

The Evaluation of Liquefied Petroleum Gas (LPG) Utilization as an Alternative Automobile Fuel in Nigeria

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Abstract

The utilization of liquefied petroleum gas (LPG) as an alternative automobile fuel in Nigeria was studied, focusing on varying different blend ratios of propane and butane as an alternative fuel in a single-cylinder, four-stroke, and spark ignition (SI) engine. Ricardo WAVE, 1-Dimensional engine simulator was used to model the internal combustion engine where the different blend ratios of propane and butane (P100, P90B10, P80B20, P70B30, P60B40 and P50B50) were tested and compared with a gasoline engine operating under same conditions. From the simulation results for the different LPG blends, there was no significant difference in the engine performance and emissions, but when compared with pure gasoline, it was observed that the LPG showed improved engine performance and lower emissions. The engine power output in using the blends was 25% higher compared to using gasoline; CO emission was 50% less, UHC was 20% less while NO_x at low speed was significantly lower.

Keywords

LPG, SI Engine, Emissions, Simulation

1. Introduction

Air pollution is fast becoming a serious issue nationwide and globally, with the increasing population and the associated increase in energy demand, the depleting fossil fuel reserve, and the increasing cost of imported refined petroleum products. Hence, there is an urgent need to find an alternative to conventional gasoline fuel to mitigate the listed challenges locally and globally.

Using alternative fuels in vehicles is a proven technology and has been in use in many developed countries. The current global energy demands are unsustainable and the situation is critical in the transport sector which is heavily dependent on crude oil, especially in Nigeria. A gap between the supply and demand of transportation fuels is being observed gradually and this can lead to a critical situation in the near future. As a result, urgent innovative action must be taken so as to bridge that gap. Currently, the global transportation system is undergoing transformation to zero emission vehicles. But fossil fuel based vehicle constitutes a greater percentage of registered vehicles globally, and this will continue in the near future.

The main alternatives currently being used as transport fuels are CNG, LPG, bio-fuels, hydrogen fuels and methanol. Despite the fact that CNG as a natural gas fuel has been certified suitable for use as automobile fuel, CNG requires high pressurization of up to 200 bar. This, however, presents automobile safety concerns, acquisition, and maintenance cost implications.

One of the fastest-growing natural gas derived fuels in Nigeria is liquefied petroleum gas as an alternative fuel because it can be liquefied in a low pressure range of 0.7 - 0.8 MPa at atmospheric conditions, it also has a higher heating value of 46,500 KJ/Kg compared to other fuels, but liquefied petroleum gas in Nigeria is basically utilized as cooking fuel, while its use as an automobile fuel is rarely discussed.

LPG applies widely to any mixture of propane and butane and it is a by-product of petroleum and natural gas. It can be obtained from two sources, the refining of petroleum and the extraction of natural gas. LPG obtained from the refining of petroleum is about 10% to 15% of the quantity of petroleum, while that from the extraction of natural gas amounts to 3% of the quantity of natural gas [1]. LPG consists of major gases such as; propane (C_3H_8) and butane (C_4H_{10}) with minor quantities of propene (C_3H_6), various butenes (C_4H_8), iso-butane (C_4H_{10}) and small amounts of ethane (C_2H_6). The composition in commercial quantities depends on a country's climate, in countries with colder climates, LPG has a higher proportion of propane and propene while in warmer countries, consists mostly of butane and butenes.

LPG occurs naturally in oil and gas reservoirs and it is gaseous at normal atmospheric conditions but can be liquefied by pressure alone. Components that are heavier than butane are liquids at atmospheric conditions and components lighter than propane cannot be liquefied without a refrigeration process. The composition of LPG used as an automotive fuel varies from almost pure propane to pure butane. LPG as a liquid is colorless, and in vapor form cannot be seen. Pure LPG has no smell, but for safety reasons an odoring agent, usually a mercaptan is added during manufacture to aid detection of gas at very low concentrations (Table 1).

LPG has the following main uses LPG is the most versatile fuel used in domestic applications such as cooking, central heating, space heating and hot water

Table 1. Typical properties of LPG [2].

Property	Propane	Butane
Liquid density	0.50 - 0.51	0.57 - 0.58
Conversion (ltr per ton)	1968	1732
Gas density/air	1.40 - 1.55	1.90 - 2.10
Boiling point (°C)	-45	-2
Lat heat vaporiz (KJ/Kg)	358	372
Spec heat cap (Btu/deg)	0.60	0.57
Sulfur content (%)	0 - 0.02	0 - 0.2
Cal value (Btu/ft ³)	2500	3270

supply as well as in a large number of home appliances.

LPG is increasingly being used as automobile fuel because it is a clean burning fuel compared to gasoline. The absence of sulfur and very low levels of nitrogen oxides (NO_x) and particulate emissions during its combustion makes LPG a most environmentally friendly source of energy. In industrial applications, it is used to power industrial ovens, and for various heating applications.

The potential benefits of using LPG in an SI engine are both economic and environmental. LPG has real future opportunities as a fuel due to the following; the NO_x, HC and CO emissions are lower; engine efficiency is increased due to higher octane number and compression ratio. According to Ambaliya *et al.* [3] LPG protects the particles filter and environment because it doesn't contain Sulphur.

Ngang and Abbe [4] investigated the performance and emission characteristics of a dual-fuel (diesel-LPG) engine by varying the mass fraction of LPG. Their study showed that at low load and part load operations, the performance of the diesel-LPG is poor, however, at high load, the power produced by the dual fuel engine is superior to that generated using pure diesel, the authors concluded that the output torque of diesel-LPG engine increases as the quantity of LPG fuel also increases.

Sulaiman *et al.* [5] experimentally analyzed the performance and characteristics of a single-cylinder SI engine using LPG and gasoline fuel. The fuel consumption was measured so that they can determine which fuel is more practical for SI. They observed that results show that using LPG reduced the specific fuel consumption (SFC) by 28.38% at a speed of 2600 rpm and this they indicated was due to LPG's higher energy content. In addition, their results also showed a 4% reduction in power output when using LPG, which they attributed to a low compression ratio thereby leading to losses in volumetric efficiency.

Wang *et al.* [6] conducted an experimental study on the emission characteristics of a single-cylinder spark ignition engine for a motorcycle using LPG which had a composition of 35.5% propane, 30.5% iso-butane and 34% I-butene. Their test results showed the effect of lambda, compression ratio and spark timing on

LPG combustion and emission characteristics.

Mustafa and Gitano-Briggs [7] conducted an experimental study on the performance and emission characteristics of a four-stroke SI engine using a blend of 60% propane and 40% butane and a compression ratio of 6.3:1. They performed the test using pure gasoline and blends of 5%, 10% and 20% LPG in gasoline. From their experimental results, they observed a drop in the engine power and torque output in using blends of 5%, 10% and 20% LPG in gasoline compared to the pure gasoline fueled engine. However, the brake-specific fuel consumption (BSFC) showed an improvement with LPG, and the concentration of CO, CO₂, UHC and NO_x recorded were found to be lower than the using pure gasoline.

Migdam *et al.* [8] investigated the use of CNG and LPG on a single-cylinder SI engine. The results from their study showed that the power output for CNG and LPG were lower compared to using pure gasoline with a compression ratio of 8:1. They also observe the power output to be similar to that of pure gasoline when the engine was operated at a higher compression ratio of 10.5:1 and 13:1 for LPG and CNG (Table 2).

2. Wave Simulation

Wave is an engineering code developed by Ricardo software [10] to analyze and predict the pressure waves, mass flows and energy losses associated with flow through pipes, plenums and components of inlet and exhaust systems. Wave provides a fully integrated treatment of time-dependent fluid dynamics and

Table 2. Energy content, GGE, DGE values of conventional and alternative fuels (Alternative Fuels Data Center (AFDC) fuel properties, 2017 [9]).

Fuel	Energy content	Quantity of Fuel in 1 GGE	Quantity of fuel in 1 DGE
Gasoline	114,000 Btu/gallon	1.00 gallon	1.11 gallon
Low Sulfur Diesel	128,448 Btu/gallon	0.90 gallon	1.00 gallon
Biodiesel (B20)	126,700 Btu/gallon	0.92 gallon	1.01 gallon
Biodiesel (B100)	119,550 Btu/gallon	0.97 gallon	1.07 gallon
CNG	923 Btu/cubic foot (ft ³) or 20,160 Btu/lb	125.77 ft ³ or 5.76 lb	139.21 ft ³ or 6.37 lb
Liquefied Natural Gas	21,240 Btu/lb	5.47 lb	6.05 lb
Ethanol (E100)	76,330 Btu/gallon	1.52 gallon	1.68 gallon
Ethanol (E85)	88,258 Btu/gallon	1.32 gallon	1.46 gallon
Electricity	3414 Btu/Kilowatt hour (kWh)	34.00 kWh	37.64 kWh
Propane	91,200 Btu/gallon	1.38 gallon	1.53 gallon
Hydrogen	288.88 Btu/ft ³ or 51,585 Btu/lb	401.86 ft ³ or 2.25 lb	444.78 ft ³ or 2.49 lb

thermodynamics by means of a one-dimensional finite-difference formulation, incorporating a general thermodynamic treatment of working fluids such as air, air-hydrocarbon mixtures, liquid fuels and combustion products [11]. Wave models a network of pipes, volumes and junctions in terms of a set of building blocks which includes the followings: constant area or conical pipes and ducts, passages with abrupt changes of area, junctions of multiple ducts, elbows, orifices and plenums.

The wave software also includes a library of mechanical components such as engine cylinders, fuel injectors, pistons, compressors, turbocharger compressors and turbines, pumps and catalytic converters. These components can be attached to a pipe network to serve as sources or absorbers of pulsating flows. It is an engineering code designed to analyze the dynamics of pressure waves, mass flows, energy losses in ducts, plenums and the manifolds of various systems and machines [12].

The basic operation of the WAVE code analyzes flow networks composed of ducts, junctions and orifices [12]. The method by which Wave produces a simulation of the flow through a duct system is to solve the compressible flow equations governing the conservation of mass, momentum and energy. The duct system is subdivided or discretized into a series of smaller volume. The quasi-one dimensional governing equations are then produced for each of these elementary volumes in a finite difference form. The equations for mass and energy are solved for each volume, and the momentum equation is solved for each boundary between volumes [11]. Once a simulation is completed, the post processing is performed, the WAVE post allows for a detailed analysis of the simulated engine operation [12].

WAVE models engine gas exchange processes within the engine by reducing the intake to a network of 1D ducts and junctions, the WAVE modeling method is done with respect to mass, energy and momentum conservation equations [13].

The main governing equations are as follows;

$$\text{Mass} = \frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} = 0 \quad (1)$$

$$\text{Energy} = \frac{\partial(\rho e T)}{\partial t} + \frac{\partial(\rho u e T + p u)}{\partial x} = \frac{\partial}{\partial x} \left(\frac{4}{3} \mu u \frac{\partial u}{\partial x} + k \frac{\partial T}{\partial x} \right) \quad (2)$$

$$\text{Momentum} = \frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2 + p)}{\partial x} = \frac{\partial}{\partial x} \left(\frac{4}{3} \mu \frac{\partial}{\partial x} \right) \quad (3)$$

Model Building and Validation

The engine model used for this study was validated using experimental results obtained from a Ricardo single-cylinder Electro-Hydraulic Valve Actuation Camless research engine, the model has been validated using RON95 fuel. The engine specifications used for the validation are shown in **Tables 3-5**.

Table 3. Engine data specification.

Specification	Value
Engine type	Single-cylinder EHVA Camless engine
Number of Cylinders	1
Bore (mm)	81.6
Stroke (mm)	66.8
Rod length (mm)	144.5
Compression Ratio	11.78
Fuel injection system	Direct Injection (DI)
Clearance height	2.0 mm

Table 4. Experimental data obtained from Ojapah *et al.* [14].

Testing condition	1500 rpm @ 3.5 bar IMEPnet
Start of injection (° ATDC)	422
Injection rate	0.06802
EVO (degCA)	160
EVC (degCA)	359
IVO (degCA)	360
IVC (degCA)	-161

Table 5. Model validation.

Output	Experimental results [15]	Simulation results	Relative error %
BMEP (bar)	1.97	1.90	3.5
IMEPnet (bar)	3.5	3.3	5.7
lambda	1.008	1.006	0.19
RGF_(5-5) %	8.6	7.5	
CA50_(8-10) ATDC	8.04	9.00	

3. Results and Discussions

The 1-D engine simulation model was carried out using an engine speed of 1000 rpm to 6500 rpm at 500 rpm intervals. The obtained results are shown and discussed.

Figure 1 shows the results of brake thermal efficiency measured against the engine speed. Efficiency is the measure of the performance and how the energy contained in the fuel is utilized for useful work. From the result, it was observed that at a speed of 1000 rpm the brake thermal efficiency of gasoline and the different blends of LPG were almost the same at 17.4% and 17.9% respectively, but as the engine speed increased to 6500 rpm, the brake thermal engine efficiency for RON95 fuel decreased by about 60%, while LPG decreased by 40% at 6500 rpm

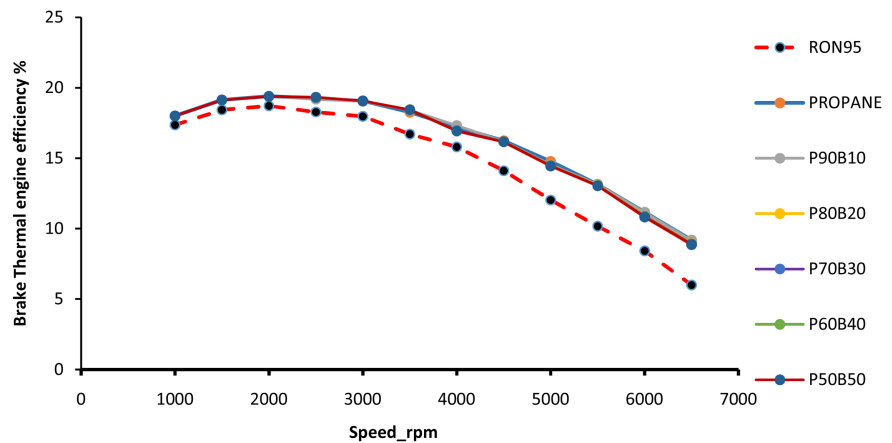


Figure 1. Effect of varying engine speed on brake thermal efficiency.

making it 20% better than conventional fuel. This result shows that LPG fuel is better because of its nature with higher calorific value, increase in air-fuel ratio, and better mixture preparation at high speed. This is an indication that when fueled with LPG [16], the engine can operate in leaner air-fuel conditions without loss of power even at higher engine speed.

Figure 2 shows a plot of brake-specific fuel consumption (BSFC) of the different fuel blends measured against the engine speed. The BSFC is the ratio of the engine fuel consumption to the engine brake power output, it is used to measure the efficiency or the economy of the fuel conversion in an internal combustion engine [5]. It was also observed that different blends of LPG are lower compared to gasoline, this is because the heating value of LPG (46.6 MJ/kg) is higher than gasoline (44 MJ/kg) another reason for this phenomenon is because LPG has a higher stoichiometric air/fuel ratio. The lower BSFC of LPG is an indication that LPG consumes less energy per unit of power produced compared to gasoline. The result also shows that as the speed increases so does the BSFC for all fuels, this is likely due to the reduced time for mixture preparation at higher engine speeds which is in agreement with the work of Pourkhesalian *et al.* [17].

Figure 3 shows the engine power measured against the engine speed. At low speed, the difference in engine power for both fuels is almost negligible with 1.9 kW for LPG and 1.6 kW for RON95 fuel, but at a speed of 6500 rpm, the different LPG blends increase by 20% higher than RON95.

Figure 4 shows the effect of speed on the engine torque. The result shows that the engine torque is inversely proportional to speed for all fuels but with the LPG blends having a torque output which is about 25% higher than the RON95 fuel for all the speed range, this is likely due to the higher octane number of the LPG fuel blend.

The NO_x emission characteristics as the speed increases are shown in **Figure 5**. From the plot, it was observed that as the engine speed increases from 1000 rpm to 4000 rpm, the emitted NO_x emission for RON95 fuel increases from 636 ppm to 3279 ppm, and was constant up to 4500 rpm speed, and decrease to

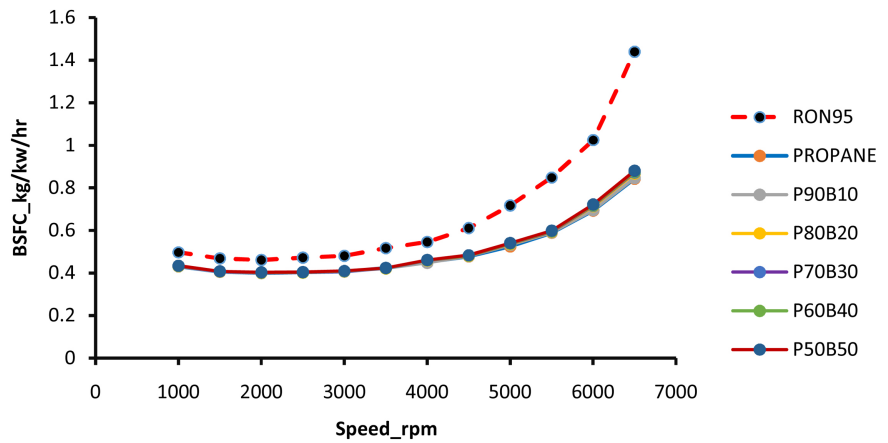


Figure 2. Effects of varying engine speed on brake-specific fuel consumption.

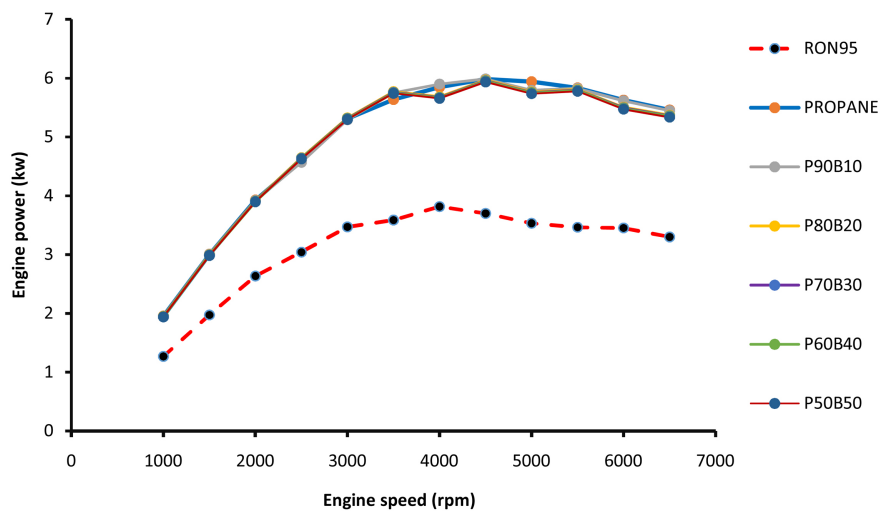


Figure 3. Effects of varying speed on engine power using different fuel blends.

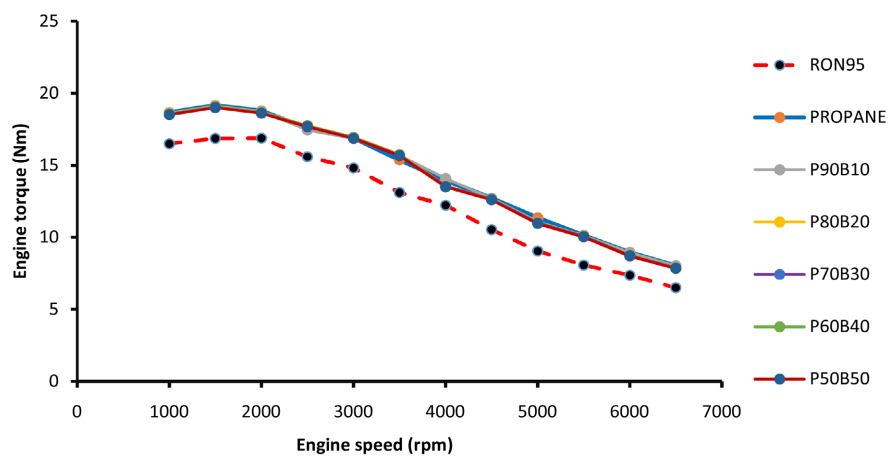


Figure 4. Effect of varying speed on engine torque.

1594 ppm at 5500 rpm. From the speed of 5500 rpm to 6500 rpm the NO_x increases to about 9204 ppm. For the LPG blends, the NO_x emissions were 347

ppm throughout the speed range. The formation of NO_x is facilitated with high combustion temperature and when spark timing is advanced. This unusual behavior in the emitted NO_x in using RON 95 may likely be due to the fixed spark timing used in the simulation, since in production and operational engine the spark timing is usually adjusted for optimum performance and emissions by the engine control unit (ECU).

Figure 6 shows the plot of UHC emissions measured against engine speed. It is observed from the graph that emissions from both fuels maintain a steady trend with increasing speed but with LPG emitting lesser UHC emissions, which was about 20% less than the RON95 fuel. The UHC is usually a result of incomplete combustion and piston wetting by the impinging fuel spray, the result clearly shows that the LPG fuel blend is a neater fuel compared to RON95 as propulsion fuel.

The behavior of CO emission as a result of increasing engine speed is shown in **Figure 7**, it was observed that the CO emissions for both fuels at low speeds of 1000 rpm and 2000 rpm were the same at 0.18 ppm, but as the engine speed increases, there is a rapid increase in emission for RON95 fuel, having an emission

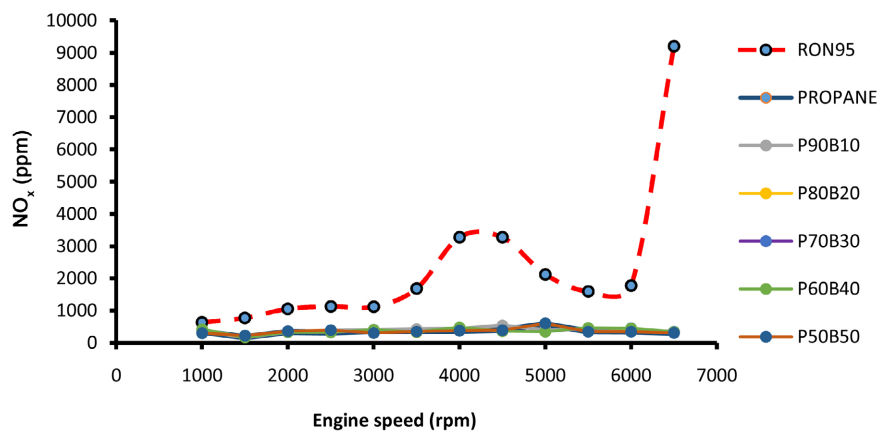


Figure 5. Effect of increasing engine speed on NO_x emission.

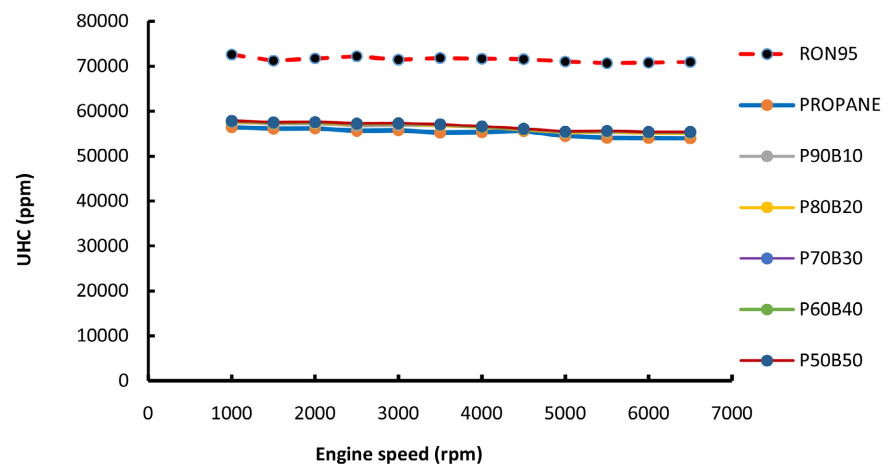


Figure 6. Effect of increasing engine speed on UHC emissions.

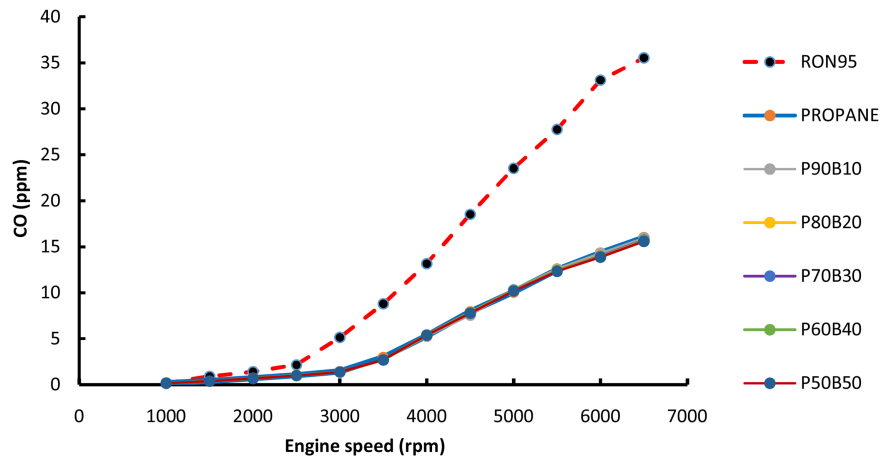


Figure 7. Effects of varying engine speed on CO emissions.

of 35.5 ppm at 6500 rpm compared to LPG having an emission of 15.9 ppm at 6500 rpm which is more than 50% less than the emissions from gasoline. The carbon monoxide CO emissions in gasoline fueled engine are results of incomplete combustion in the engine and this happens when proper air-fuel mixture is not achieved.

4. Conclusions

A state-of-the-art Ricardo single-cylinder electrohydraulic valve actuation (EHVA) camless engine with a compression ratio of 11.78 was used for the experiment that was used to validate the model built with the Ricardo WAVE. The model was validated using experimental data and results from Ojapah *et al.*, 2016 [14]. The performance and the emission characteristics of the simulated engine were studied when fueled with different blend ratios of LPG and compared with RON95 fuel. From the results, it was observed that there is no significant difference in the performance of the different blend ratios, but when compared with conventional gasoline with increasing speed, the LPG shows 20% improvement in the thermal efficiency of the engine. The brake-specific fuel consumption was lower for LPG. This was likely a result of LPG's higher heating value and higher stoichiometric air/fuel ratio. For the engine torque, LPG showed a 20% increase at high speeds while there was a 25% increase in power output for LPG at all speeds. The results also showed that emissions from LPG fuel blends were lower, with CO and UHC emissions being 20% and 50% lower compared to pure gasoline and this agreed with the literature. From the analysis, it is obvious that using LPG fuel will not only reduce the emissions associated with using pure gasoline but there will be savings in fuel cost. Many production engines currently in use in Nigeria can easily be modified to run on LPG with little additional cost. This alternative fuel will also serve as initial diversification from pure gasoline in compliance with global norms while we seek to develop local technology for future electric-powered vehicles. In addition, many of the three-wheelers and two-wheelers that dominate the local transportation in ur-

ban, peri-urban and rural communities can easily be converted to run on LPG. Lastly, the obtained results can be used to guide the policy-makers on the need and the advantages of retrofitting current vehicles to run on LPG fuel in Nigeria.

Further work on the possibility of using Dimethyl Ether (DME) on a spark ignition engine should be carried out to analyze the performance and emission characteristics of the engine when compared to LPG and RON95 fuels. It is highly suggested that there is a need for an experimental engine test bed set up to carry out this DME test experimentally.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Nilaj, D. and Nitesh, P.Y (2006) Investigation on Feasibility of LPG as a Fuel for Motorcycle. Rodriguez Institute of Technology, Mumbai.
- [2] Demirbas, A. (2002) Fuel Properties of Hydrogen, Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG) for Transportation. *Energy Sources*, **24**, 601-610. <https://doi.org/10.1080/00908312.2002.11877434>
- [3] Ambaliya, A.M., Patel, A.B. and Shaikh, M.A. (2014) Experimental Investigation on Effect of Compression Ratio and Spark Timing in Single Cylinder four Stroke C.I Engine Fuelled with LPG for Performance Enhancement. *International Journal for Scientific Research and Development*, **2**, 441-444.
- [4] Ngang, E.A. and Abbe, V.N. (2018) Experimental and Numerical Analysis of the Performance of a Diesel Engine Retrofitted to Use LPG as Secondary Fuel. *Applied Thermal Engineering*, **136**, 462-474. <https://doi.org/10.1016/j.applthermaleng.2018.03.022>
- [5] Sulaiman, M.Y., Ayob, M.R. and Meran, I. (2013) Performance of Single Cylinder Spark Ignition Fueled by LPG. *Procedia Engineering*, **53**, 579-585. <https://doi.org/10.1016/j.proeng.2013.02.074>
- [6] Li, L. Wang, Z., Deng, B., Han, Y. and Wang, H. (2002) Combustion and Emissions Characteristics of a Small Spark-Ignited LPG Engine. *International Spring Fuels and Lubricants Meeting and Exhibition*, Reno, Nevada. <https://doi.org/10.4271/2002-01-1738>
- [7] Mustafa, K.F. and Gitano-Briggs, H.W. (2009) Liquefied Petroleum Gas (LPG) as an Alternative Fuel in Spark Ignition Engine: Performance and Emission Characteristics. *Proceedings of ICEE 2009 3rd International Conference on Energy and Environment*, Malacca, 7-8 December 2009, 189-194. <https://doi.org/10.1109/ICEENVIRON.2009.5398647>
- [8] Chaichan, M.T., Kadhun, J.A. and Riza, K.S. (2016) Spark Ignition Engine Performance When Fueled with NG, LPG and Gasoline. *Saudi Journal of Engineering and Technology*, **1**, 105-116.
- [9] Ryskamp, R. (2017) Emissions and Performance of Liquefied Petroleum Gas as a Transportation Fuel: A Review. Center for Alternative Fuels, Engines and Emissions, West Virginia University.
- [10] <https://www.ricardo.com/en>
- [11] Giles, A.P. (2006) Alternative Fuels and Technology for Internal Combustion En-

- gines. PhD Thesis, University of Wales, Cardiff.
- [12] Cordon, D., Dean, C., Steciak, J. and Beyerlein, S. (2007) One-Dimensional Engine Modeling and Validation Using Ricardo WAVE. National Institute for Advanced Transportation Technology, University of Idaho.
- [13] Claywell, M., Horkheimer, D. and Stockburger, D. (2006) Investigation of Intake Concepts for a Formula SAE Four-Cylinder Engine Using 1D/3D (Ricardo WAVE-VECTIS) Coupled Modeling Techniques. *Motorsports Engineering Conference & Exposition*. <https://doi.org/10.4271/2006-01-3652>
- [14] Ojapah, M.M., Zhao, H. and Zhang, Y. (2016) Effects of Ethanol on Combustion and Emissions of a Gasoline Engine Operating with Different Combustion Modes. *International Journal of Engine Research*, **17**, 998-1011. <https://doi.org/10.1177/1468087416634517>
- [15] Ojapah, M.M. (2016) *Advanced Combustion Engines: Performance and Emissions*. LAP LAMBERT Academic Publishing, London.
- [16] LPG Installation Manual Version 1.2. <https://www.opwglobal.com/>
- [17] Pourkhesalian, A.M., Shamekhi, A.H. and Salimi, F. (2010) Alternative Fuel and Gasoline in an SI Engine: A Comparative Study of Performance and Emissions Characteristics. *Journal of Fuel*, **89**, 1056-1063. <https://doi.org/10.1016/j.fuel.2009.11.025>