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Impact of Inorganic Nanoparticle Additives on Gasoline and Compressed Natural Gas Lubricants for Enhanced Power Efficiency and Emissions Reduction

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Abstract
The study investigates the impact of boron addition on gasoline and compressed natural gas (CNG) lubricants, aiming to improve power efficiency as well as minimize the emissions of climate-changing gases from moveable electrical systems. Featuring a 2.5 kW, 50 Hz, and 230V four-stroke fuel-injected engine model, the research examined the impact of boron addition on torque and emission data in boron-containing lubricants. The tests utilized SAE 40 Total Motor oil and SAE 20W50 Total Quartz 3000 Car Engine Oil, both sourced from authorized dealers. The measurement process involves using a digital tachometer, a contact-type torque meter, and a 5-gas exhaust analyzer to analyze average measurements for data analysis. The finding reveals a 3.57% torque output loss at 3992 rpm high speed in all lubricating oils, with boron additions minimizing this loss significantly in SAE 20W50 oils compared to SAE 40 oils. At higher speed, the risk of carbon monoxide (CO) poisoning, nitrogen oxide (NOx), total hydrocarbons (THC), and carbon dioxide (CO_2) reduced by 82.35%, 50%, 87.53%, and 92.86%, respectively, in greenhouse emissions. The addition of CNG and boron-containing enhancements to rubbing lubricants resulted in an elevated torque of 11.5 Nm at low speed, and there was an appreciable low in emissions of 82.68%. The combined additives suspended contaminants in oil, burned cleaner, and kept the engine neat and cost-effective, improved fuel and power efficiencies, and reduced emissions in portable household generators for a prolonged service life.

Keywords: *Boron additives, greenhouse gas emissions, lubricating oils, power efficiency, portable generator.*

1.0 Introduction

Global temperature increase is due to carbon dioxide (CO_2) toxins produced by combustion of petroleum and natural gas, with human activities being the second largest. Nigeria has a small population of over 60 million, with 73% using fossil-fuel-powered electric generators (Sharaf, 2013). Nigeria's well-being and industrial development are linked with the electrical power use for each person, with 14 watts. This poses challenges for electricity consumers, as over 60 million have power generators for domestic, industrial, and business needs. Burning fossil fuel in internal combustion (IC) engines produces harmful greenhouse gases, causing environmental harm (Korakianitis *et al.*, 2021). Nigeria's low CO_2 emissions per capita are owing to its low usage of fossil-fuel-powered electric generators, causing harmful greenhouse emissions and potentially excessive toxic gases from generator usage, particularly carbon monoxide. Nitrogen oxide (Singh *et al.*, 2016).

Generator exhaust gas contains sulfur dioxide, causing irritation, choking, and increased mucous secretion. Internal combustion engines (ICE), used in various industries like automotive, marine, aircraft, and industrial, release harmful gases into the combustion chamber. ICE provides machine power to various mechanical systems, such as automobiles, locomotives, yachts, airplanes, and maritime vessels, and power generators, with various components (Sharaf, 2013). Private power generation (PPG) classifications are based on 4-stroke (or 2-stroke) engines cycle operations, as illustrated in Figures 1 and 2. Burning fossil fuel in generators sparks ignition (SI) or compression ignition (CI) engines for domestic and industrial purposes, producing harmful greenhouse gases (GHGs). Common fuels include gasoline, diesel, and compressed natural gas (CNG). CNG engines offer advantages over conventional engines, are suitable for various industries, and can be improved for lean operating regions (Wargula and Kukla, 2020).

World environmental pollution from fossil fuel-fueled IC engines prompts the adoption of alternative fuels like compressed natural gas (CNG), which is clean, economical, and adaptable to gasoline and diesel engines (Mihan *et al.*, 2015). CNG outperforms gasoline in emissions, brake-specific fuel consumption, and lubricant degradation performance, despite lower carbon monoxide (CO) emissions in IC engines due to aged lubricating oils (Jahirul et al., 2010; Valencia *et al.*, 2019). Researchers are exploring natural gas as a potential alternative fuel for internal combustion engines, offering lower emissions compared to diesel and gasoline (Ohia e*t al.*, 2020). Nigeria's population faces a power generation shortage due to 13,000 MW capacity, leading to alternative energy sources like gasoline- or diesel-fueled generators (Adefeso *et al.*, 2013; Adefeso, 2010).

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The fuel used in generators and IC engines significantly influences emissions, including unburned hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter. These pollutants are considered criteria pollutants. Gasoline and diesel fuels, which are mixtures of hydrocarbons, produce unburned hydrocarbons, nitrogen oxides, and exhaust pollutants (Barthel et al., 2015). Modern internal combustion engines (IC) require lubricating oil that meets their construction requirements, maintains stability under changing temperatures, and doesn't corrode metal surfaces. Addition of boron additives in lubricating oil serves six functions: controlling friction, reducing wear, limiting temperature, reducing corrosion, dampening mechanical shock in gears, and creating a seal on cylinder walls (Bas and Karabacak, 2014; Daggash and Mac Dowell, 2021). Conventional lubricating oils, such as zinc dialkyl dithiophosphates (ZDDP), have higher oxidation capacity and can cause tar and sludge precipitation. Boron-containing lubricating oil has advantages over ZDDP in enhancing catalytic converter and particulate filter properties (Shah, 2019). Borate esters provide greater effectiveness in terms of electricity generated compared to ZDDP (Aninasham, 2017; Hirani, 2016).

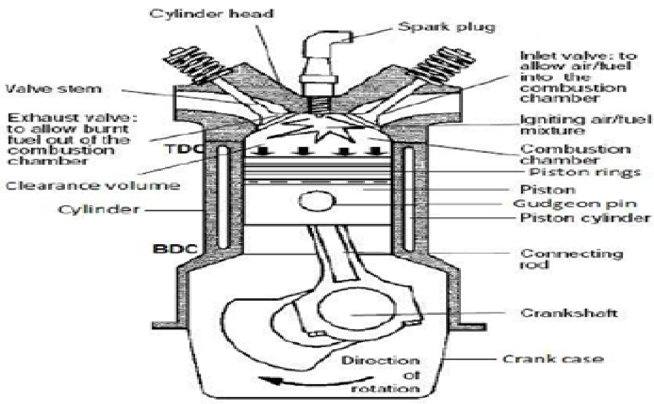


Figure 1: ICE components (Korakianitis et al., 2021)

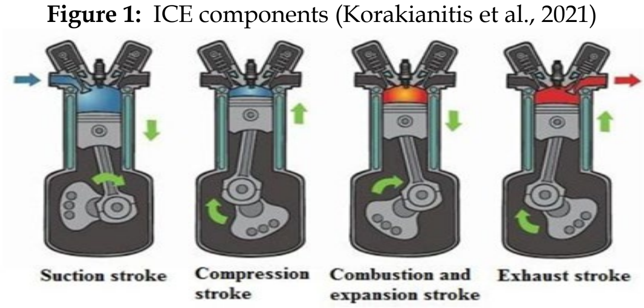


Figure 2: Cycle of operation of four-stroke engine (Korakianitis et al., 2021)

Figure 3: Exhaust emissions from portable domestic generator (Aremu, 2020)

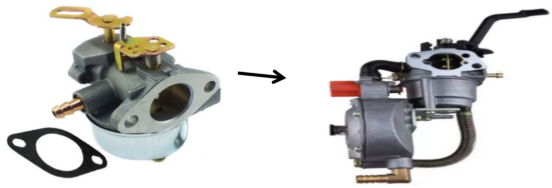
The Nigerian government's failure to regulate electricity generation has led to a rise in standby generators, causing significant environmental and safety risks. These generators emit harmful gases like carbon monoxide (Aremu, 2020). Without changes in power generation, usage will continue to rise, potentially causing more harm. Investigation is needed in Nigeria to address the emission issues in domestic portable power generators, which are devoid of particle filters and discharge filtering systems. Investigating zero-SAP additives and fuel types is crucial to reducing emissions from generators without compromising mechanical power output. The current study aims to analyze the utilization of inorganic boron nanoparticles in greasing, gasoline, and CNG-fueled PPG and the impact of different lubricants on emission gases and friction torque in generators, focusing on emission reduction.

2.0 Materials and Methods

This study uses a 2.5 kW, 50 Hz, 230V compact device uses a four-stroke fuel-injected engine to generate electricity. SAE 40 oil was utilized owing to meeting the viscometrical standard and being good for high-temperature climates, reducing friction, and protecting against engine wear. SAE 20W50 has high-temperature stability, antifriction and wear protection versatility, good cold-start performance, reduced oil consumption, and enhanced engine cleanliness for optimal performance and fuel efficiency. The choice of inorganic nanoparticle boron additive because of its potential to improve the engine parts lubricity, reduce friction and wear, and extend the service life of engine oil. It is advantageous in reducing fuel consumption and exhaust emissions, thereby improving the effectiveness of old or worn engines. The addition of CNG was brought forth by clean burning and cost-effectiveness as well as non-corrosive excellent operational efficiency.

The alternator is disconnected from the engine to measure production of power from machines utilizing a TQ-8800 torque meter. Figure 4 (a–b) illustrates how an indirect rate electronic tachometer (type DT-2235B) is used to gauge the IC engine's speed. An analysis of a PPG's deplete tract was conducted to identify pollutants from gasoline fuel and conventional lubricating oils, either alone or combined with boron-containing additives. The tests used SAE 40 and SAE 20W50 lubricants, with two mixtures containing 2.5 wt.% of AR9100 oil additive, a fabricated distribution stress enhancer made of hydrated potassium borate nanoparticles.

The research involves running a generator with appropriate fuels and lubricating oils, adjusting engine speed, and using a computerized tachometer to measure torque. Analysis of statistics on pollutants from petrol-fueled devices was done to see if fluids having boron had a major impact on gases compared to non-boron additives in petrol fuel. This demonstrates the retrofitting of a petrol carburetor on a generator using two fuels system, allowing an easy switchback to petrol fueling as seen in Figures 5 (a – b). A meter for gas flow was attached to the fuel system using a flexible hose, guaranteeing a secure separation from the generator's outflow. The fuel container is located above the power source and alternator was removed to enable rapidity and torque possible measurement, as depicted in Figure 6. A generator test was conducted outdoors, ensuring gas cylinder leaks, avoiding experiment site proximity, and upgrading for optimal performance.



(a) Petrol carburetor (b) Dual fuel (petrol/gas) carburetor

Figure 4: Modification of a single to dual fuel carburetor.

(a) Gas regulator (b) Gas carburetor

Figure 5: Schematics of gas valve to gas carburetor

Figure 6: Set-up of CNG fuel power generation

3.0 Results and Discussion

3.1 Torque Change with Drive Utilizing CNG and Different Lubricating Oils

Figure 7 displays emission results from domestic generators using conventional and boron-containing oils, revealing torque output variations with speed for different CNG oil combinations. The findings found that torque changes significantly (11.3 to 11.0 Nm) in SAE 40 oils between 2128-3473 rpm, while SAE 20W50 was not significantly affected (11.0 to 11.1). Both lubricants' boron additions increased torque production (11.3 to 11.6 Nm) and good torque variation control, with their effect being more significant at 2128 rpm. Both low and high levels of engine speeds are favored by the addition of boron additives to lubricants, which extends the engine oil service life.

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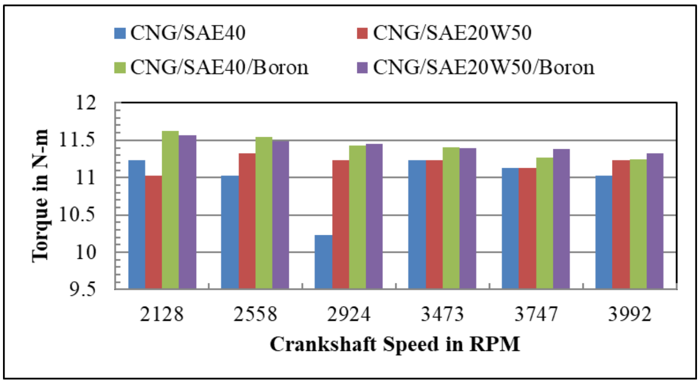

Figure 7: Torque fluctuations in relation to speed for oil mixtures utilizing CNG as fuel

Examining torque outcomes using gasoline, conventional oils, and boron additives is depicted in Figure 8. All oil utilized in the testing shows a noticeable drop in torque with (10.4 to 11.6 Nm) and without (9.8 to 11.4 Nm) boron for petrol fuel use, with used oils showing the highest reduction. Boron additives improved torque transmission at higher speeds by 30%. The addition of boron lubricants improved torque performance at all levels of speed but partly increased at 2128 rpm.

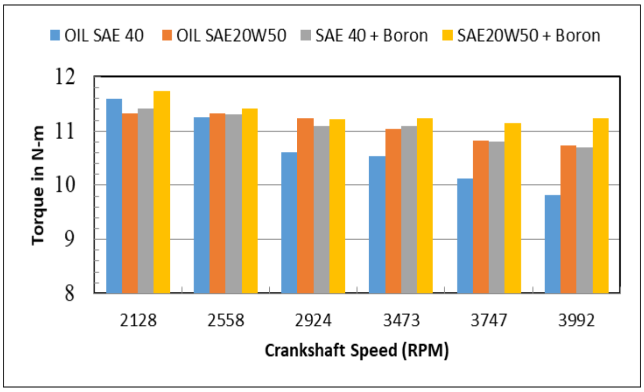

Figure 8: Variance in oil torque in relation to speed combinations using petrol as fuel

3.2 Variation in emission with engine speed using CNG for SAE 40 lubricating oils

Figure 9 (a–d) shows how engine speed and SAE 40 lubrication affect combustion gas changes. The vehicle is lubricated with SAE 40 and fueled by CNG, with various additives including CO, (NOx) NOx, total hydrocarbons (THC), SAE 40 with a boron additive, and CO_2 for SAE 40. A decrease in CO emission with increasing engine speed has a 7% decrease in boron additive effects at all speeds except at 3992 rpm. No significant change in nitrogen oxide emission was observed. The highest THC emission was at the lowest speed, suggesting that the boron additive played no role in the reduction, perhaps as a result of the CNG gas being utilized as fuel, as seen in Figure (a and b). Regardless of the boron ingredient, the release of CO_2 dropped with speed; however, Figures (c and d) showed a smaller decline in the particulate matter discharge from PPG oiled with SAE 40 oil that had the boron added. Introducing boron nanoparticles in the lubricants yielded a significant reduction in greenhouse gas emissions, specifically at low speed.

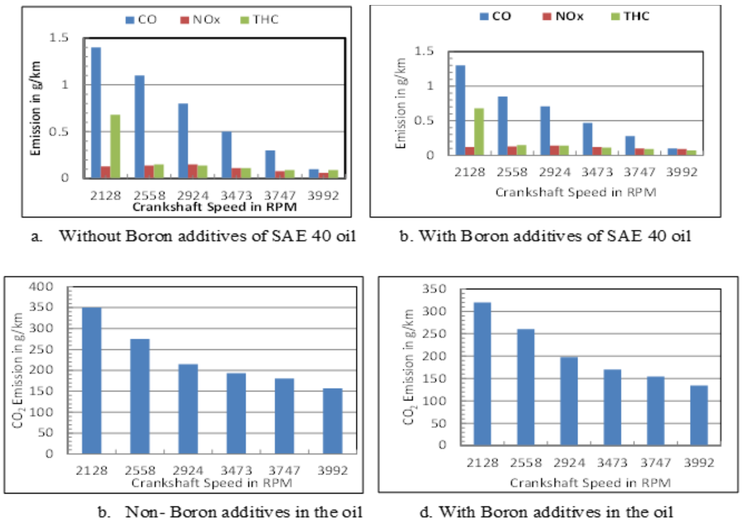

Figure 9: Effects of engine speed on fumes using CNG for SAE 40 lubricants

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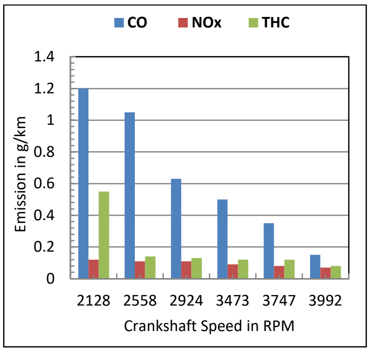
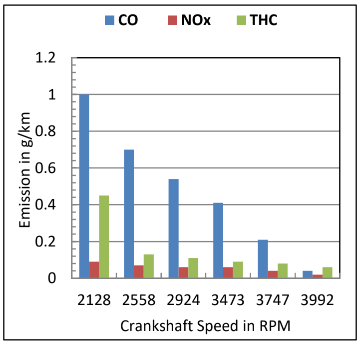
3.3 Effect of Engine Speed on Emissions when Using CNG for SAE 20 W50 Lubricating Oils

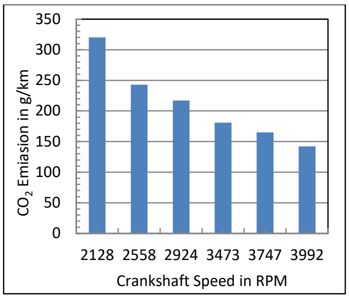
Figure 10 (a–d) compares the impacts of boron and other additives to show how SAE 20W50 oils affect dangerous exhaust gasesand CO2 emissions. a reduction in CO emissions as engine speed increases, with a 17%–33% drop in boron synergistic impact between 2558 and 3992 rpm. The hazardous exhaust gas variations with engine speed using SAE 20W50 lubricants with and without boron additions are depicted in Figure 10 (a–b). According to the data, there were notable variations in NOx output between machines greased with CNG and SAE 20W50. The maximum THC toxins occurred at the smallest speeds, while the boron addition reduced emissions at greater rates. Figure 10(d) shows the CO2 levels in the fume flow with boron additions in the oils, while Figure (c) shows the CO2 rates absent boron additives. The combustion product discharge from PPG lubricated with SAE 20W50 oil, including a boron addition, was reduced by 7–17%, although CO2 emissions decreased with speed with or without a boron additive. The addition of inorganic boron nanoparticles into the choice of lubricants drastically degrades CO_2 and emissions compared to without additives.



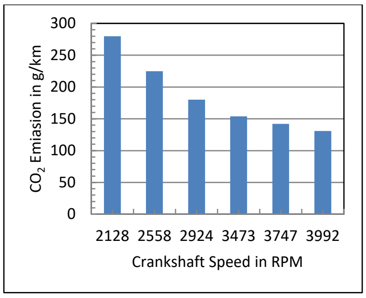
(a) Non-Boron additives of SAE 20W50 oils



(b) With Boron additives of SAE 20W50 oils



(c) Without Boron additives in the oil

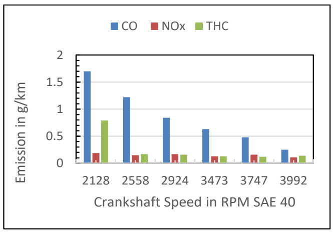


(d) With Boron additives in the oils

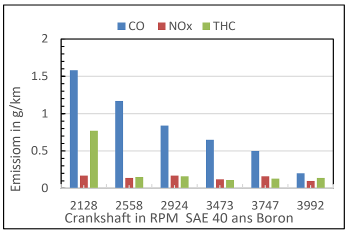
Figure 10: Changes in emission with engine speed using CNG for SAE 20 W50 lubricating oils

3.4 Change in Emissions with Engine Speed for SAE 40 Lubricating Oils Utilizing Petrol

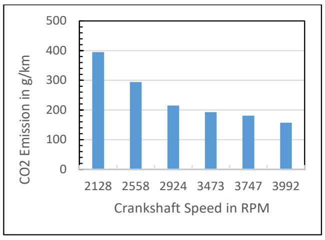
The effects of gasoline and SAE 40 lubricating oils on CO2 emissions and hazardous exhaust gases at varying engine speeds are shown in Figure 11 (a–d). Different emissions from generators lubricated with SAE 40 and powered by gasoline exhibit variations in speed in the following ways: (a) CO, NOx, and THC for SAE 40, (b) CO, NNOx, and THC for SAE 40 with Boron addition, (c) CO2 for SAE 40, and (d) CO2 for SAE 40 with Boron additive. Figure 11 (a–b) compares the CO2 emission stream with and without boron additions, respectively. Figure 11 (c) shows the findings without boron additions, whereas Figure 11 (d) shows the results with boron added in the oils. An outstanding performance and historic decrease in all types of greenhouse gas emissions in the environment are indicated by the influence of boron in lubricants.



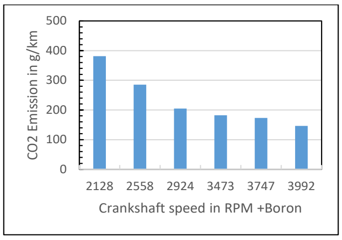
a. Without Boron additives of SAE 40 oil



b. With Boron additives of SAE 40 oil oil



c. Non-Boron additives in the oil

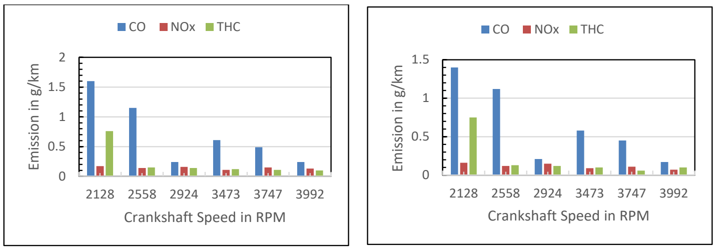


d. Without Boron additives in the oil

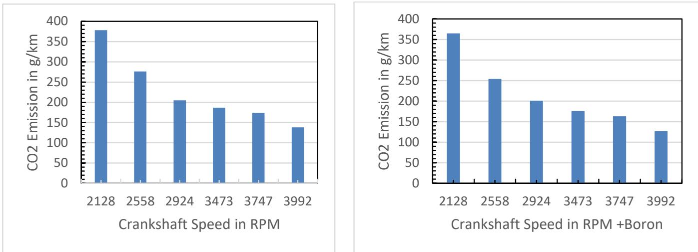
Figure 12: Differences in emissions with engine speed when using SAE 40 lubricating oils and gasoline

3.5 Transition in Emissions with Engine Speed for SAE 20W50 Servicing Oils Using Petrol

The variations in exhaust gases, such as CO, NOx, THC, and CO2 for SAE 20W50 with a boron addition, that correlate to engine speed are shown in Figure 13 (a–d).. Figure 13 shows decreased carbon monoxide emissions in engine oil types without SAE 20W50, having lower emissions with SAE 20W50. The engine cleanliness is determined by unburned hydrocarbon levels during tests. The highest NOx emission was observed at the minimum speed of 2128 rpm, suggesting less influence of boron additive. The impact of boron in lubricant shows an appreciable reduction in greenhouse gas emissions in the environment.



a. Without Boron additives of SAE 20W50 oil b. With Boron additives of SAE 20W50 oil



Non-Boron additives in the oil d. Boron additives in the oil

Figure 13: Changes in emissions from plants hydrated with SAE 20W50 gasoline

Higher activation energy of CO oxidation delays its oxidation until original and intermediate hydrocarbon species are consumed, causing higher OH concentration and conversion of CO to CO_2. The results excluded evaporative emissions of hydrocarbon fuel, which could lead to higher values than recorded in practice. The boron-based tribofilms reduce torque due to friction and antiwear mechanisms. Friction reduces due to air moisture interaction, while antiwear results from boron oxide digestion of abrasive iron oxide. Results align with car internal combustion engine research.

3.6 Comparison of Torque from PPG Fueled by Petrol to CNG for Both Lubricating Oils

The application of CNG with SAE 40 lubricants at speeds above 3473 rpm significantly increased torque outputs, with a percentage increase above 5% at significant levels. Torque changes were minimal at 3473 rpm, indicating that CNG utilization, particularly SAE 40, can significantly impact power output compared with SAE 20W50.

3.7 Comparison of pollutions from PPG Fueled by Petrol to CNG for Both Lubricating Oils

The results compared CNG and petrol-fueled PPG in CO gase decrease using various lubricating oils. Results showed a 33% decline in CO emissions in SAE 20W50 oil without boron, and increased to 40% with boron-containing additives. The result of CNG, when used in SAE 40 lubricating oils, reduced CO emissions by about 21% and 22% when boron was present, but not significantly compared to SAE 20W50.

3.8 Impact of Boron Additives in Oils of CNG and Gasoline Engines

The additives in lubricants help to suspend contaminants, keep engines clean, and prevent harmful deposits from forming, proper lubrication, and prolong the use of motors in modern ICE. It enhanced existing base oil properties with antioxidants, corrosion inhibitors, and demulsifying agents for improved engine performance and longevity. CNG burns cleaner than other fossil fuels, producing fewer pollutants and greenhouse gases. It is cheaper than petrol or diesel. It, however, reduced emissions, lower costs, higher energy density, limited flammability, and non-corrosive excellent operational efficiency. Some of the applications of CNG include power generation and reducing carbon footprint, fuel for furnaces and burners, and raw materials in manufacturing industries. It serves as an alternative cooking gas and vehicle fuel used in transportation systems that are economically and environmentally friendly. The application of boron additives is found in energy storage devices and industrial catalysts. This provides a green solution to the stubble burning.

4.0 Conclusion

The study examines internal combustion engines' dangerous pollutants in portable power generators, highlighting their detrimental effects on air quality, human health, and global warming. The results of the study found that torque decreases with speed in CNG-powered domestic generators lubricated with SAE 40, SAE 20W50, and boron additives, with minimal carbon monoxide emissions and no significant NOx emissions. The choice of fuel and oil type significantly impacts emissions from a portable domestic power generator, with clean energy sources such as compressed natural gas and biofuels being environmentally friendly. CNG fuel in PPG significantly impacts CO emissions, with boron-containing

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additives being more effective in reducing these emissions. The effect of additives in lubricant in ICE produced high torque at low speed, while at high speed, the torque is lower, thereby leading to appreciable greenhouse gas reduction that is economical.

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