission analyzer used in this project.

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