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Effects of Gaseous Fuel and Lubricating Oil Additives on Emissions and Power Outputs from Portable Power Generator

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Abstracts: Global concern for the release of harmful emissions from Internal Combustion (IC) engines requires the optimization of quantity and type of fuel used in addition to the type of lubricant. Gasoline-powered generators are known to produce exhaust fumes that are harmful to humans and the environment. This study investigates the effect of compressed natural gas (CNG) and lubricating oils on portable power generators. The effect of Boron additive in these oils was also investigated to compare results of torque and emission measurements from oils containing Boron to oils without Boron additives. The instruments used to carry out the measurement are a digital tachometer; contact type torque meter and a 5-gas exhaust analyzer. Average measurements from these instruments are used for the analysis of data obtained. One important finding of this study is the general loss in torque outputs with increased speed for all the lubricating oils. However, oils lubricated with Boron additives minimized this loss at different speeds more in SAE 20W50 than SAE 40 oils. Another important finding of this study is that hazards from Carbon monoxide poisoning, NOx, THC, and CO_2 are highest at lower engine speeds than at higher speeds. It is expected that results from this study will inform users of portable household generators on the benefits of using CNG and boron-containing additives in lubricating oils for power efficiency and harmful emission reduction.

Keywords: Additives, Boron, Compressed Natural Gas, Emission, Torque.

Introduction

The internal combustion (IC) engines are used in providing mechanical energy to power ships, vehicles, trains, boats, aircraft, power generators, and many mechanical systems that require mechanical power in form of a rotating shaft. The combustion of air and fuels such as petrol, natural gas, diesel, and biodiesel blends in a combustion chamber of IC engines can either be complete (formation of CO_2 and H_2O) or incomplete (formation of CO, CO_2, C, H_2O, etc.) (Akin, 2016). The release of uncontrolled harmful gases will not only affect mechanical power outputs from IC engines, but also the environment and humans alike.
The electricity availability and utilization in any country of the world are very important to its growth and economic prosperity. However, many countries do not have proper grid infrastructure. Nigeria, has a population of with a population above 200 million people (Ohia, Bakarey, & Ahmad, 2020), with an installed power generation capacity near 13,000 MW and an actual generation that has never been greater than 5,000 MW (Daggash & Mac Dowell, 2021). This is grossly inadequate to cope with the growing population of people who needs electrical power for their various homes and businesses.

This shortfall comes at the expense of alternative sources of energy with a major contribution coming from power generators. Most of these generator engines used in Nigeria are either gasoline- or diesel-fuelled. The diesel is used commonly by medium to heavy-duty engines (5-100 kVA upwards), while small portable power generators (PPG) range from 0.75 to 5 KVA which provides temporary electrical power up to certain wattage and is designed for outdoor use. Users of PPG often place generators near or in their homes due to generator theft and noise to neighbors (Adefeso, Sonibare, Akeredolu, & Rabiu, 2013). A research study reveals that an estimated 60 million Nigerians invest about N1.6 trillion to purchase and maintain standby generators annually (Emem, Gorbunov, Rakhmanov, & Sergienko).

A major hazard from the use of PPG is carbon monoxide (CO) poisoning where five out of 104 deaths in the U.S are caused by a generator placed outside the home near open windows, doors, or vents (Marcy & Ascone, 2005). In Nigeria, the effects of exposure to high concentrations of CO had resulted in several deaths where more than 60 people suffocated to death in 2008 alone (Adefeso, 2010). Each year in Britain and countries all over the world, approximately 50 people die and two hundred people suffer severe morbidity by carbon monoxide poisoning and according to one estimate, CO poisoning symptoms occurs in as many as 25,000 people in the UK. can be attributed to faulty gas appliances (Afolayan, Olajumoke, Amadasun, & Isesele, 2014; Guy, Pimlott, Rogers, & Cross, 1999).

Exposure to CO emission can be very harmful to human health with the poisoning symptoms often going unnoticed. CO intoxication can result in a variety of acute symptoms in low doses. These include; headache, dizziness, weakness, nausea, confusion, disorientation, and visual disturbances (Hampson & Weaver, 2007). In extreme cases, exposure can lead to unconsciousness, coma, convulsions, and even death. CO is a colorless, odorless, tasteless, and non-irritating gas that is a product of incomplete combustion. It mainly originates from IC engines of motor vehicles, heaters, appliances that use carbon-based fuels, and household fires (Khadem-Rezaiyan & Afshari, 2016).

Environmental pollution from IC engines fuelled by conventional fossil fuels is becoming a global source of concern coupled with the increasing cost of petroleum-based fuels and the stringent regulations regarding limits for exhaust emissions have triggered the use of alternative fuel for automotive engines. Among several alternatives, the compressed natural gas (CNG) has been considered as a replacement for fossil fuel because of its availability throughout the world, inherent clean-burning, economical as fuel, and adaptability to the gasoline and diesel IC engines. In comparison to gasoline, CNG showed greater benefits in terms of engine emissions. CNG is primarily methane, with only one carbon atom per molecule, CO_2 formation from the combustion of CNG is reduced with a substantial reduction in CO emissions (Khan, Yasmin, & Shakoor, 2015; Usman & Hayat, 2019). In addition, some reduction in the content of total hydrocarbons was observed but an increase in NOx due to combustion properties of CNG which include leaner burning and minimal crevice leakages during operation (Singh, Pal, & Agarwal, 2016).

The studies on the effects of CNG on lubricant degradation and emission indicated that CNG not only gave a better performance in terms of emission and brake-specific fuel consumption, but also of lubricant degradation (Usman & Hayat, 2019; Valencia, Fontalvo, Cárdenas, Duarte, & Isaza, 2019). Previous studies on emissions from PPG using CNG as fuel have shown that CO emission in IC engines is lower than gasoline (Jahirul et al., 2010) with little mention of the combined effects of aged lubricating oils or oil degradation on performance and emissions from the exhaust gases.

In modern vehicles powered by IC engines, the effect of noxious gases is controlled by the use of exhaust catalytic converters and particulate filters installed in them (Hugh Spikes, 2008). However, portable power generators for domestic applications do not have these devices installed in them. These emissions can arise from the type of fuels, base oil, and chemical agents (additives) used in the lubricating oil of these generators. Hence, the need to investigate the effects of different engine oils and changes in additives used in lubricating oils on power outputs and emissions from portable generator usage in Nigeria is necessary

The lubricating oils are produced during crude oil refining to give base oil or base stock which is blended with additives. When lubricating oils are used continuously in IC engines chemical degradation of the additives due to the incorporation of oxygen through the air, moisture, catalytic metals, water, and heat can occur. This is known as oil oxidation. One of the additives used in conventional lubricating oil as an antioxidant is zinc dialkyl dithiophosphate (ZDDP) (Hn Spikes, 2004). At high concentrations of ZDDP in the lubricating oils, products of combustion of ZDDP are known to form compounds that deactivate the catalytic converters and block particulate filters in vehicles catalytic converters (Hugh Spikes, 2008). However, restrictions due to environmental concerns through various legislations in many countries have over the year been limiting high quantities of Phosphorus and Sulphur added to lubricating oils used in IC engines.

Research has shown that there is benefit in using lubricant-containing boron additives compared to Sulphur and Phosphorus additives for CO, HC, and NOx reduction in the exhaust stream of IC engines (Baş & Karabacak, 2014; Twigg et al., 2004). The use of synthetic borate additives in lubricating oils of internal combustion engines is known to provide antiwear and friction-reducing functions (Animashaun, 2017; Barthel, Luo, & Kim, 2015; Canter, 2008). Given independent CO emission reduction by CNG as fuel and boron additives in the lubricating oils used in IC engines that one of the objectives of this study is to convert a gasoline fuelled portable generator to a CNG-fuelled. Another objective of this study is to investigate the combined effects of

CNG fuel and boron-containing lubricating oils in PPG in terms of not only emission but also power loss due to torque reduction at different operating speeds.

Materials and Methods

In this study, the portable gasoline power generator used is a 2.5 kW, 50 Hz and 230V; four-stroke internal combustion engine and of model EC5800CX for the various tests as shown in **Figure 1** (a). The alternator of the generator was dis-coupled from the main engine to access the actual mechanical power output from the crankshaft using a TQ-8800 hand-held torque meter from Lutron Inc. as shown in Figure 1 (b). The digital torque meter is expected to measure the friction torque. This is subtracted from the theoretical torque the generator can transmit to obtain the actual torque output at different speeds for every oil change. The speed of the IC engine is measured using a contact/surface speed digital tachometer (model-DT-2235B) as shown in Figure 1 (c). In addition, a TotalGas 8050, exhaust 5-gas (CO, CO2, HC, O2, and NO) analyzer from Motor SCAN as shown in **Figure 1** (d) was used to determine emissions from the exhaust manifold of the PPG.

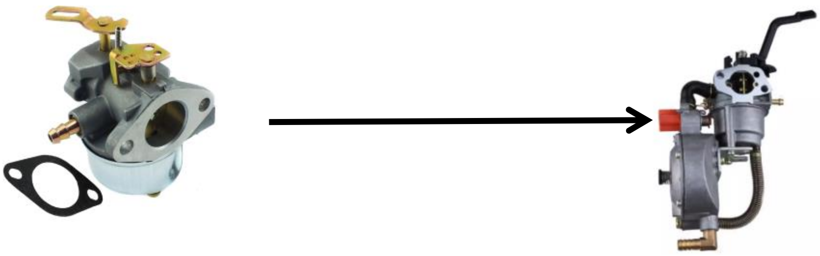
Figure 1 Equipment used for the study; (a) gasoline-fueled PPG, (b) hand-held digital torque meter, (c) contact/surface speed digital tachometer, (d) 5-Gas exhaust analyzer.

The lubricants used for lubrication in these tests are of two main types are obtained from authorized dealers. These are SAE 40 (Total motor oil) and SAE 20W50 (Total Quartz 3000 Car Engine Oil). Two mixtures were formed with 2.5 wt. % of synthetic hydrated potassium borate nano-particle dispersion friction modifier with nanoparticle size of about 50-100 µm in an organic matrix (Canter, 2008) with a product name of AR9100 oil additive.

The speed of the engine was varied by adjusting the throttle valve of the speed governor. For every speed change, a DT-2235B digital contact/surface tachometer is used. The results of torque output concerning emissions from these generators will be determined from a hand-held digital torque meter and tachometer. These are expected to provide information and evidence on whether emission reduction occurs due to boron-containing oil usage without adversely affecting power output. Data collected at different speeds on emissions from the gasoline power generators will be analyzed and used to determine whether lubricating oils containing boron have significant effects on emission from power generators compared to oils without the boron additives.

Results

To collect data for this study, a new Elepaq (EC5800CX) gasoline generator of 2.5 kW capacity was obtained. In this study the petrol carburetor that was originally on the new generator as shown in **Figure 2** (a) was retrofitted with a dual fuel carburetor; petrol and gas carburetor for generators with capacities between 2.0 - 3.5 kVA as shown in **Figure 2** (b), while retaining the capability of switching back to its petrol fueling system easily.



(a) (b)

Figure 2: Conversion of; (a) petro carburetor to (b) dual fuel (petrol/gas) carburetor

To connect the carburetor to a 6.0 kg gas cylinder, a small flexible hose long enough to provide a safe distance from the generator exhaust was used to connect a gas pressure regulator to the carburetor as shown in

Figure 3 (a) and

Figure 3 (b).

	
(a)	(b)

Figure 3: Schematics of; (a) gas regulator, (b) connection of gas regulator to carburetor using flexible hose

As a result of these changes, the petrol tank on top of the generator and the alternator were removed to facilitate measurement of speed and torque as shown in

Figure 4.

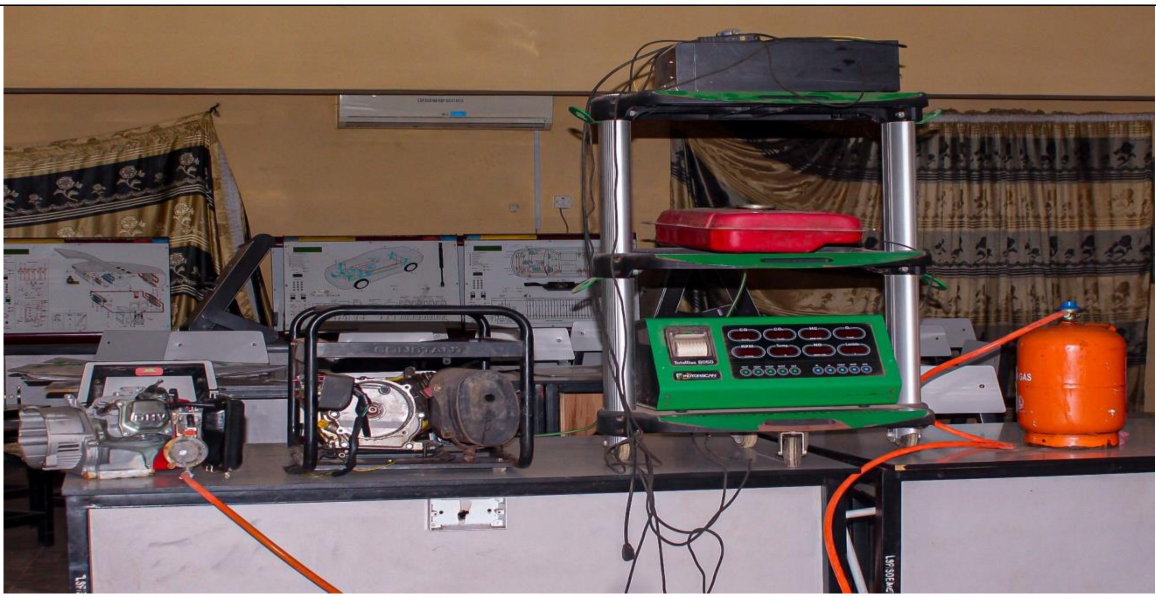


Figure 4 Set-up of the experiment after conversion of a gasoline generator to CNG fuel

3.1 Variation of torque with speed

Results from this study using conventional oils and oils containing boron additives are expected to provide information on emissions from new generators for domestic use. The variation of torque outputs with speed for different oil combinations is shown in Figure 5.

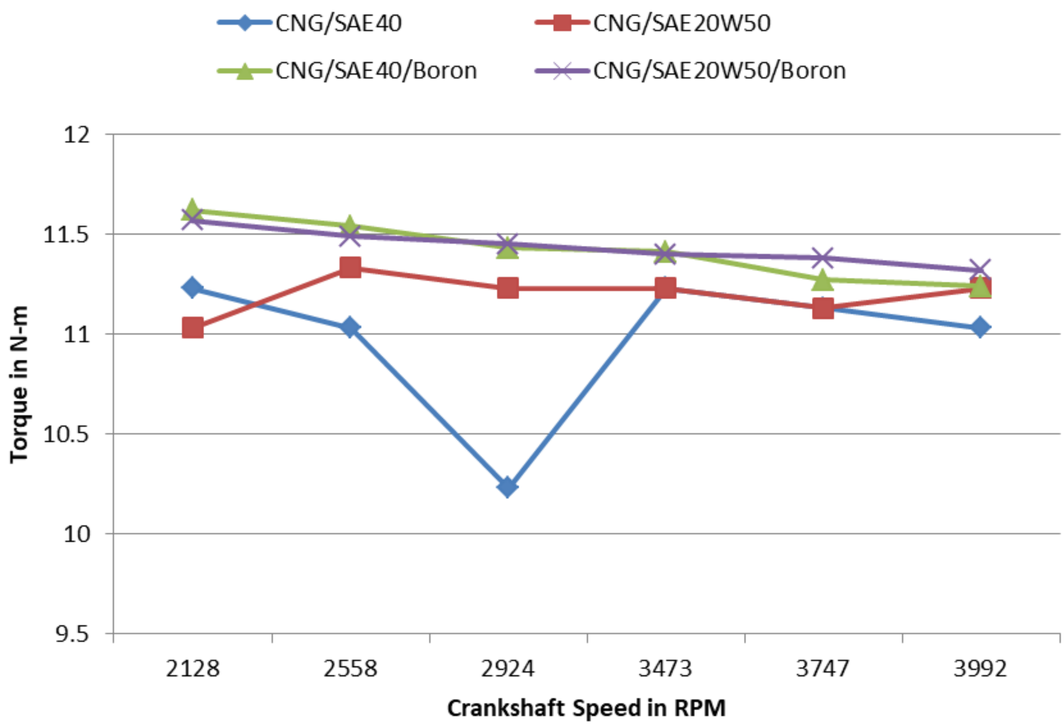


Figure 5: Changes in torque concerning speed for various oil combinations

These results indicated in Figure **5** shows that significant changes in torque occurred between speeds range 2128-3473 rpm for SAE 40 oils, unlike SAE 20W50 that was not greatly affected by changes in speed. On the other hand, Boron additive in both SAE 40 and SAE 20W50 oils not only provided higher torque output compared to when there were no boron additives, but also good control of torque variation. This shows that Boron additives provided effective control of torque in SAE 20W50 oil and SAE 40 oil. However, the effect of the Boron additives was observed to be more significant at 2128 rpm than at any other speeds during the tests.

3.2 Variation in emission with speed for SAE 40 oils

The changes in exhaust gases with engine speed lubricated with SAE 40 are shown in Figure **6** (a) to (d).

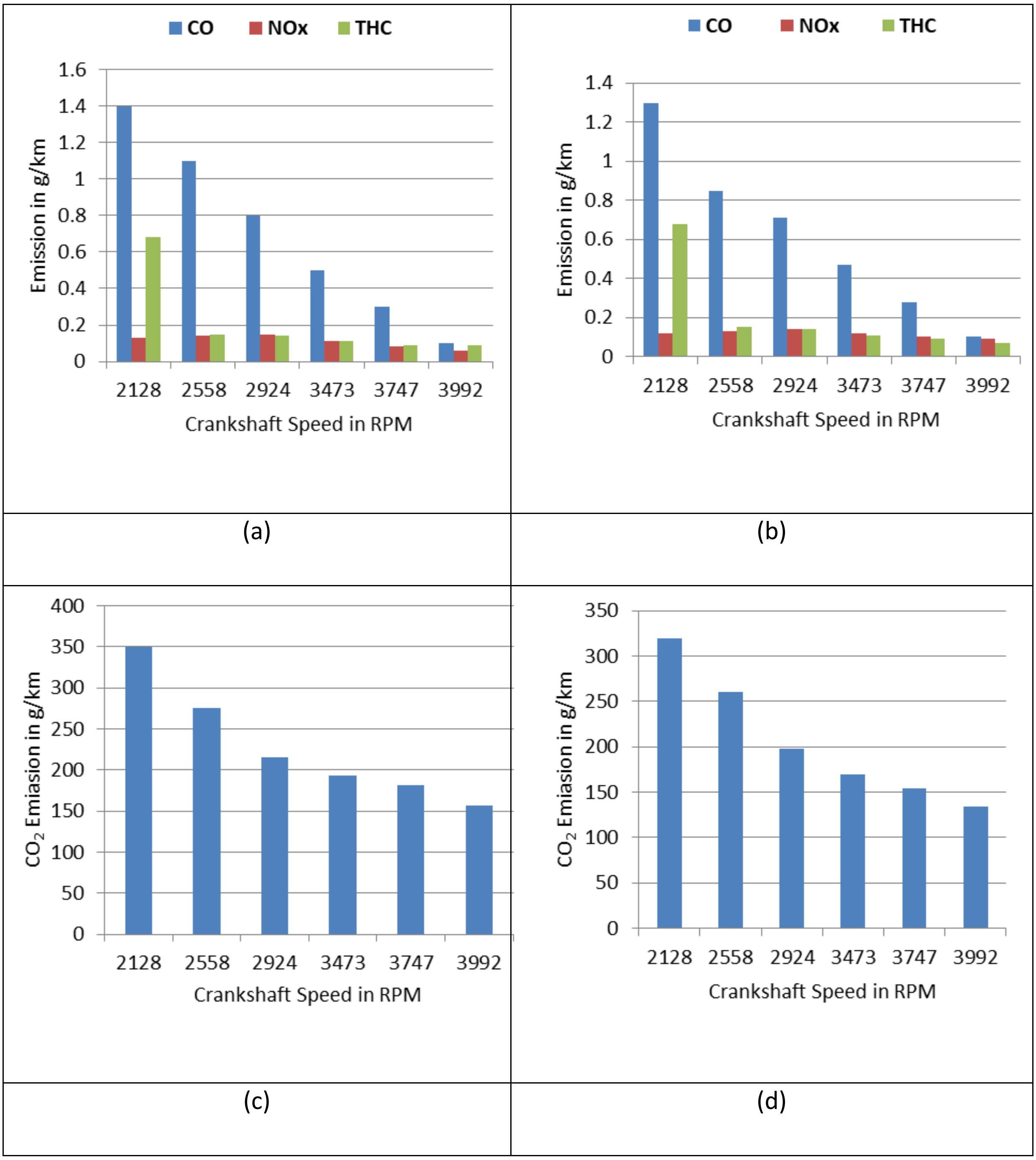


Figure 6 Changes in emission with respect to speed for various emissions from generators lubricated by SAE 40 and fueled by CNG; (a) CO, NO_x, and THC for SAE 40, (b) CO, NO_x, and THC for SAE 40 with Boron additive, (c) CO_2 for SAE 40 and (d) CO_2 for SAE 40 with Boron additive.

The results of CO emission shown in Figure **6** (a) without Boron additives and Figure **6** (b) indicated a general decrease with increasing engine speed. However, Boron additive effect on CO emission was found to decrease by about 7%, 23%, 11%, 6%, and 7% at all tests speeds except at the highest speed of 3992 rpm. There was no significant change in NO_x emission when Figure **6** (a) is compared to Figure **6** (b) at all speed range used in this test. At the lowest speed, THC emission in SAE 40 and SAE 40/Boron oils are highest; after which there was no considerable change up to the highest speed of the tests. This shows that the Boron additive in the oil played no role in this process. Hence, this decrease could be due to the CNG gas used as fuel to power the generator. Hence, CNG could have played a major role in NO_x emission reduction.

The emission of CO_2 was observed to decrease with increasing speed with or without Boron additive as shown in Figure **6** (c) and Figure **6** (d). However, CO_2 emissions reduction in exhaust gas stream from PPG lubricated with SAE 40 oil containing Boron additive was lower than SAE 20W50 oil without Boron additive varied between 6 and 15% at all speed range of these tests. This indicated that Boron additive played a role in this process**.**

3.3 Variation in emission with speed for SAE 20W50 oils

The changes in constituent harmful exhaust gases with engine speed using SAE 20W50 oils are shown in

Figure 7 (a) without Boron additives and

Figure 7 (b) with Boron additives respectively, while those of CO_2 in the emission stream are respectively shown in

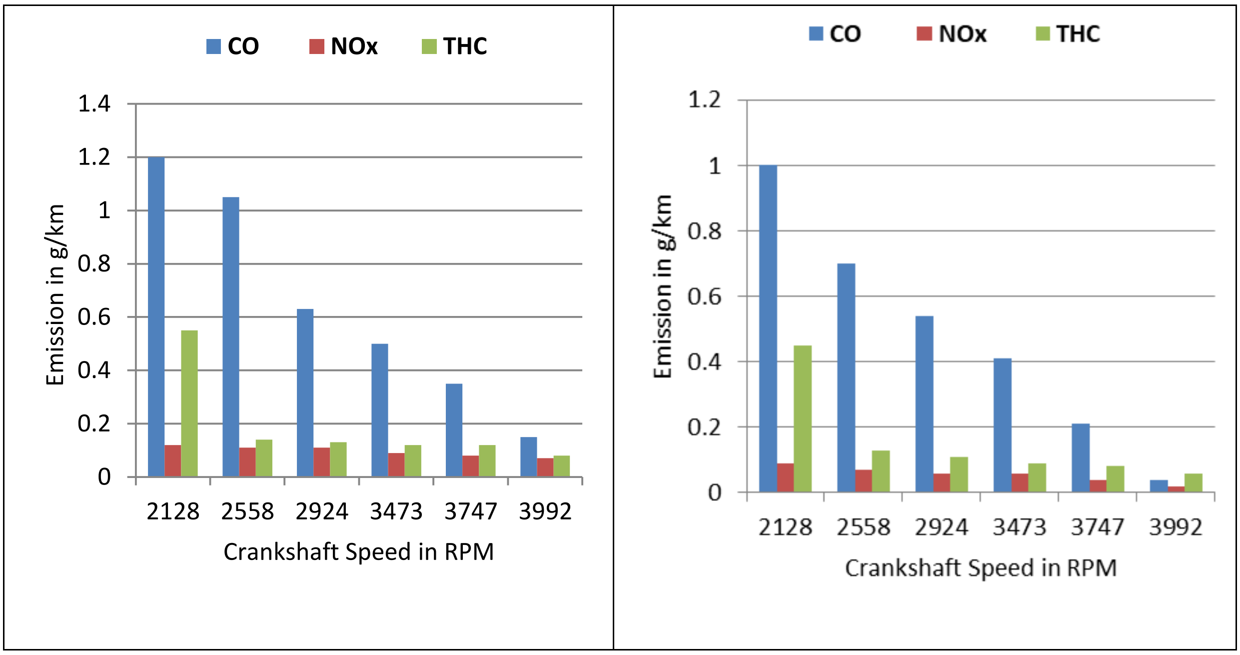
Figure 7 (c) without Boron additives and

Figure 7 (d) with Boron additives in the oils.

The results are shown in

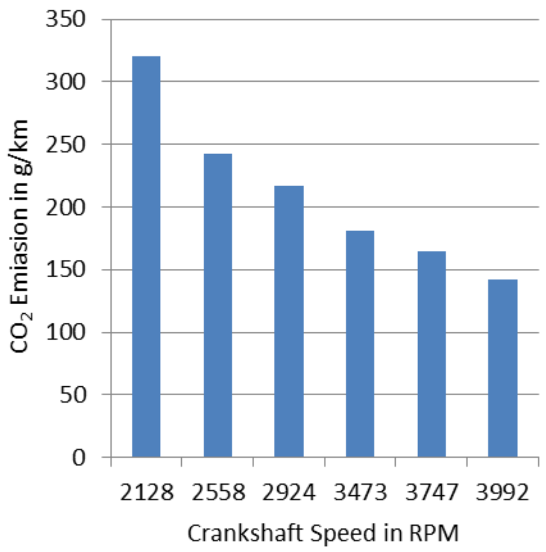
Figure 7 (a) and

Figure 7 (b) indicated a general decrease with an increased engine speed of CO emission. However, a Boron additive effect on CO emission was found to decrease by about 17% -33% between the 2558 and 3992 RPM speed range.

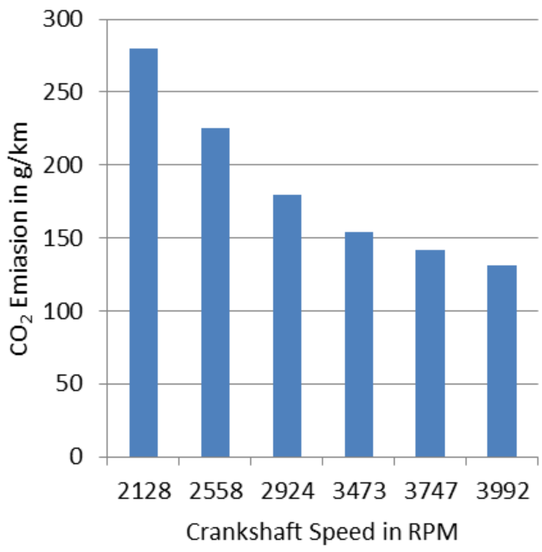


(a)

(b)



(c)



(d)

Figure 7 Changes in emission with respect to speed for various emissions from generators lubricated by SAE 20W50 and fueled by CNG; (a) CO, NO_x, and THC for SAE 20W50, (b) CO, NO_x, and THC for SAE 20W50 with Boron additive, (c) CO2 for SAE 20W50 and (d) CO2 for SAE 20W50 with Boron additive.

This is an indication that the boron additive could have played a major role in this process. There were considerable differences in NO_x emission when

Figure 7 (a) is compared to

Figure 7 (b) at all speed range used in this test. A reduction of NO_x emission with increasing speed in generator lubricated by SAE 20W50 oils containing Boron additive compared to SAE 20W50 without Boron additive.

At the lowest speed, THC emission from the PPG lubricated with SAE 20W50 oil and SAE 20W50 containing Boron additives are highest; after which there was no considerable change up to the highest speed of the tests. However, Boron additive in SAE 20W50 oil gave about 18% and 7% reduction at 2128 and 2558rpm respectively. Above this speed, the effect of Boron additive on THC emission was not significant. When compared to results in Figure **6** (a) and Figure **6** (b), this indicated that the Boron additive in SAE 20W50 played a more active in THC emission reduction at lower engine speeds than in generators lubricated by SAE 40 oil.

The emission of CO_2 was observed to decrease with increasing speed with or without Boron additive as shown in

Figure 7 (c) and

Figure 7 (d). However, CO_2 emissions reduction in exhaust gas stream from PPG lubricated with SAE 20W50 oil containing Boron additive was lower than SAE 20W50 oil without Boron additive within 7-17% at all speed range of these tests. This indicated that the Boron additive in SAE 20W50 and SAE 40 lubricating oils could have played a role in CO_2 emission reduction from the generator.

4.0 Discussions

The results of the behavior of changes in mechanical torque outputs from the shaft of the PPG in this study indicated that Boron-containing oils prevented the large reduction in torque at different speeds that were similar to results obtained in a recent research study (Animashaun, 2017; Jahirul et al., 2010). This could be attributed to different functions of the antiwear additives in the oils.

The use of ZDDP in conventional lubricating oils such as SAE40 and SAE 20W50 is practically universal in crankcase lubricants is not only to act as an antiwear agent, but also as an antioxidant that forms a glassy phosphate film on the surface of Fe-based materials to reduce wear and friction (Özkan, Yağci, Birer, & Kaleli, 2016; Hn Spikes, 2004). On the other hand, higher torque results obtained in Figure 5 indicated that the Boron additives not only act as antiwear and antioxidants but also more as a friction modifier. This friction-reducing behavior of Boron additives was attributed to the boron oxide in the oil reacting with the moisture of the surrounding air to form boric acid on surfaces in tribological contacts (Barthel et al., 2015; Canter, 2008; Erdemir, Fenske, Erck, Nichols, & Busch, 1991).

The results of this study were able to show that reduction in output torques from gasoline-powered generators lubricated by fresh SAE 40 is more than SAE 20W50 oils. It showed that fresh multi-grade oil had less torque reduction than fresh mono-grade oil at different operational speeds. This may be attributed to the blending of low-viscosity oil with special additives called Viscosity Index Improver (VII) to form multi-grade oils. Hence, the ability of SAE 20W50 to combine good starting and friction properties of a thin oil at low temperatures with the good lubricating properties of a more viscous oil at high temperatures could have made this possible. The degree of torque reduction is has been related to friction loss in IC engines' research studies (Holmberg, Andersson, & Erdemir, 2012; Holmberg & Erdemir, 2017).

On the contribution of lubrication to emission reduction shown in Figure 6 and

Figure 7, this could be attributed to the affinity for oxygen by atoms of boron in the oil (Choudhary & Pande, 2002) that could be attributed to high oxygen level on the wear tracks (Johnsson, 2015). This was due to electron-deficient boron with its vacant p-orbitals that make it always exist as borates. The boric acid formed when the borates (B_2O_3) react with moisture in the surrounding air catalyzes the air oxidation of CNG hydrocarbons and increases the yield of alcohols by forming esters that prevent further oxidation of hydroxyl groups to ketones and carboxylic acid.

Carbon monoxide emission reduction results from this study as shown in Figure **6** (a)/(b) and

Figure 7 (a)/(b) were in agreement with the results of a similar study on internal combustion engines on cars (Twigg et al., 2004). The complete combustion of the CNG fuel used in IC engines was linked to emission reduction (Khan et al., 2015). In addition, CNG is known to burns with lower burning velocity as compared to other fuels due to its major fraction, i.e. methane where Carbon dioxide and nitrogen, and other inert gases act like diluents to decrease laminar burning velocity by reducing flame temperature (Usman & Hayat, 2019).

5.0 Conclusions

In the search for minimization of emissions from PPG use in Nigeria that alternative fuels and lubrication oil with their associated effects on engine performance characteristics and emissions are an ongoing process. In the current work, a comparative study has been conducted by converting a gasoline-fueled PPG to CNG-fuelled in a SI engine. Performance characteristics of the engine by comparing the performance of two conventional lubricating oils with and without boron-containing additives in terms of torque reduction and emissions have been investigated at different operating speed conditions with the following conclusions:

1) Torque reduction in CNG-fuelled portable power generators is better controlled in lubricating oils containing synthetic Boron additives than that without Boron additives.
2) By taking advantage of the abundance of CNG availability in Nigeria and new technology in lubricant utilization, results from this study have indicated that considerable friction reduction and power losses in IC engines of PPG are possible.
3) The results of harmful emissions in this study indicated that Boron-based additives in conventional lubricating oils complemented that achieved by CNG use as fuel in PPG.
4) This study has shown that boron additives utilization in carbon monoxide emission reduction in vehicles is also possible in gasoline-powered generators used for domestic applications/
5) There is a need for government to support the use of CNG as fuel in domestic PPG in Nigeria.
6) Future work from this study should study the effect of using CNG in fuelling PPG on the durability of tribological components in PPG concerning lubricating oil.

6.0 Acknowledgments

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