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Performance, emission and cost analysis of LPG and gasoline in a single cylinder engine

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ABSTRACT

An experimental investigation has been carried out on a single cylinder 4-stroke carburetor engine using gasoline and liquefied petroleum gas (LPG). As there is urgent need to diversify to sustainable and low carbon fuel for transportation and power generation across the globe due to the limited availability, non renewable, global and environmental impact of fossil fuel. In this transition stage there is need for energy vector for propulsion and power generation. This investigation provides a practical study in comparing the use of LPG and gasoline in terms of emissions and cost from a single cylinder production engine. This is necessary as we are now in energy transition stage, and all energy vectors must be investigated for suitability and sustainability as a replacement of high carbon fossil fuel. In this work we are focusing on making internal combustion engine (ICE) fuel to be zero emission compliance or ultra low-carbon. In the obtained test results, it was observed that LPG has a better fuel economy, cheaper, and more environmental friendly. The emissions of carbon dioxide (CO2), carbon monoxide (CO), unburnt hydrocarbon (UHC), and nitric oxide (NOx) in using LPG were about 50% lower than gasoline. In addition using LPG also leads to an improved engine service life and lubricants because there is no accumulation of carbon.

Key words: Internal Combustion Engine, Liquified Petroleum Gas, Gasoline, Emission.

INTRODUCTION

The availability, accessibility and sustainability of energy is an indicator of industrialization, economic expansion, and sustainable development. With an estimated eight billion people on the planet and ongoing population growth, energy demand is expected to increase. This is driven by the desire for quality lifestyle and to improve ourselves, ease of mobility, and satisfaction of energy demand in whatever form it is needed for use. In recent times, all efforts to match the rising population and poor economic situation with adequate energy supply have had negative environmental impacts because of the processes used in energy conversion such as the ICE, many of which are detrimental to the ecosystem. The growing environmental concern and limited and non sustainable fossil fuel reserve. The petroleum crisis had led many countries to source for more cleaner, efficient and cost effective alternative fuel for transportation and other uses. This had led the automotive industry, automotive research engineers, and others to urgently seek an alternative and sustainable propulsion fuel [1].

In gasoline engines the main emissions generated are nitrogen oxides (NOx), carbon monoxide (CO), unburnt hydrocarbons (UHC), carbon dioxide (CO2), 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 high temperature combustion in-cylinder. The only control of NOx is to minimize the incylinder combustion temperature through varying strategy 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].

There are other alternative fuels such as liquefied petroleum gas, hydrogen, ethanol, biodiesel, coal-derived liquid fuel, fuel derived from biological materials, and electricity. LPG is a mixture of several hydrocarbon compounds that are gases at standard room temperature and pressure, but can be liquefied under moderate pressure at atmospheric temperature. It has many properties that make it useful as a vehicle fuel, gaseous fuels in general are promising alternative fuels due to their economic costs, higher octane numbers, higher calorific values and lower polluting exhaust emissions. It is petroleum derived colorless gas, consisting of propane or butane or from mixtures of both. Propane is an odorless, nonpoisonous gas that has the lowest flammability range of all alternative fuels. LPG has the potential to help the reduction of harmful exhaust emissions from traffic in cities and other transportation sector. LPG has been recently used in automobiles on a widespread basis as alternative to gasoline because of its low cost, its effect on increasing the life of the engine and spark plugs, the longer interval between oil changes, and its cleanliness which are all due to its improved burning characteristic. Apart from LPG use in vehicle engines, it can also be used in stationary engines used for electrical power generation [3].

In many parts of Nigeria especially in the urban areas such as Lagos, air pollution is a major public health concerns [3]. 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 CO2 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 CO2, 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.

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 and in abundance, increased use of these fuels would reduce dependence on foreign energy sources and could benefit local economies [4].

The internal combustion engine has been around for over a hundred years and has undergone many changes and improvements. It can be in the form of 2- or 4-stroke, and this can be fuelled using gasoline or diesel. In addition, the fuel air mixture preparation can be a carburetor, port fuel injection, direct fuel injection, or even combined port and direct injection. There has been a tremendous achievement in improving the engine performances and emissions to control or reduce the harmful emissions through improved fuel quality, better atomization of fuel, use of exhaust gas recirculation (EGR), engine downsizing, advanced combustion and different combustion modes. In addition catalytic converter or exhaust aftertreament are also an enabling strategy for the emissions reduction [5]. Unfortunately the role of the catalytic converter needs to be looked into by automotive researchers as it also contributes to CO2 emissions during the cause of its exhaust gas treatment.

LPG utilization has soared in the previous decade and is in widespread use today. This may be in part due to its low investment cost, improved ignition attributes combined with moderately lower emissions. Higher octane properties, superior auto ignition temperatures, more prominent combustibility and faster flame propagation capacities in present LPG driven vehicles as a key enabler [6].

Łukasz Warguła et al [7], investigated the influence of the use of LPG fuel in woodchippers that was powered by small engines on exhaust emissions and operating cost. In their result they observed that the LPG fuelled engine was characterized by higher CO and NOx emission of 22% and 27%, the fuel consumption was also observed to decrease. However, they concluded that the positive impact of using LPG fuel was the reduction in CO2 and UHC emissions.

Aydin Mustapha et al [8], investigated the impact of diesel-LPG dual fuel on performance and emissions in a single cylinder diesel engine electric generator. Their investigation was to seek solution to increasing environmental concerns and the limited oil reserve, also because the diesel engine are more economical and can generate high power. The diesel engines dominate the light and heavy manufacturing industry power backup, agriculture, transportation, and electricity generation. Their mode of fuel admission into the engine was direct injection (DI), constant engine speed was maintained under varying loads. In their experiment, they observed that smoke density drastically reduced compared to pure diesel. In addition, the CO and UHC emissions also decreased, the brake specific fuel consumption was also observed to have decreased. However, their NOx was observed to increase while the efficiency increased slightly.

Ashish M. Ambaliya et al [9], carried out a review of compression ratio and spark timing on performance and emission of dedicated 4-stroke SI fuelled with LPG. They observed that due to the high octane number associated with LPG it can be run at higher compression ratio. They also noted that the UHC and CO emissions are lower for LPG when compared to gasoline fuelled engine. In their conclusion they showed that varying the compression ratio and spark timing will lead to improved performance and lower emission.

Giovani Vidal Tchato Yotchou et al [10], performed an experimental study on the effect of air and gas fuel ratio on the performances, emissions and combustion characteristics of diesel-LPG fuelled single stationary diesel engine. In their work using and engine of 3.5KW rated power at a constant speed of 1500rpm, they observed that the dual fuel mode gives better performances and reduced emission. In addition, they also reported an increase in the brake thermal efficiency, indicated thermal efficiency, and mechanical efficiency.

Murat Cetin [11], investigated the emission characteristics LPG-ethanol blend as a fuel in an SI engine. In his experiment a dual throat carburetor was used for mixing LPG and ethanol before being fed into the engine, he also applied the engine cooling water temperature to evaporate the ethanol before entering the carburetor using lambda 1.0. HE analyzed the exhaust gas emission for CO, CO2, NOx, HC, and O2 for the mixtures using different blends and varying the engine speed between 100 and 5000rpm. He observed that depending on the rate of ethanol increase in the mixture. The emission levels in the engine exhaust decreases.

Dheeraj kalra et al [12], they carried out investigation on the effects of LPG on the performance and emission characteristics of a spark ignition (SI) engine. In their work, they observed that the emission level of CO, HC, and CO2 were lower when using LPG fuel but the level of NOx was observed to be higher in LPG than in gasoline. They also observed that using LPG resulted in decrease in power output and volumetric efficiency compared to gasoline, but the specific fuel consumption for LPG was slightly higher than that of gasoline.

Thonas Kivevele et al [13], carried out a review on technology and market trend on LPG-fuelled vehicles. They discovered that LPG fuelled vehicles are increasing in number globally. In addition, countries like Turkey, Poland, India, Ukraine, and Mexico have the best LPG vehicle on average of 23%. But the early starters of LPG vehicle such as Australia, Japan, South Korea, UK, Netherlands, France, and Germany are experiencing drop in LPG vehicles, this may likely be due to shifting to hybrid and battery electric vehicle due to stringent legislation on emission standard.

Nagoro, I H A et al [14], they investigated the performance and emission characteristics of LPG in an SI engine, this was to enable them to understand the characteristic of LPG compared Pertamnina fuel and turbocharging in an SI engine. They use carburetor as the fuel delivery system controlled by Arduino Uno. They observed from their results that liquid fuel enhances engine performances than LPG. In addition, the result of HC, CO, and CO2 was lower in using LPG than using liquid fuel over a wide operating range.

Venkata Ramesh Mamilla et al [15], carried out an investigation on the performance and emission characteristics of 4-Stroke petrol engine fuelled with Biogas and LPG blends. In their results they observed that the emission values for CO, HC, and NOx are lower in biogas compared to LPG. They also observed that NOx increases for all loads used, but it was highest for gasoline.

Compared to gasoline, the emissions of vehicles fueled with LPG are significantly reduced. In general, the NOx and CO emissions of LPG-fueled vehicles are, respectively, 20% and 60% lower than those of gasoline-fueled vehicles. Besides, when combining the use of LPG and ethanol, the high oxygen content in ethanol improves the burning rate, promotes complete combustion, so the HC and CO emissions in the exhaust gas decrease significantly compared to gasoline fueling mode [16].

Kumar et al [17], evaluated the effect of engine load on the emissions of LPG, bioethanol, and gasoline in a single cylinder engine. Their results showed that at low engine loads, LPG had the lowest emissions of CO and HC, while bioethanol had the highest emissions of NOx. At high engine loads, the emissions of all three fuels increased, but LPG and bioethanol had lower emissions of CO and HC compared to gasoline.

Odjugo P A O [18], revealed that fossil fuel based emissions which caused climate change have led to a shift in crops cultivated in Northern Nigeria, the effect had lead to multiplier effect of banditry and plunged the zone further into poverty.

From all the literature examined some results showed an increase or decrease in either of the key emissions of CO, UHC, NOx and CO2. The result variation may likely be due to the source of the LPG and the engine operational conditions. But one thing is certain, attention is currently being focused on the use of LPG for the small size single cylinder engines that are used for various applications.

As a result of the reported challenges locally and globally, has made this investigation necessary for better understanding of the behavior of LPG fuel when used in an ICE to the Nigerian communities. It is significant in the sense that the fossil fuel powered engines still dominate the propulsion systems and the portable domestic power generators, and it will continue to dominate in the nearest future. It will provide a guide to the policy makers and to enlighten the public on the benefits of using alternative fuel such as LPG. This investigation reports the emissions and economic value of LPG as a fuel substitute in addition to the dominant use of LPG for cooking.

Lastly, as the Nigerian population continues to increase with increasing level of poverty and increasing unemployment rate. The automotive industry is one of the highest employers of labour in any nation, and Nigeria is not an exception Hence this work will also encourage the National Automotive Design and Development Council Nigeria to further rejuvenate its research and development of the internal combustion engine which had been suspended. Though the battery electric vehicle is the main focus now but in this energy transition period, we have to harvest all available technology be it old, current or emerging for the overall benefits of our citizens. Hence we need to look at low carbon fuel as well as biofuel as alternative transportation fuel.

This experiment on the domestic power generating set will be limited to varying the engine load using locally made loading system using halogen lamps of different power rating as the applied loads. The measured emissions will be limited to UHC, NOx, CO, and CO2, the particulate emission which is also an important emission is not being considered as the facility to measure it is not available..

II. Experimental set-up

A comparative and emission analysis test of gasoline and LPG was conducted on a 4-stroke 1-cylinder electric generator engine. The engine was modified to dual fuel carburetor that can use both gasoline and LPG. The experiments comprised of gas analyzer and a Maxi generator engine, the detail specification of the engine is given in Table 1, and Table 2 is the gaseous emission analyzer specifications. Table 3, is the fuel pysiochemical properties.

Table 1: General Specification of Test Engine

Model	75(M/K/KWH)
Displacement	459cc
Rated Frequency	50Hz
Rated RPM	3000rpm
Rated Voltage	230V
Rated Amperage	10.9A
Rated Power	7.5KW
Max Power	8.0KW
Full load continuum running time	6.0h
Exhaust gas analyzer	NH4-506EN Gas analyzer
Number of cylinder	1

Table 2: General specification of the Gas analyzer

Measured Quality	Measurement Range
CO	0… 10(*10^{-2}) %
CO_2	0… 18(*10^{-2}) %
O_2	0… 25(*10^{-2}) %
HC	0… 10000(*10^{-4}) ppm
NO	0… 5000(*10^{-4}) ppm
RPM	300rpm-8000rpm

A comparative analysis of gasoline and LPG was done from the obtained results for emissions and the specific fuel consumption calculated at different operational loads. The emission measurement was measured using the NH4-506EN Gas analyzer comprising of the instrument host, prefilters, sampling pipe, sampling probe. The sampling probe was connected and tested for leakage, then inserted into exhaust outlet, once the analyzer is heated up and ready for measurement after about 10 minutes in Figure 1. The engine was fuelled with gasoline first, on completion of the test period the fuel is then switched to LPG. The gaseous emission of UHC, CO, CO2 and NOx for each load tested was recorded. The amount of fuel consumed for the testing period was calculated. The load was varied from 560W, 1000W, 1313.6W, 2000W, 3000W, 3500W. This loading was selected because this is typical of the load range such engine are used for in Nigeria.

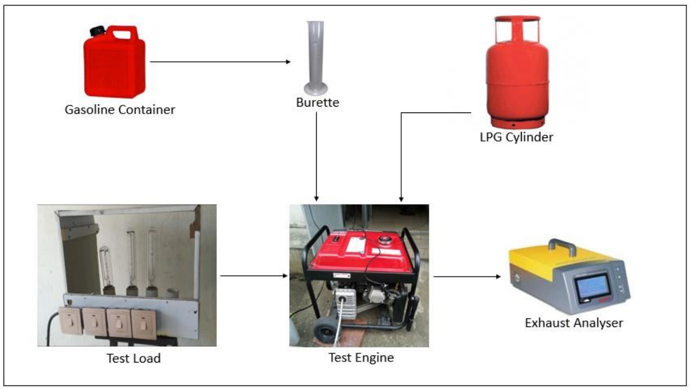


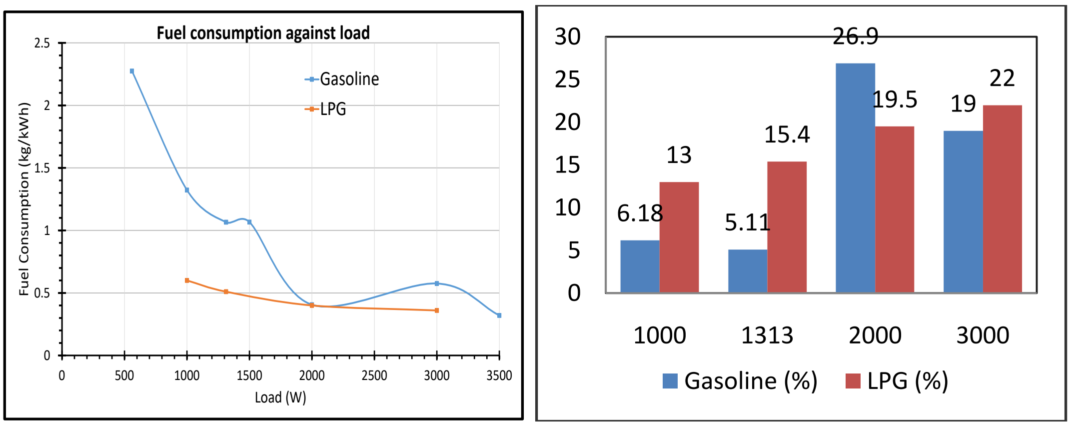
Figure 1: Experimental set up of the exhaust gas analyzer connected to the engine.

Table 3 A comparison between the Physiochemical Properties of Gasoline and LPG.

S/N.	Property	Gasoline	LPG
1	Chemical Formula	C_8H_8	C_3H_8/C_4H_{10}
2	Molecular Weight	114.2	44
3	Composition by weight - %	-	-
	Carbon	84.0	83.0
	Hydrogen	16.0	18.0
	Oxygen	Nil	Nil
4	Specific gravity at 15.5° C	0.7 to 0.75	0.55
5	Boiling point or range °C	30.0	-42 to -0.5
6	Latent heat of vapor Kcal/kg	70-100	380-420
7	Vapour Pressure at 58°C	0.8	3.1
8	Lower Calorific Value KJ/Kg	44000	46500
9	Mixing heating value Kcal/kg air	714	46000
10	Stoichiometric air/fuel ratio	14.17	15.4
11	Ignition limit	6.0 – 22.0	2.0-10.0
12	Self-ignition temp. °C	300-450	365-470
13	Research octane number (RON)	92-98	94-112
14	Motor octane number (MON)	80-90	89-98
15	Reid Vapour Pressure (RVP) (kPa)	61.4	nil
16	Enthalpy of vaporization (KJ/kg)	305	440-520

RESULTS AND DISCUSSIONS

Fuel consumption and Thermal Efficiency against Load

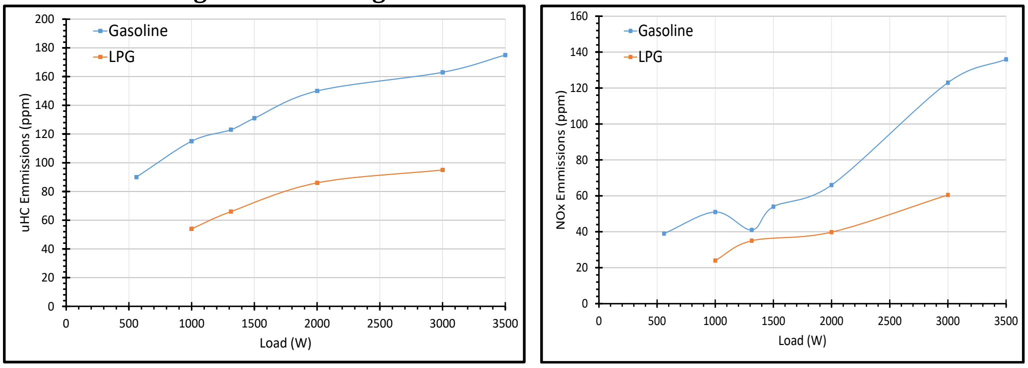


(a) (b)

Figure 2 Fuel Consumption and thermal efficiency against Load

From Figure 2a we observed that the fuel consumption for gasoline was more than that of LPG in all the engine loads. It is estimated that over the varied electrical loads, the total of 1.86kg of LPG was expended, however about 6.14kg of gasoline was used over the same amount of electric load. As the load increases the fuel consumption was seen to be decreasing with minimum values at the highest load. It can be said that at low load the throttle of the engine was partly opened, but at high load it was well opened. The higher fuel consumption was mainly due to pumping loss. It can be concluded that the best operational load is 3000Watts. Through this comparative data analysis from the obtained data, it is economical to use LPG rather than gasoline. From Figure 2b, it was observed that the thermal efficiency of the engine in using LPG was higher at loads of 1000W, 1313W and 3000W compared to gasoline, but at 2000W gasoline display a higher thermal efficiency compared to gasoline. But gasoline display the maximum value at 2000Watts and it start to decrease. Hence LPG will be a more suitable fuel on the overall average thermal efficiency.

UHC and NOx Emission against increasing load

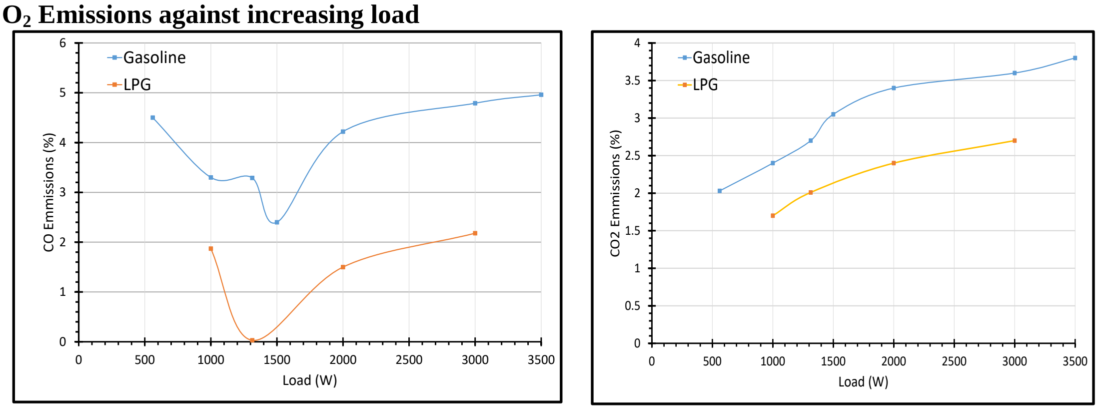


(a) **(b)**

Figure 3 UHC and NOx emissions with increasing load

Figure 3a shows that unburnt hydrocarbon increases with increasing loads for both Gasoline and LPG, it is seen that the emissions at the various point loads for gasoline was twice that of LPG and in Figure 3b shows that emissions of NOx varies with increasing loads for both Gasoline and LPG. The maximum emission for Gasoline occurred at 136ppm and 60.5ppm for LPG, which is about two times higher than that for LPG, the obtained results is agreement with some of the results in the literature. From the obtained results across all the engine loads LPG reduce the UHC by half, similar trend was also observed in NOx emission.

CO and CO_2 Emissions against increasing load



(a) (b)

Figure 4 CO and CO_2 emissions with varying load

The emissions of CO is shown in Figure 4a, the CO emission is usually as a result of rich mixture when there is not enough oxygen, and 50% of CO emission is due to reduced oxygen to oxidize CO to CO_2, incomplete combustion may also be responsible. But in all the operational loads the CO emission in gasoline was twice that of LPG. At low load in both LPG and gasoline, the CO emission was seen to be decreasing with minimum for LPG at 1300W and for gasoline at 1500W, but as the load increases beyond 1500W the emission of CO for both fuel continue to increase, this is likely due to the fact that at this load there was an increase in fuel admission to the engine. From Figure 4b, the CO_2 emission was observed to be increasing as load increases. The emission of CO_2 is usually an indication of how complete the combustion is, it is usually an indication of how well the engine is converting the fuel into useful energy. However, due to global warming it has now been classified as one of the culprit. In all the operational loads the emission of CO_2 was lower than that of gasoline and it is about two times lower.

Comparative cost analysis of gasoline and LPG

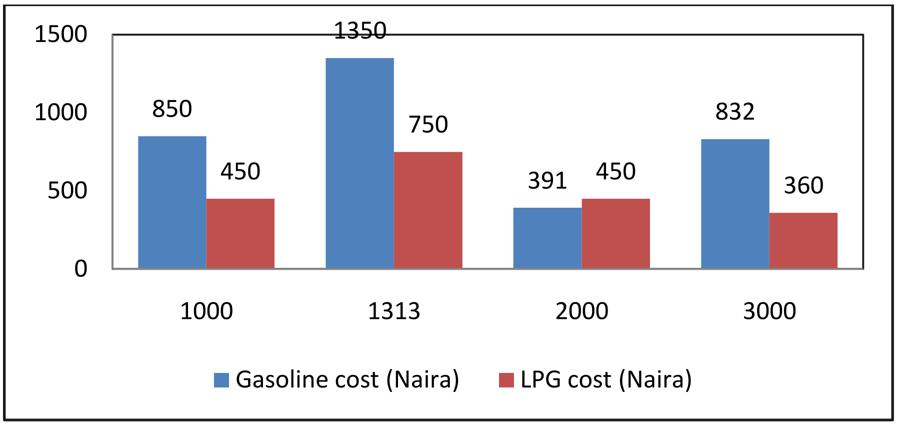


Figure 5: Comparison of cost of fuel against load

The result presented in Figure 5 indicates that LPG was more cost effective than gasoline under the same engine loads. Infact the price of gasoline was twice that of LPG, except at 2000W where gasoline fuel displayed a slightly higher fuel economy than LPG, this is also evident in the thermal efficiency. This cost benefit and the emission data will be a good strategy in enlightening the public about the advantages of using LPG instead of gasoline.

CONCLUSIONS

The comparative analysis of gasoline and LPG was carried out and the result analysis revealed that LPG as fuel in internal combustion engines resulted in improved emissions of CO, CO_2, UHC, NOx and fuel consumption when compared to the use of gasoline. From the experimental work, LPG reduced all the emissions by about 50% compared to gasoline, it will be a better replacement during this energy transition stage as a fuel for ICE, be it for 2- and 3-wheelers as well as in cars and buses especially where cost, efficiency and low emissions are critical as well as in hybrid vehicle and power generation. In the cost analysis the price of LPG was half of gasoline under the same loading conditions.. In recommendations, it is expected that this modification for generators to run on LPG can be improved on by using port fuel injection (PFI) or direct injection (DI). In addition, since Nigerian government has advocated for use of LPG due to rising cost of fuel and to mitigate global warming through use of low carbon fuel, there is also the need for the government to fund further research into using LPG and ethanol blend using port and direct injection to maximize the benefits of bifuel engine. This can also be extended to LPG and biodiesel using the same port and direct injection system. There is high possibility of further improvement in the engine fuel economy and emission reductions. Bioethanol is readily available in the Southern part of Nigeria and biodiesel is also readily available in the Northern part of Nigeria. There is urgent need to sensitize the general public on the advantages of using LPG fuel. Lastly a standard engine testbed with all the necessary data acquisition system is urgently needed for further advanced test for improved performances and emission studies.

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