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editorialsecretary.erjournal@gmail.com

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Emissions Characteristics of LPG Retrofitted Generator

Nwaokocha CN[1,*], Giwa SO[1,2], Kuye SI[3], Okezie SU[1], Adeala AA[4], Layeni AT[1], Nwaokocha JC[5], Kale SA[6]

[1] Department of Mechanical Engineering, Olabisi Onabanjo University, Ago-Iwoye, Nigeria.
[2]Department of Mechanical & Aeronautical Engineering, University of Pretoria, South Africa.
[3] Department of Mechanical Engineering, Federal Univ. of Agriculture, Abeokuta, Nigeria.
[4]Department of Mechanical Engineering, Vaal Univ. of Technology, Vanderbijlpark, South Africa
5Department of Environmental Technology, Federal Univ. of Technology, Owerri, Nigeria
[6]Department of Mechanical Engineering, Trinity College of Engineering and Research, Pune, India

***Author for Correspondence:** collinsnwaokocha@gmail.com

Abstract

Concern on air pollution continues to receive a great deal of global interest due to its negative impacts on human health and by extension the surroundings. Recent studies reported the important correlations between air pollution and certain diseases including asthma, breath distortion, sore throat, chest pain, nausea, bronchitis and lung cancer, acute health effects include eye irritation, headache. The World Health Organization (WHO) states that 2.4 million people die yearly from causes directly attributable to air pollution. Epidemiological studies suggest that more than 500,000 Americans also die yearly from cardiopulmonary disease linked to breathing fine particle air pollution. The objective of this study is focused on the emission analysis of different ratios of two fuels: LPG (propane) and gasoline (petrol) under different loadings. The components used in the research consist of a 4- stroke, spark ignition ELEPAQ generator, carbon-monoxide analyzer (CO meter), weighing balance and particulate matter (PM) meter which measures the particulate matter. The fuels, gasoline in litre (litres) and LPG in kilogram (kilogramme) were used to assess their impacts on the exhaust gas emission released. The results revealed that particle number concentration, carbon-monoxide (CO) increased as the engine loading increases in gasoline (fuel). Using LPG, the carbon monoxide (CO) concentration level was less, significant reduction in exhaust emissions, but high temperature in the environment than gasoline (petrol) on engine loading. The engine, while running with LPG fuel showed improved engine performance in terms of – fuel economy, overall efficiency and significantly better exhaust emission characteristics, compared to that of gasoline.

Keywords: *Emission, Pollution, Generator, LPG, Gasoline.*

INTRODUCTION

The need for electricity as the most used and desired form of energy has led households in Sub-Sahara Africa to the use of generators. Nigeria, a prominent country in the Sub-Sahara Africa region is yet to fully resolve her energy issues. The use of generators in households provides electrical power for domestic use such as air-conditioning, entertainment gadgets, kitchen appliances, navigation systems, communications equipment etc. The generators are similar in size compared to the engines used on small automobiles. Nearly 75% of households use generators. Emissions from Internal Combustion Engines (ICE) are poisonous gases such as CO_2, CO, O_3, SO_X, NO_X and particulate matters ($PM_{2.5}$ and PM_{10}). Particulate Matter (PM) originates from various sources, like transportation emissions, industrial emissions, forest fires, cigarette smoke, volcanic ash and climate variations. In summary, every combustion process produces particulate matter, CO_2, CO, SO_X, NO_X, etc. and various combustion processes vary in their emission more than others. For example, the use of coal as fuel in power plants create great amounts of particulate matter than wood burning in households (Dunn et al. 2001; Yücesu et al. 2006; Alberto et al. 2007; Koç et al. 2009; Giwa et al. 2016; Nwaokocha et al. 2016a; 2016b).

Generally, generators are mostly powered by gasoline, a derivative of fossil fuels. Most of these engines have fuels been burnt inside the combustion chamber. The fuels get burnt to produce heat energy which leads to increasing the pressure in the engine. The pressure expands and turns the crankshaft thus producing mechanical energy which is later converted to electrical energy. The flue gas from combustion of fossil fuels is discharged to the air.

These gases contain carbon dioxide, carbon mono-oxide, nitrogen oxides, sulphur oxides, water vapor, particulate matters and other traces of other metals. These gases contribute greatly to global warming. The emissions of pollutants depend not only on fuel type, but also on the type of generators and the quality and quantity of fuel consumed. However, the level of SO_2 emissions released is directly proportional to the sulfur content in the fuel, and the quantity of fuel consumed. CO gas is a lethal poison produced as a result of burning fuels such as gasoline or propane. It is one of the chemicals found in engine exhaust, formed as a result of incomplete combustion. These gases cause the depletion of ozone layers which leads to global warming. The effect of global warming is felt both by animals and man (NIOSH, 1979; NIOSH, 2000; Al-Hasan, 2003; Giwa et al. 2016; Nwaokocha and Okezie, 2016; Nwaokocha et al. 2016b).

Worldwide, air pollution contributes a portion of 6.7% of all deaths. CO is a colourless, odourless and tasteless gas, which makes it possible to affect the exposed person without warning. The initial symptoms of CO poisoning include headache, dizziness, drowsiness or nausea, etc. Secondary symptoms include vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Exposure to CO affects the ability of the blood to carry oxygen to the tissues by binding with the heamoglobin to form carboxyheamoglobin (COHb). Blood has a higher estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body. If the exposure level is unchecked, loss of consciousness is imminent. Coma or death could also occur if high exposures continue. The display of symptoms varies widely from people to people, and may occur sooner in susceptible individuals such as young or aged people, people with pre-existing lung or heart disease, or those living at high altitudes locations (NIOSH, 2000; Alberto et al. 2007; Koç et al. 2009; Giwa et al. 2017a, 2017b).

High release of CO_2 into the atmosphere constitutes major health issues to the human body, which includes respiratory diseases (such as coughs, phlegm, tightness of the chest, wheezing, distortion of breath), cardiovascular effects (such as chest pain, palpitations, unusual fatigue, coronary artery diseases, abnormal heart rhythms, congestive heart failure), increased sickness and premature death (from asthma, acute or chronic bronchitis, emphysema, pneumonia) and development of new diseases (chronic bronchitis and early aging of the lungs) (Earnest, 1997; NIOSH, 2000; Giwa et al. 2016, 2017b). The other emissions include the noise level in the environment, the sulphur oxides, and other trace metals.

Most fine particulates matter are as a result of fuel combustion, both from mobile transport sources such as small vehicles, heavy-duty vehicles, tricycles, motorcycles, also from stationary sources such as power plants, heavy-duty machinery, factories, households or burning of biomass. Particulate matter pollution is an environmental health hazard that affects people worldwide, both low-and middle income countries disproportionately experience this hazard. This is what initiated the use of LPG as substitute fuel for internal combustion engines. The advantages of LPG over fossil fuels are so numerous, viz; the clean burning of LPG makes the CO_2 emission to be low (this is because it has high cetane rating than petrol and diesel), it has minimal sulphur content which makes it to be an environmental friendly fuel, it has a high thermal efficiency, it produces no soot when burnt which makes the generator to have longer life (require less maintenance), it has high heating value which makes it versatile and lastly, the carbon content in LPG is low compared to fossil fuels. The high octane rating (about 104) allows it to mix with air properly (Al-Hasan, 2003; Yücesu, 2006; Koç et al. 2009; Giwa et al. 2016; Nwaokocha et al. 2016).

The normal operation of internal combustion engines results in the emission of hydrocarbons, CO, CO_2, O_3, NOx, SOx, and Particulate Maters ($PM_{2.5}$ and PM_{10}). The actual concentration of these criteria pollutants differs from engine to engine, mode of operation, and is strongly related to the type of fuel used per time. The vast majority of generator engines used around the world normally rely on two stroke internal combustion engines. The internal combustion engines contain a reciprocating piston within a cylinder, two classes of valves (intake and exhaust), and a spark plug in the case of a SI engine. Diesel engines do not use a spark plug.

Emissions depend both on the engine operating parameters (e.g. engine temperature, speed, load, air-fuel ratio and spark timing) and the fuel type. These emissions result from complex processes which involves interactions between the fuel and engine parameters. Emission comprises of volatile organic compounds (VOCs), CO, NO_x, and PM (Wallington et al. 2006; Wang et al. 2011). VOCs and NO_x form photochemical smog in urban atmospheres; CO, CO_2 and PM may have adverse health impacts. Engine constituents and its operating conditions, after-treatment catalysts and fuel composition all determine the amount and composition of emissions leaving the generator exhaust port per time. While engine and its after treatment effects are generally larger than fuel effects, engine and after-treatment hardware may require specific fuel properties. Consequently, the best method for achieving the highest efficiency and lowest emissions lie with optimizing the entire fuel engine configuration after treatment system (Kaiser, 2000; Yücesu, 2006; Koç, 2009; Giwa et al. 2017b).

Some pollutants are released untreated directly into the atmosphere, while some pollutants are formed in the air. Ground-level ozone forms when emissions of NO_x and VOCs react in the presence of sunlight. Similarly, some particles are formed from other directly emitted pollutants. For example, sulphate particles are formed from complex reactions in the atmosphere with SO_2 emissions from power plants and industrial work facilities. PM is a complex mixture of extremely small particles and liquid droplets. These small particles are made up of a number of components that include: acids, such as nitrates and sulphates, as well as organic chemicals, metals and dust particles from the soil (Wallington et al. 2006; Wang et al. 2011; EPA, 2012). Summary detail is in Table 1. Many strategies to reduce these emissions have been experimented by different researchers. This paper assessed the use of liquefied petroleum gas to power the generator, thus replacing the use of gasoline or diesel.

MATERIALS AND METHODS

Materials and Equipment

The materials needed for this research includes measuring instruments such as CO meter (CEM CO-180), CO_2 meter (TIM10), PM meter (TES-5321), and other materials such as electric cable, junction box, writing pad, stopwatch and source of power (retrofitted generator – which could use LPG and gasoline as fuel).

Study Setting

The study was conducted in the Mechanical Engineering Laboratory of the Olabisi Onabanjo University, College of Engineering and Environmental Studies, Ibogun Campus, Ifo, Ifo Local Government Area (LGA), Ogun State. Ogun State is bounded in the west by Benin Republic and in the south by Lagos State. It occupies a total area of 1,400 km^2. The climate of the study area follows a tropical pattern with the rainy season. The selection of the study area is informed by the alarming rate of urbanization of Ifo and its proximity to Lagos metropolis, which will help to obtain the applicable scenario for this study in terms of ambient air quality, population, generator usage, etc.

Experimental Setup

The experimental set-up for this work consisted of the following main features:

ELEPAQ generator set: This is a single cylinder, 4-stroke, SI engine. A number of electric devices were used as variable electric loads (e.g 100 Watt bulbs, 60 W laptops, etc). Although the engine was designed to run on petrol, it was re-adapted to also run on supply of LPG. It was desired to run the engine on LPG with minimum modification, while retaining the capability of switching back to its gasoline fueling system easily. For this modification in the air intake structure, it entails incorporating an external mixing chamber which was designed. A measuring scale was used to measure the LPG when the generator was been run on LPG, to know the total mass of LPG burnt. The supply cylinder was fitted with a regulator valve. A meter rule was used in measuring the distance of the exhaust port to the measuring equipment so as to allow an equal distance. The pollutants CO_2, CO and $PM_{2.5}$ were carefully selected based on their degree of concern and impact on the environment and public health. The concentrations of CO_2, CO and $PM_{2.5}$ released from the generator (when ran on gasoline or LPG) were determined using CO_2, CO and $PM_{2.5}$ meters, respectively. The distance was kept at 1 meter throughout the experiment. The purpose was to ensure good contact between the meters and the exhaust of the generator. While measuring the concentration of the pollutants released via the exhaust pipe, readings were taken every 10 minutes for 1 hour. Precautions taken were to avoid taking readings where possible emission interference was observed and the use of nose mask to prevent inhalation of the exhaust while taking the measurement.

Table 1. Types of Pollutions from ICEs and their Effects

Pollutants	**Effects**
Suspended Particulate Matter (SPM)	It has ability of penetrating deep into lungs and blood streams unfiltered, causing permanent mutations, heart attack and premature death.
Sulphur dioxide (So_2)	High concentration of sulphur dioxide can result in breathing problems, wheezing, chest tightness and cardiovascular disease. It results in acid rain.
Oxides of Nitrogen (NO, No_2, Nox)	It combines with sulphur and O_3. It causes irritation of lungs and increase susceptibility of respiratory infections. It also causes ozone depletion.
Carbon monoxide (CO)	Inhaling of this poisonous gas causes severe illness or death in just minutes.
Carbon dioxide Co_2	Leads to global warming which has effect on food production, forest, fresh water supplies, etc.

Data Processing and Analysis

Measurements of the concentration of the pollutants was collated and analyzed during the study. The mean of the concentrations of pollutants was also estimated and garnered together with appropriate operating parameters. Statistical analyses were carried out using Microsoft Excel 2013. The results obtained from the study were compared with the ambient air quality standards (World Health Organization [WHO] and American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE]), so as to ascertain relevant standards.

RESULTS AND DISCUSSION

Carbon monoxide (CO) in Generator Exhaust Gas

The experiments is conducted using the two sample fuels: LPG and gasoline - on varying loads of 0 w, 180 W, 300 W, 600 W and 800 W – to assess the level of CO emission released as compared to ASHRAE and WHO standards. Figure 1 explains the CO data collected from the study and presents the mean CO emission from LPG and gasoline fuel. It is deduced from Figure 1, that the volume of CO in the exhaust from LPG and gasoline differs. The maximum mean value of CO is 87.8 ppm and 158.7 ppm for LPG and gasoline respectively, while the minimum value is 38 ppm and 95.4 ppm for LPG and gasoline respectively. It's of note that the estimated mean concentration of CO obtained in this work for both LPG and gasoline is significantly higher than 9 ppm which is recommended by ASHRAE (IAQ, 2013) and 10 ppm as stipulated by WHO (2014). The CO from LPG is lesser in concentration as compared to that of gasoline. This is because the LPG has a good mix with air intake and the combustion is more complete compared to that of gasoline. Also, the lower Carbon content of LPG also defined the reduction in the CO released when LPG was burnt. Figure 1 shows that at 300 W, the behaviour of the two graphs contrast each other.

Particulate Matter ($PM_{2.5}$) in Generator Exhaust Gas

The experiments is conducted using the two sample fuels: LPG and gasoline - on varying loads of 0 w, 180 W, 300 W, 600 W and 800 W – to assess the level of $PM_{2.5}$ emission released as compared to ASHRAE and WHO standards. The Particulate Matter $PM_{2.5}$ data collated from the study is presented in Figure 2. In the study, the highest concentrations of $PM_{2.5}$ are 50.7 μg/m^3 and 52.5 μg/m^3 for LPG and gasoline respectively. While the lowest concentrations of $PM_{2.5}$ are 36 μg/m^3 and 36.8 μg/m^3 for LPG and gasoline respectively. These values of $PM_{2.5}$ is considerably higher than the value of 25 μg/m^3 prescribed by WHO for 24 hours exposure (WHO, 2014). The effect of this is that the exposure to the fume emitted from the generator when ran on both fuels is unsafe as $PM_{2.5}$ can penetrate deep into the lungs and blood streams, thus damaging the body system (UNEP, 2014). The PM from the LPG is slightly lower compared to that of gasoline. This is also due to lower carbon content of LPG and the cleanliness of the fuel.

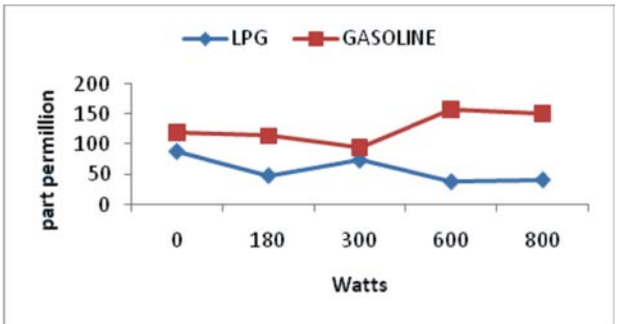

Figure 1: Mean CO emitted from LPG and gasoline.

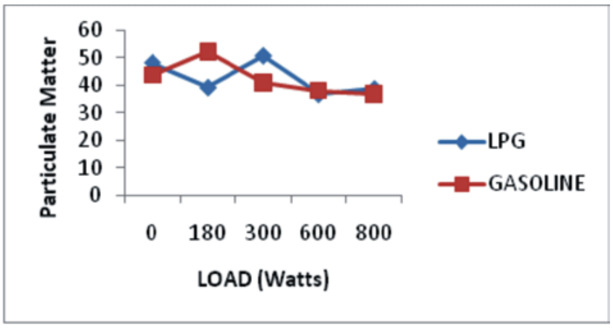

Figure 2: Mean Particulate Matter (PM) emitted from LPG and gasoline.

CONCLUSION

The option of self-generation of electricity by the increased use of generators by households is an offshoot of the electricity supply not meeting the ever-increasing demand for electric power. This portends an ongoing increase in emission which will continue to affect the environment and public health.

Hence, there is need for an urgent solution to address this looming catastrophe. Long and short term solutions must be implemented immediately. Long term solution involve the embrace of renewable and energy sources. A short term plan is the focus of this study. A 4-stroke, single cylinder Spark Ignition engine was successfully studied and the emission released was analyzed using different meters. The use of retrofitted generator in which LPG serves as alternative fuel has been proved to be of many advantages. LPG has been proved to be an excellent substitute for conventional gasoline fuel with its superior exhaust emission and characteristics. The results obtained from the experiments conducted on a load of 0w, 180 W, 300 W, 600 W, and 800 W shows substantial reduction in the levels of exhaust emission of LPG fuel since combustion of gaseous fuel occurs in a nearly uniform fuel-air ratio, which leads to a reduction in incomplete combustion deposits such as soot on the wall of the combustion chamber. Also there is reduction is fuel consumption. As the price of LPG falls due to the increase in the production of fuel, this will provide savings in terms of fuel cost and also maintenance cost will be reduced since it requires less maintenance.

The engine running with LPG fuel showed improved performance, especially in the area of fuel economy, overall efficiency and also significantly better exhausts emission characteristics compared to the gasoline. Due to economic and environmental benefits of using LPG over gasoline, we recommend this retrofitted generator as a short-term strategy for achieving the engine emission target in Nigeria.

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