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Evaluation of Impact of Additive-Blended Biofuels (ABFs) on Single-Cylinder Motorcycle Engines

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ABSTRACT

The elimination of subsidies for conventional gasoline (E0) in Nigeria has led to a surge in fuel prices, prompting researchers to explore alternative automotive biofuels. Among the promising options are additive-blended biofuels, which can be used in spark ignition engines (S.I.E.). However, biofuels have limitations, such as lower energy density, compatibility issues, and potential infrastructure degradation. Additive-blended biofuels (ABFs) represent an advanced technology that can address these shortcomings and enhance the performance of blended biofuels in automotive engines. In this study, additives were prepared and added to ethanol-gasoline blends, which are referred to as additive-blended biofuels (ABFs). E0 and ABFs were then tested in a single-cylinder motorcycle engine on a chassis dynamometer to evaluate the performance and emission characteristics of ABFs at partial and full load respectively. It was found that ABFs exhibited an increase in engine torque (T), brake power (BP) and brake mean effective pressure (BMEP) by 42.3%, 25.2% and 48.3%, respectively over E0. In addition, ABFs showed a 40% reduction in brake specific fuel consumption (BSFC) compared to E0. On the other hand, the emission measurements showed that NO_X and HC emissions were reduced by 76 % and 35.3 % respectively for ABFs compared to E0.

1. Introduction

Given the abundant ethanol resources in Nigeria and the comparatively high cost of gasoline arising from total subsidies removal, the use of ethanol-gasoline blends is a viable alternative to lower fuel costs and reduce greenhouse gas emissions [1-3]. The decision to use single-cylinder engines in Nigeria is a strategic response to the high cost of fuel. These engines offer improved fuel efficiency, affordable manufacturing and maintenance, adaptability to local transportation needs, ease of maintenance and the potential to reduce environmental impact [2,7,11]. The decision is in line with the economic realities created by the complete removal of fuel subsidies by the Federal Government of Nigeria. This has led to increased transportation costs and impacted various sectors for low-income

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Nigerians, as most vehicles and cars in Nigeria run on conventional gasoline. Figure 1 shows ethanol production in Africa, which present Nigeria as leading candidate. This has further strengthened and renewed the hope of energy sustainability using biofuel as a viable alternative to the expensive and depleting hydrocarbons [12,14,16]

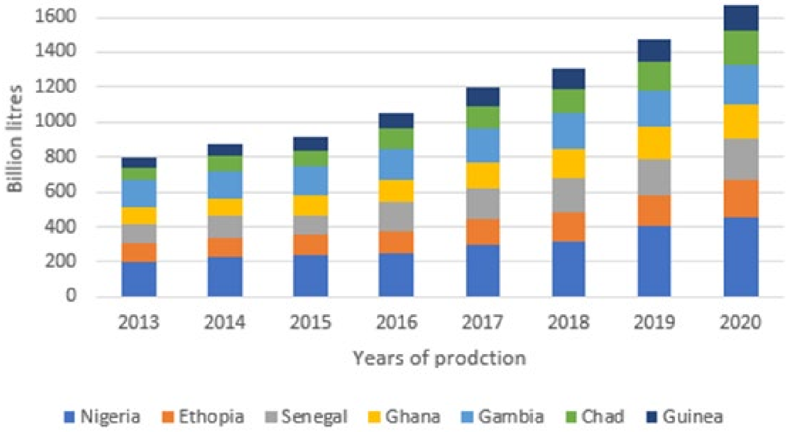

Fig. 1. African ethanol production[1]

However, compressed natural gas (CNG) is also a viable alternative to conventional gasoline, but the use of CNG as a fuel is associated with specific disadvantages, such as limited vehicle range, limited availability of re-fuelling facilities, high initial investment costs, safety risks and competition with the cooking gas in households [3,6,9]. In addition, significant efforts are required from both the government and investors to drive the development of Nigeria's gas infrastructure and distribution facilities to facilitate the rapid adoption of CNG but as it can be seen in Figure 2, CNG usage in Nigeria is not common. The shortage of gas in northern Nigeria poses a challenge to the introduction of CNG as an alternative fuel in Nigeria. Hence the continuous usage of gasoline powered engines.

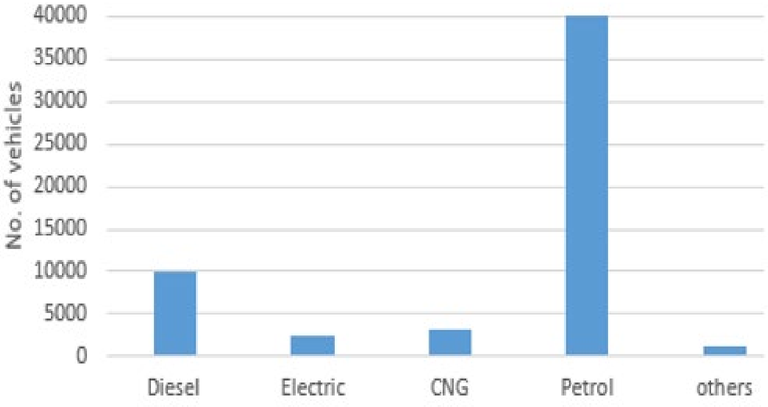

Fig. 2. Fuels used by different vehicles in Nigeria [4]

1.1 Fuel Subsidies Removal in Nigeria

A fuel subsidy is a government discount on the market price of fossil fuel, enabling consumers to pay less than the prevailing rate. This practice, subject to global debates, involves significant financial commitments and raises concerns about its impact on citizens' welfare and a nation's fiscal health. The International Energy Agency reports that the global fossil fuel subsidy reached $1 trillion in 2022, a substantial increase from $325 billion in 2018. This amount surpasses the estimated $204 billion global aid and exceeds the combined revenue of developing countries [5,]. Hence, the call for subsidy removal aim to redirect funds to assist the poor and vulnerable in need of humanitarian aid in Nigeria

Fuel subsidy in Nigeria was introduced in the 70's due to the oil price shock of 1973 and partially abolished in 1986. Despite regular adjustments, the subsidies were maintained until their abrupt removal in 2012, which led to widespread protests and their reintroduction in the same year. Subsidy payments rose to ₦4 trillion (USD 6.088 billion) by 2022 as shown in Figure 3, accounting for 23 percent of the national budget [6,9]. Unable to sustain this, the government announced the abolition of fuel subsidies in June 2023 leading to a rise in the price of gasoline from a subsidized price of #200 per litre in May 2023 to an unsubsidized price of #600 in June 2023 causing a significant increase in the prices of essential goods and services in Nigeria [7-9]

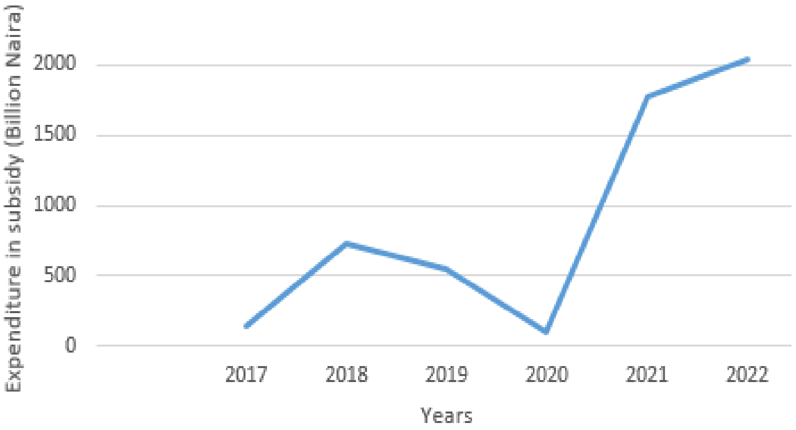

Fig. 3. Subsidy expenditure in Nigeria between 2017 and 2022 [6]

1.2 Ethanol-Gasoline Blends as the Fuel of Choice in Nigeria

Nigeria is identified as the world's leading producer of cassava [7,8] and recorded an approximate cassava production of 34.5 million metric tons (MT) in 2021, surpassing Brazil and Thailand, which produced 24.5 million (MT) and 21.8 million (MT) annually, see Figure 4. Cassava plays a significant role in Nigerian households, serving as a crucial source of both food and income. The cassava tubers are processed by peeling and crushing into granules, which are then either roasted as "Garri" (roasted granules) or fermented into a cooked paste known as "Fufu." Knowing that cassava contains cellulose, hemicellulose, and starch, there is potential for utilizing cassava wastewater in bio-ethanol production [8, 11,13]. The ethanol yield depends on the starch content of the cassava chips; as a reference, 50 kg of chips with a 30% starch content produced 7.5 liters of ethanol, while 20 kg of chips with a 15% starch content yield 3liters of ethanol respectively [9,12].

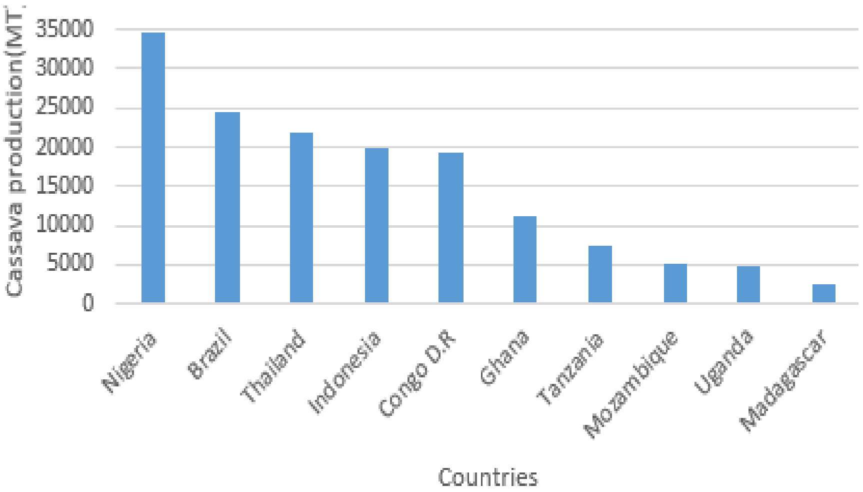

Fig. 4. Cassava production (metric tons) in the world 2021 [8]

In 2017, the National Bureau of Statistics reported that Nigeria's daily consumption of gasoline was 54.3 million liters in the first quarter. To create E10 gasohol (90% gasoline with 10% ethanol), approximately 5,430,000 liters per day or 1,981,950,000 liters of ethanol per year would be required [8,13-15]. This substantial demand could be met by converting waste from 40% of the annual 57 million tons of cassava produced in Nigeria into ethanol[13,17,18]

Ethanol is gaining prominence as a promising fuel for internal combustion engines due to its renewable nature, blending flexibility with gasoline, high oxygen content, and reduced greenhouse gas emissions [16-18]. As shown in Figure 5, ethanol comprising two carbon atoms, six hydrogen atoms, and one oxygen atom [17,19,23], it is produced through the fermentation of sugars from sources like corn, sugarcane, and cellulose. To overcome challenges such as lower energy density, infrastructure adjustments, and compatibility issues, a promising strategy involves creating ethanol-gasoline blends with additives [19-21]. This innovative technology aims to address high gasoline costs, enhance engine performance, and reduce emissions, contributing to a more sustainable and efficient fuel solution [20,22]. Hydrogen atoms support the complete combustion of ethanol, as shown in Eq. (1) and contribute to the formation of water molecules as a by-product. However, an insufficient oxygen during combustion results in incomplete combustion, producing carbon monoxide (CO) and partially oxidized compounds that contribute to the emission of harmful pollutants such as CO [9,15,16,21].

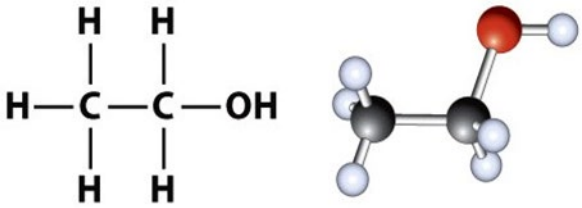

Fig. 5. Structural formular of ethanol [9]

$$C_2H_5OH\ (l) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (g) \quad (1)$$

The increasing addition of ethanol to gasoline to reduce greenhouse gas emissions has significantly changed the composition and properties of fuels. While ethanol-blended fuels (EBFs) offer environmental benefits, they also pose challenges in terms of engine performance and emissions [21,23,25]. The addition of different concentrations of additives to these blended fuels aims to improve fuel economy, combustion efficiency and emissions. However, the interactions between these additive concentrations, EBFs and their overall effects on engine performance and emissions are not yet sufficiently known. Therefore, this study aims to investigate the effect of polyisobutylene additives at different concentrations in EBFs on the performance and emissions of a single-cylinder motorcycle engine

1.3 Additive Blended Fuels (ABFs)

ABFs are a promising advancement for gasoline engines, offering improved performance and reduced emissions. These fuels combine gasoline with additives like ethanol, methanol, or butanol, enhancing fuel properties and boosting engine power and efficiency [10,26,27]. Additionally, additive-blended fuels contribute to cleaner air by reducing emissions of CO, HC, NO_X [27,28,30].

2. Methodology

950ml of commercial gasoline (RON95) representing 95% gasoline in the blends and 50ml of ethanol representing 5% ethanol in the blend were weighed and poured into a mixing flask and PIB polyisobutylene additive was added at the proportion shown in Table 1. This process was repeated five times to produce a total of five ABFs.

Table 1
Testing motorcycle (150cc) and chassis dynamometer technical specification

Base fuel	% Gasoline	% Ethanol	Additive (mg/l)	Sample code
100	100	-	-	E0
“	95	5	100	E5P100
“	95	5	500	E5P500
“	75	25	100	E25P100
“	75	25	500	E25P500
	100	-	100	E0P100

Formulated blended fuels were tested on a motorcycle engine mounted on chassis dynamometer with technical specifications in Table 2. The engine was tested under two conditions: Half Load (HL) and Full Load (WOT) using specific fuel blend for each test condition and the tests were conducted at road speeds of 30, 40, 50, 60 and 90 km/h. These speeds correspond to the speed limits set by the Federal Road Safety Commission of Nigeria for rural, urban and highway driving. In this study, performance and emission tests measured speeds in terms of (km/h), this is in compliance with FRSC driving regulations which specified road speeds in (km/h) as the standardize testing procedure for urban, rural and highway driving. The mixed gas sample was analyzed using a gas analyzer (model number: QGA 6000) to determine the concentration of HC, CO, CO_2, and NO_X.

Table 2
Testing motorcycle (150cc) and chassis dynamometer technical specifications

Component	Specifications
Engine	4-stroke, SOHC
Dimension	1,920mm x 680mmx 1,130mm
Weight	105kg
No. of cylinder	1
Fuel capacity	6.6 Liters
Bore x stroke	5.74cm x 5.78cmm
Air/fuel ratio	Stoichiometric or lean
Carburettor	Spark ignition
Maximum power	10.3hp
Cooling system	Air-cooled
Fuel type	Gasoline
Chassis dynamometer	Model no: MDC 400L

3. Results

The experimental outcomes of testing ABFs and E0 in a single-cylinder motorcycle engine are presented in the Table 3

Table3
Performance and emission tests result on Motorcycle engine

Engine testing condition	Half-load					Full-load				
Road speed (km/h)	30	40	50	60	90	30	40	50	60	90
Additive (mg/l) in ABFs	100	100	500	100	500	100	100	500	100	500
% Ethanol in ABFs	-	5	5	25	25	-	5	5	25	25
% Gasoline in ABFs	100	95	95	75	75	100	95	95	75	75
Torque (Nm) ABFs	4.6	4.5	5.5	5.7	5.9	4.8	5	5.6	6.1	6.9
100 % gasoline	4.2	3.9	4.6	4.6	4.6	4.2	3.9	4.6	4.8	5.3
Brake power (kW) ABFs	2.2	2.1	2.9	3.6	5.8	2.6	2.7	3.6	4.0	4.5
100 % gasoline	2.0	1.9	1.9	2.5	4.0	2.5	2.5	3.1	3.0	3.5
BSFC (g/kWh) ABFs	1.2	1.3	1.7	2.1	2.3	1.3	1.5	1.9	2.5	2.8
100 % gasoline	3.1	4.2	4.6	4.8	5.3	1.7	2.8	3.6	4.4	5.6
BMEP Cbar) ABFs	3.9	3.8	4.3	4.7	4.9	3.8	4.2	4.5	4.9	5.7
100% gasoline	3.4	2.9	3.2	3.1	3.3	3.1	2.8	3.1	3.2	3.5
NO_X (g/km) ABFs	1007	1068	1239	1286	2301	1021	1098	1342	1477	2594
100% gasoline	1451	1578	1720	2998	3015	1553	1602	1543	1790	4005
CO (g/km) ABFs	1985	2060	2211	2240	2498	2189	2365	2540	2855	3025
100% gasoline	1287	1328	2247	2280	2390	1980	2295	2488	2801	2945
HC (g/km) ABFs	1034	1279	1290	1506	1650	1125	1375	1389	1780	1980
100% gasoline	1209	1886	2184	2882	3550	1525	1732	1945	2150	2444

3.1 Results and Discussion

This section provides graphical representations and discussion of the performance and emission results for ABFs and E0 across different road speeds and testing conditions.

3.2 Torque (T)

Figure 6 and Figure 7 illustrate the engine torque comparison between ABFs and E0 at partial and full loads. At 90km/h PL, E0 exhibits a peak torque value of 4.30 Nm. However, as the concentration of additives in the blends increases, there is a corresponding rise in torque, reaching a peak of 5.94Nm for ABFs at 90km/h. During partial and full load operations, a noticeable torque gap exists, with ABFs displaying 42.3% torque increase over E0. This enhancement is attributed to the higher-octane rating of ABFs, which improves combustion efficiency and consequently results in increased torque values, particularly at full load. Higher additive concentrations in the fuel blends correspond to higher torque value, making the highest blended ABFs reference values in terms of torque performance. On average, ABFs yielded torque of 7.23 Nm, while E0 yielded 4.71Nm, a difference of 37.3% in average torque for ABFs and E0 was achieved. Again, this difference is mainly due to factors, such as lower intake air temperature and higher oxygen content in ABFs and all of which contributed to the higher torque compared to E0 for the same test cycle.

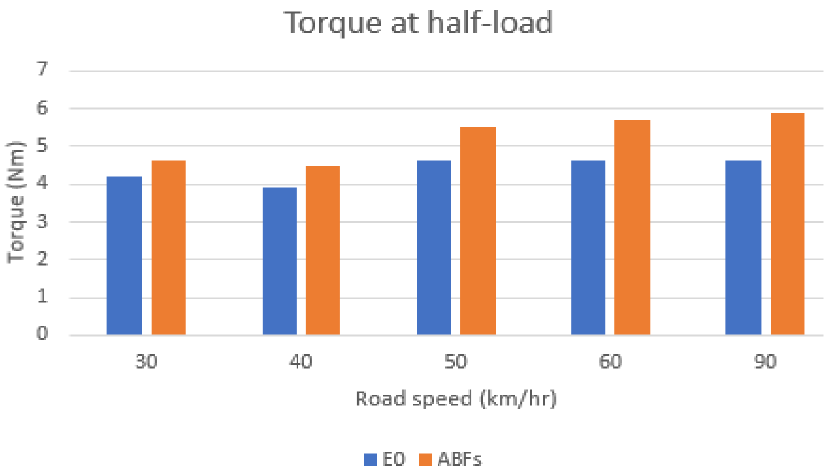

Fig. 6. Torque for E0 and ABFs at half-load

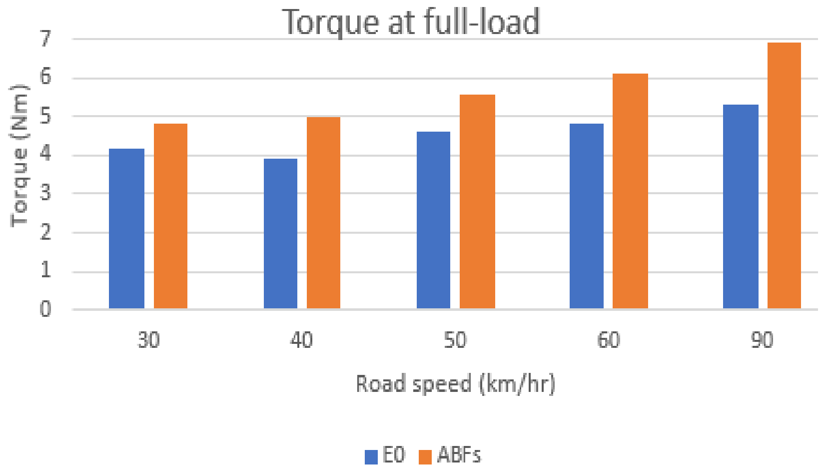

Fig. 7. Torque for E0 and ABFs at full-load

3.3 Brake Power (Bp)

Referring to Figure 8 and Figure 9 which depict the comparison of brake power (Bp) between ABFs and E0. Notably, E0 yielded the lowest values, registering 1.59 kW at 40km/h and 1.94 kW at 90km/h for half-load and full load operations, respectively. Conversely, ABFs achieved the highest power output, reaching 3.71 kW at 90km/h half-load and 5.65kW at 90km/h during full-load operations. The diminished Bp for E0 was attributed to a delayed ignition period and lower flame speed for pure gasoline. It should be noted that, ABFs exhibited a substantial increase in Bp output, averaging 45.2% more than E0 for both partial and full load operations. This enhancement proved the positive impact of ABFs on power generation in comparison to E0.

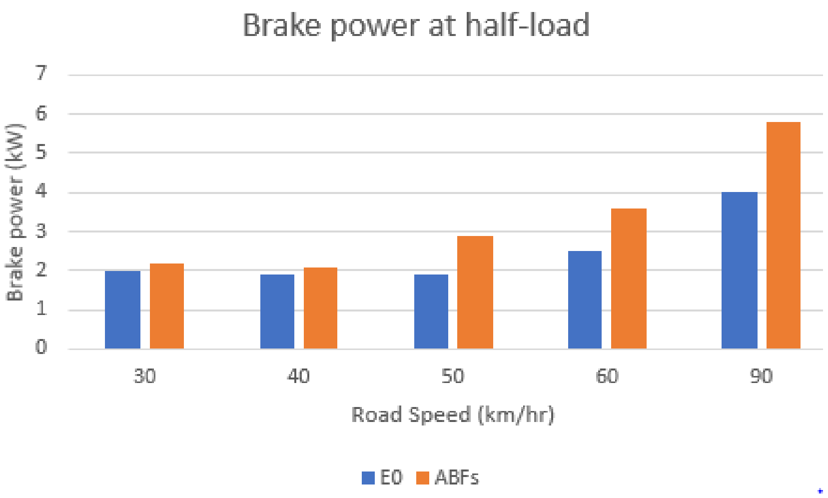

Fig. 8. Brake power for E0 and ABFs at half-load

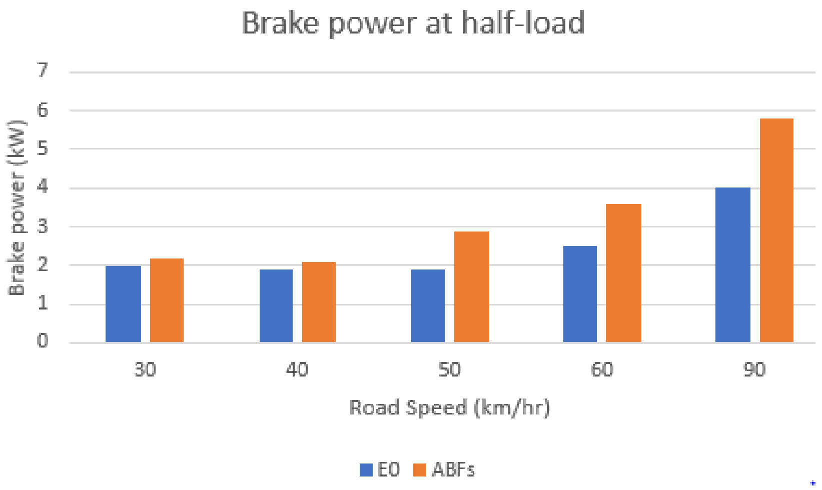

Fig. 9. Brake power for E0 and ABFs at full-load

3.4 Brake Specific Fuel Consumption (BSFC)

Figure 10 and Figure 11 illustrate BSFC for ABFs and E0. E0 exhibits higher BSFC than ABFs at both partial and full load. On average, E0 requires 2.537 g/kW-h, while ABFs demands 1.034 g/kW-h, indicating a substantial 40% reduction in BSFC compared to E0. Consequently, ABFs demonstrates superior BSFC performance when compared to E0. The fuel consumption of ABFs is lower at all engine speeds and test conditions. This is to be expected as ABFs have higher energy density compared to E0. The average energy content of ABF is 0.7654 g/cm3, while that of E0 is 0.7244 g/cm3, resulting in lower engine efficiency, higher fuel consumption and emissions under E0 tests. At PL, the engine is not running at maximum power and therefore the BSFC value is generally lower than in WOT. In particular, at the average speed of 30 km/h PL, ABFs showed a reduction in BSFC of 18.3% compared to E0 with 12.5% reduction. Generally, a significant decrease in fuel consumption for ABFs with an increase in additive concentration was observed, at 40km/h WOT, ABF with 50mg/l of additive concentration outperformed other additive blended ratios and showed 12.3% reduction in BSFC compared to other additive blended fuels and 23.7% reduction over E0. This consistent decrease in BSFC for ABFs was due to higher BTE and BP produced by ABFs as the road speed increases.

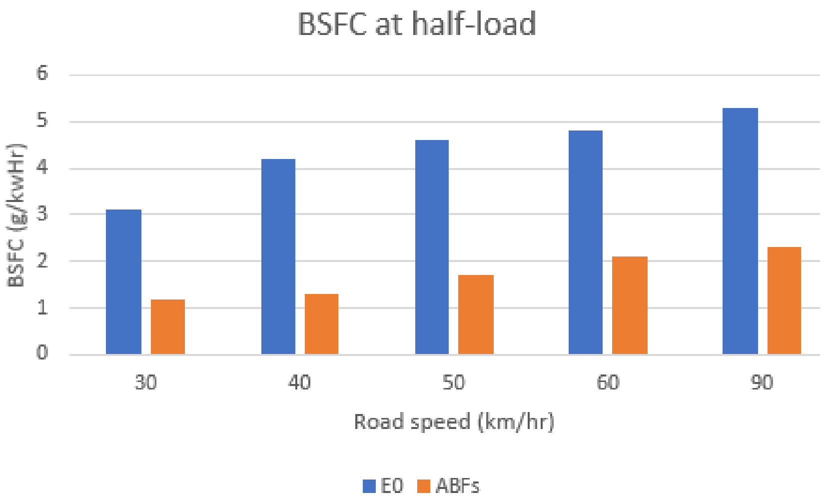

Fig. 10. BSFC for E0 and ABFs at half-load

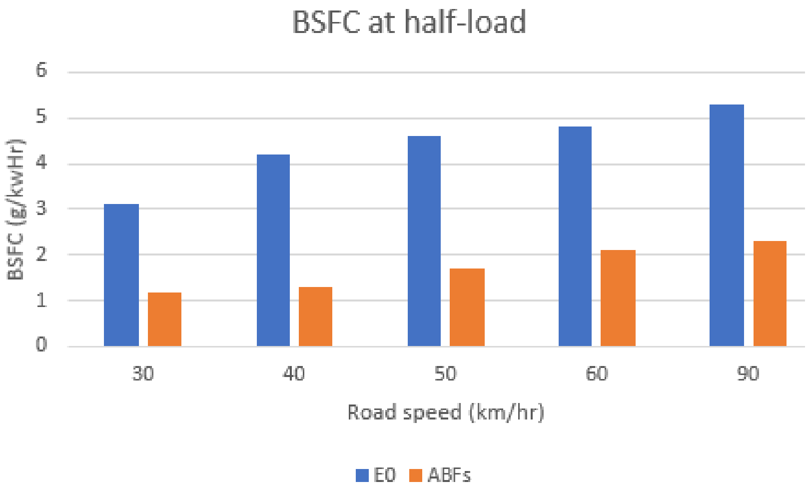

Fig. 11. BSFC for E0 and ABFs at half-load

3.5 Brake Mean Effective Pressure (BMEP)

In Figure 12 and Figure13, BMEP for ABFs and E0 at different road speeds and operating conditions are presented. At the highest road speed of 90km/h, ABFs has a BMEP value of 4.79 bar and thus outperforms E0, which has 3.87 bar. The introduction of a higher percentage of additives in the mixture leads to an increase in BMEP, especially under full load conditions (4.5bar, 4.9bar, and 5.7 bar), resulting in a notable discrepancy in BMEP performance between ABFs and E0. On average, BMEP performance of ABFs is 48.3% higher than E0 for the same test condition. It's noteworthy that there is a linear relationship between BMEP and Bp. A higher BMEP corresponds to a higher power output at optimal fuel efficiency, while a decrease in BMEP leads to a lower power output. Hence, increased BMEP contributes to improved thermal efficiency, lower fuel consumption and emissions**.**

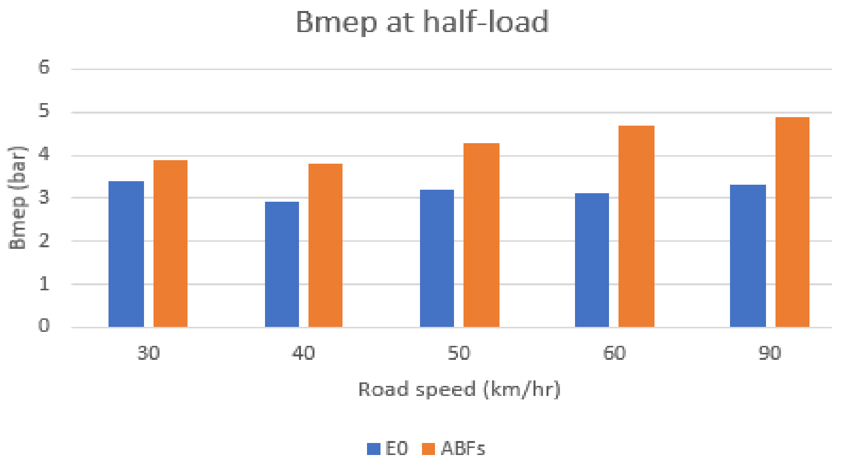

Fig. 12. BMEP for E0 and ABFs at half-load

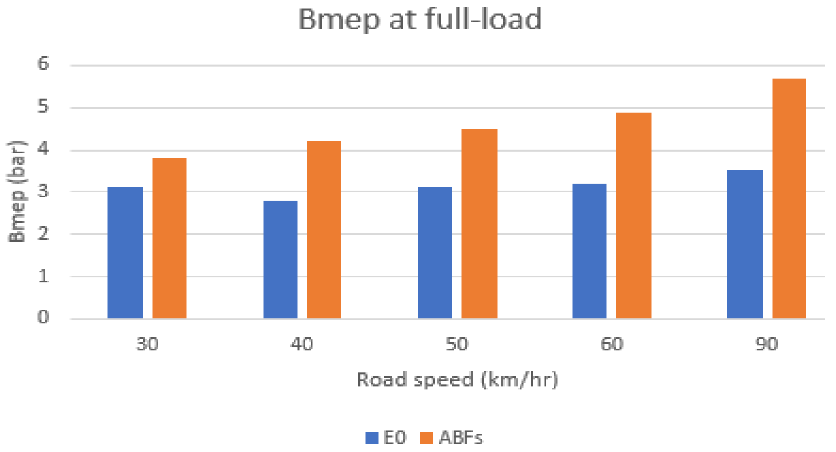

Fig. 13. BMEP for E0 and ABFs at full-load

3.6 NOX Emissions

As shown in Figures 14 and Figure 15, the NOX emission concentration for ABFs and E0. It can be seen that E0 has the highest NO_X emissions at part-load, namely 3015 g/km, while ABF has 2301 g/km. Consequently, ABF was able to reduce NO_X emissions by 36.3% compared to E0 under the same engine operating conditions. The higher combustion temperature of E0 resulted in higher NO_X emissions as it is a standard fuel with no special additives to reduce NO_X emissions. At part-load, ABFs produced a lower combustion temperature that allowed the cool gases to flow through the combustion chamber, resulting in lower NO_X emissions. However, at WOT, E0 exhibit 63.5% and 72.7% increase in NO_X emissions at 30km/h and 40km/h respectively. For ABFs, NO_X emissions at this speed were found to be 6.4 % and 4.8% lower compared to E0 under WOT test conditions. This represents a notable increase in NO_X for ABFs. The higher NO_X emissions is mainly due to increase ethanol in the blends which enrich the blend with excess O_2, thus making it more oxygenated fuel. As a result, this leads to oxidation of nitrogen from the nitrogenated fuel, ultimately increase combustion temperature and facilitate the formation of NO_X. As the driving speed increased above 40km/h onwards, the concentration of NO_X emissions also increased.

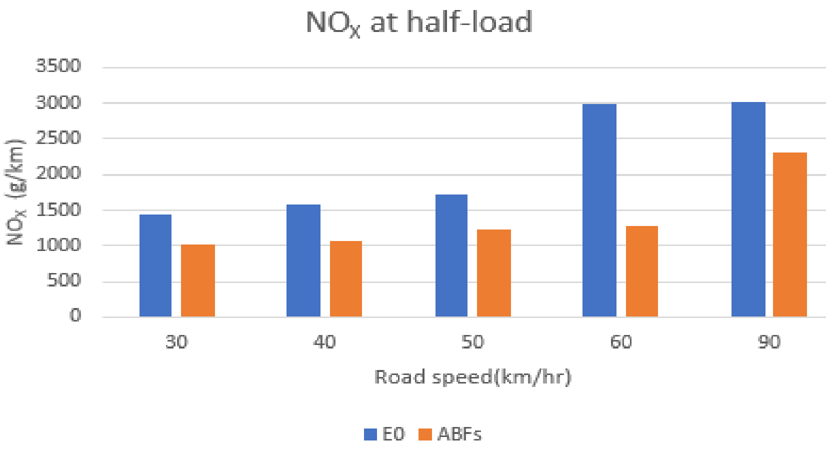

Fig. 14. NO_X for E0 and ABFs at full-load

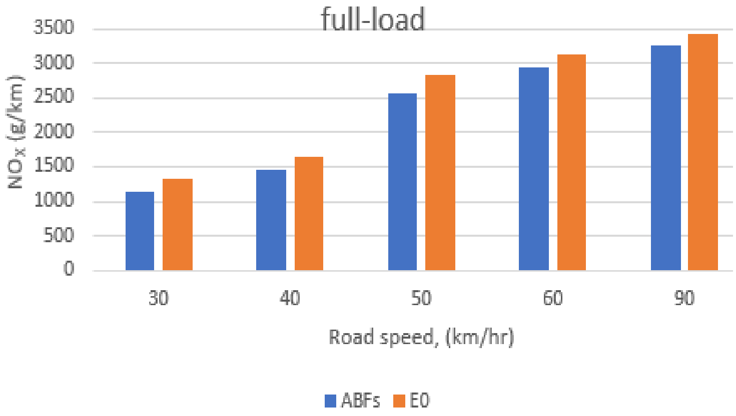

Fig. 15. NO_X for E0 and ABFs at half-load

3.7 CO Emissions

Figures 16 and Figure 17 show the CO emissions for both E0 and ABFs under different engine conditions. Surprisingly, ABFs has 13.5% higher CO emissions than E0 under full-load condition. This increased in CO emission for ABFs was attributed to problems such as poor air-fuel ratio, incomplete combustion, ignition delay and increased flame temperature. However, E0 outperforms ABFs in CO emissions, confirming its effectiveness in supporting complete combustion. The data suggests that E0 has better combustion characteristics compared to ABFs across a range of engine conditions. At 30 km/h part-load, there was 8.5% reduction in CO for ABFs. At 40km/hr full-load, there was a sudden increase in CO emission registering 14.6% compared to PL testing conditions. At 50km/hr, the CO emission increase again and recorded 11.23%, 12.3% and 13.6 at 50km/hr, 60km/hr, and 90km/hr respectively. This indicates that under full-load condition, additive blended fuels were less effective in reducing CO emissions compared to E0.

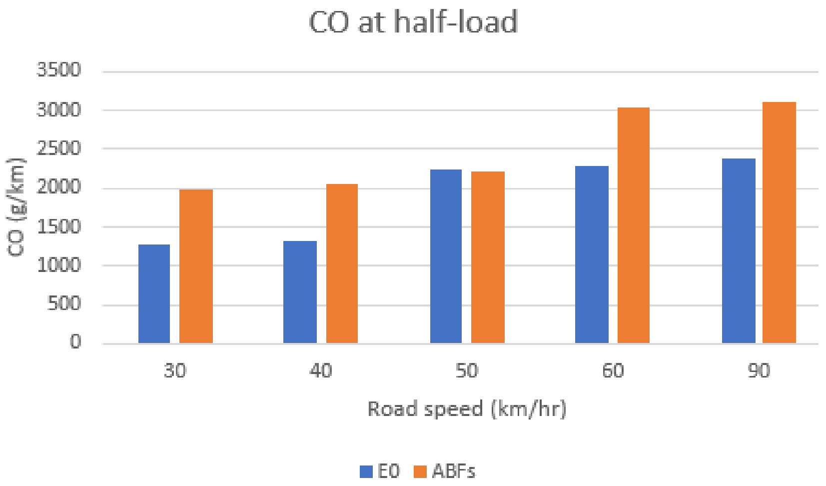

Fig. 16. CO for E0 and ABFs at half-load

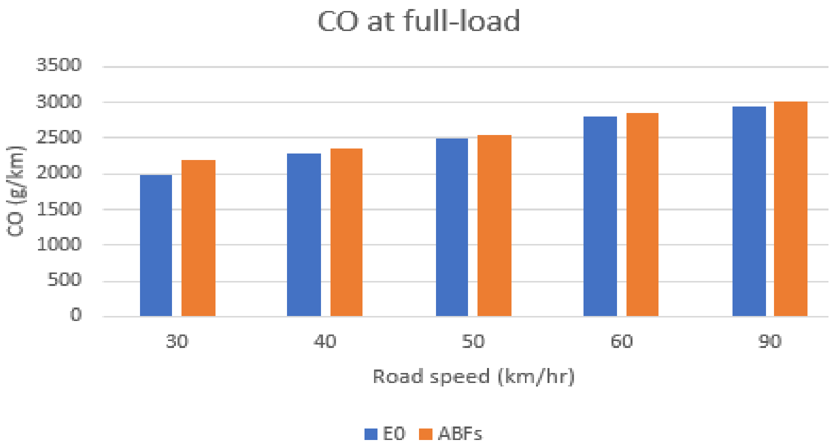

Fig. 17. CO for E0 and ABFs at full-load

3.8 HC Emissions

Figure 18 and Figure 19 illustrate HC emission concentrations for ABFs and E0. As it can be seen, E0 shows higher HC emissions, averaging 25.3% more than ABFs under full load conditions, indicating incomplete combustion. ABFs demonstrates lower HC emissions, a notable reduction in HC emissions as the additive content in the fuel blend increased was linked to its support for complete combustion with fewer harmful pollutants. This was maintained at the speeds of 40km/h, 60km/h and 90km/h under full-load as the proportion of additives in the blends increased and were lower compared to E0 under the same speeds and test conditions. On average, ABFs reduced HC emissions by 15.6% compared to E0. This value is lower compared to the performance of the ABFs for NO_X, CO and CO_2. This result maybe be due to gaps that trap the fuel in small quantities in the combustion chamber especially in the area of the volume between the piston and rings and the cylinder head gasket and cannot burn completely during the power stroke leading to loss of engine power.

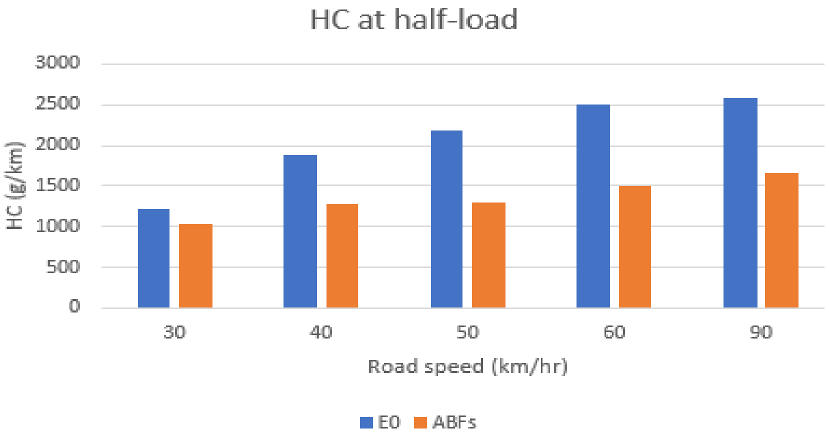

Fig. 18. HC for E0 and ABFs at full-load

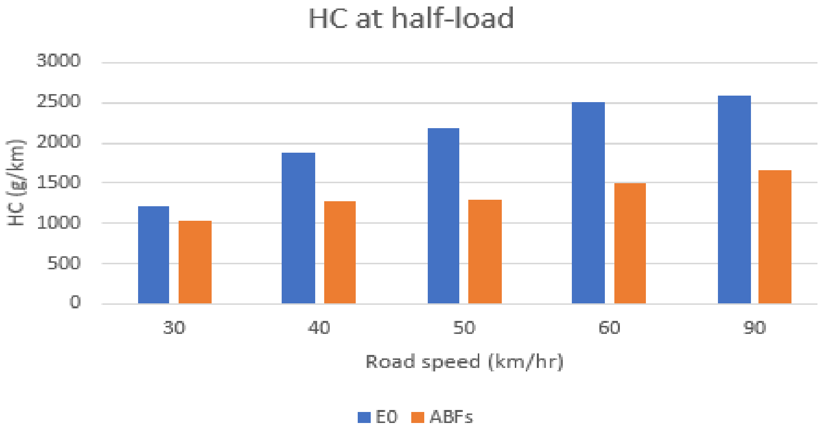

Fig. 19. HC for E0 and ABFs at half-load

4. Conclusions

Based on this study, the superiority of ABFs over E0 in terms of performance and emissions has been confirmed. Nevertheless, it's important to mention that ABFs exhibit a slight increase in CO emissions. Overall, the superiority of ABFs over E0 can be summarized as follows:

i. ABFs produced higher torque at all engine speeds with an average increase of 42.3 %.
ii. ABFs produced an increase of 25.2 % in Bp.
iii. ABFs produced higher BMEP averaging 48.3%.
iv. ABFs reduced NO_X emission by 56%.
v. E0 produced higher HC emission averaging 35.3% compared to ABFs

5. Recommendations

Further study is required to investigate the higher CO emission (up to 14%) produced by ABFs under all tests conditions and how it can be minimized. The study has offered areas of future research by adopting the methodology for the implementation in four- cylinder engines which will serve as a new platform for education and research training. The adoption of outcome of this study will in no doubt meet the government requirements on alternative renewable fuels in transportation sector in Nigeria. The study has discovered the usefulness for the food wastes in Nigeria as a potential source of bio-ethanol.

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References

[1] Jekayinfa, Simeon Olatayo, Joseph Ifeolu Orisaleye, and Ralf Pecenka. "An assessment of potential resources for biomass energy in Nigeria." *Resources* 9, no. 8 (2020): 92. https://doi.org/10.3390/resources9080092

[2] Ndubuisi, I. A., Ogbonna, J. C., Murata, Y., & Omae, H. (n.d.). *Production of Ethanol from Cassava Processing Wastes in Nigeria*.

[3] Olubomehin, Oladipo O. "The development and impact of motorcycles as means of commercial transportation in Nigeria." *Research on Humanities and Social Sciences* 2, no. 6 (2012).

[4] Alimin, Ahmad Jais, and Olawale Kazeem Babalola. "A Review on the Influence of Additive Blended Biodiesel to the Performance and Emission Characteristics of Heavy-Duty Diesel Engines." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 111, no. 1 (2023): 180-193. https://doi.org/10.37934/arfmts.111.1.180193

[5] Verma, Gaurav, Rajesh Kumar Prasad, Rashmi A. Agarwal, Siddhant Jain, and Avinash Kumar Agarwal. "Experimental investigations of combustion, performance and emission characteristics of a hydrogen enriched natural gas fuelled prototype spark ignition engine." *Fuel* 178 (2016): 209-217. https://doi.org/10.1016/j.fuel.2016.03.022

[6] Owoeye, T. (2023). Concerns over compressed natural gas-run buses in Nigeria. Gas Outlook.

[7] Ang, Chuen Yuen, Ahmad Jais Alimin, and Fuei Pien Chee. "Real-driving emissions of a Euro-4 compliant diesel-fueled commercial truck in Malaysia: Concept and issues related." In *AIP Conference Proceedings*, vol. 2530, no. 1. AIP Publishing, 2023. https://doi.org/10.1063/5.0121265

[8] Ibeneme, Ikechukwu Obiuto, and Joshua O. Ighalo. "Implementation of CNG as an alternative fuel for automobiles in Nigeria: benefits and recommendations." *Int. J. Eng. Res. Technol* 9, no. 7 (2020): 1516-1522.

[9] Ozili, Peterson K., and Kingsley Obiora. "Implications of fuel subsidy removal on the Nigerian economy." In *Public Policy's Role in Achieving Sustainable Development Goals*, pp. 115-130. IGI Global, 2023. https://doi.org/10.4018/978-1-6684-8903-1.ch007

[10] Bielaczyc, Piotr, Joseph Woodburn, Dariusz Klimkiewicz, Piotr Pajdowski, and Andrzej Szczotka. "An examination of the effect of ethanol–gasoline blends' physicochemical properties on emissions from a light-duty spark ignition engine." *Fuel Processing Technology* 107 (2013): 50-63. https://doi.org/10.1016/j.fuproc.2012.07.030

[11] Sakthivel, P., K. A. Subramanian, and Reji Mathai. "Comparative studies on combustion, performance and emission characteristics of a two-wheeler with gasoline and 30% ethanol-gasoline blend using chassis dynamometer." *Applied Thermal Engineering* 146 (2019): 726-737. https://doi.org/10.1016/j.applthermaleng.2018.10.035

[12] Wróblewski, Piotr, and Robert Rogólski. "Experimental analysis of the influence of the application of TiN, TiAlN, CrN and DLC1 coatings on the friction losses in an aviation internal combustion engine intended for the propulsion of ultralight aircraft." *Materials* 14, no. 22 (2021): 6839. https://doi.org/10.3390/ma14226839

[13] Yeşilyurt, M. K., D. Erol, H. Yaman, and B. Doğan. "Effects of using ethyl acetate as a surprising additive in SI engine pertaining to an environmental perspective." *International Journal of Environmental Science and Technology* (2022): 1-30. https://doi.org/10.1007/s13762-021-03706-3

[14] Zaharin, Muhammad Syarifuddin Mohamed, Nik Rosli Abdullah, Haji Hassan Masjuki, Obed M. Ali, Gholamhassan Najafi, and Talal Yusaf. "Evaluation on physicochemical properties of iso-butanol additives in ethanol-gasoline blend on performance and emission characteristics of a spark-ignition engine." *Applied Thermal Engineering* 144 (2018): 960-971. https://doi.org/10.1016/j.applthermaleng.2018.08.057

[15] Krajang, Morakot, Kwanruthai Malairuang, Jatuporn Sukna, Krongchan Rattanapradit, and Saethawat Chamsart. "Single-step ethanol production from raw cassava starch using a combination of raw starch hydrolysis and fermentation, scale-up from 5-L laboratory and 200-L pilot plant to 3000-L industrial fermenters." *Biotechnology for Biofuels* 14 (2021): 1-15. https://doi.org/10.1186/s13068-021-01903-3

[16] Dhande, D. Y., Nazaruddin Sinaga, and Kiran B. Dahe. "Study on combustion, performance and exhaust emissions of bioethanol-gasoline blended spark ignition engine." *Heliyon* 7, no. 3 (2021). https://doi.org/10.1016/j.heliyon.2021.e06380

[17] Tesfa, Belachew, Rakesh Mishra, Fengshou Gu, and A. D. Ball. "Water injection effects on the performance and emission characteristics of a CI engine operating with biodiesel." *Renewable Energy* 37, no. 1 (2012): 333-344. https://doi.org/10.1016/j.renene.2011.06.035

[18] Tian, Bo, Anxiong Liu, Cheng Tung Chong, Luming Fan, Shiyao Ni, Andrew Hull, Angelica Hull, Stelios Rigopoulos, Kai H. Luo, and Simone Hochgreb. "Measurement and simulation of sooting characteristics by an ATJ-SKA biojet fuel and blends with Jet A-1 fuel in laminar non-premixed flames." *Combustion and Flame* 233 (2021): 111582. https://doi.org/10.1016/j.combustflame.2021.111582

[19] Stępień, Zbigniew, Ireneusz Pielecha, Filip Szwajca, and Wojciech Cieślik. "Effects of ethanol admixtures with gasoline on fuel atomization characteristics using high-pressure injectors." *Energies* 15, no. 8 (2022): 2926. https://doi.org/10.3390/en15082926

[20] Stępień, Zbigniew, Grażyna Żak, Jarosław Markowski, and Michał Wojtasik. "Investigation into the impact of the composition of ethanol fuel deposit control additives on their effectiveness." *Energies* 14, no. 3 (2021): 604. https://doi.org/10.3390/en14030604

[21] Sukirno, Ir, and Luki Farhandika. "Synthesis and characterization of polyisobutylene-amine from polyisobutylene and tetraethylenepentamine and its performance as deposit control additive in one cylinder gasoline engine." In *AIP Conference Proceedings*, vol. 2255, no. 1. AIP Publishing, 2020. https://doi.org/10.1063/5.0021782

[22] Sharudin, Hazim, Nik Rosli Abdullah, G. Najafi, Rizalman Mamat, and H. H. Masjuki. "Investigation of the effects of iso-butanol additives on spark ignition engine fuelled with methanol-gasoline blends." *Applied Thermal Engineering* 114 (2017): 593-600. https://doi.org/10.1016/j.applthermaleng.2016.12.01

[23] Normann, Fredrik, Klas Andersson, Bo Leckner, and Filip Johnsson. "High-temperature reduction of nitrogen oxides in oxy-fuel combustion." *Fuel* 87, no. 17-18 (2008): 3579-3585. https://doi.org/10.1016/j.fuel.2008.06.013

[24] Nwufo, O. C., C. F. Nwaiwu, C. J. O. I. Ononogbo, J. O. Igbokwe, O. M. I. Nwafor, and E. E. Anyanwu. "Performance, emission and combustion characteristics of a single cylinder spark ignition engine using ethanol–petrol-blended fuels." *International Journal of Ambient Energy* 39, no. 8 (2018): 792-801. https://doi.org/10.1080/01430750.2017.1354318

[25] Myung, Cha-Lee, Juwon Kim, Kwanhee Choi, In Goo Hwang, and Simsoo Park. "Comparative study of engine control strategies for particulate emissions from direct injection light-duty vehicle fueled with gasoline and liquid phase liquefied petroleum gas (LPG)." *Fuel* 94 (2012): 348-355. https://doi.org/10.1016/j.fuel.2011.10.041

[26] Nnaemeka, Abonyi Nichodemus. "Environmental pollution and associated health hazards to host communities (Case study: Niger delta region of Nigeria)." *Central Asian Journal of Environmental Science and Technology Innovation* 1, no. 1 (2020): 30-42. https://doi.org/10.22034/CAJESTI.2020.01.04

[27] Nimje, P., D. Dandotiya, and N. D. Banker. "An experimental investigation of MPFI gasoline engine fuelled with ethanol and n-butanol." *International Journal of Environmental Science and Technology* (2021): 1-10. https://doi.org/10.1007/s13762-021-03242-0

[28] Mandloi, R. K., and Prakhar Chansauria. "Effect of SI Engine Operating Temperature Fuelled with Gasoline and Ethanol Blends for Better Emission Characteristics." In *2018 International Conference on Renewable Energy and Power Engineering (REPE)*, pp. 61-64. IEEE, 2018. https://doi.org/10.1109/REPE.2018.8657672

[29] Misra, R. D., and M. S. Murthy. "Straight vegetable oils usage in a compression ignition engine—A review." *Renewable and Sustainable Energy Reviews* 14, no. 9 (2010): 3005-3013. https://doi.org/10.1016/j.rser.2010.06.010

[30] Mahbub, Nafisa, Eskinder Gemechu, Hao Zhang, and Amit Kumar. "The life cycle greenhouse gas emission benefits from alternative uses of biofuel coproducts." *Sustainable Energy Technologies and Assessments* 34 (2019): 173-186. https://doi.org/10.1016/j.seta.2019.05.001