Investigating the Influence of Rubber Seed Oil and Used Cooking Oil on Diesel

Kazeem Aderemi Bello[1], *Temitayo* Mufutau Azeez[2*], *Olayinka* Mariam Tawose[3], *Kazeem* Olabisi Odesanya[4], *Odumuyiwa* A Odumosu[5], and *Olatunde* Ajani Oyelaran[6]

[1,6]Department of Mechanical Engineering, Federal University Oye Ekiti, 371104, Nigeria
[2]Department of Mechanical & Mechatronics Engineering, Afe Babalola University, Ado Ekiti, Nigeria
[3]Department of Animal Production and Health, Federal University Oye Ekiti, Nigeria
[4]Department of Mechanical Engineering, Lagos State University, Nigeria
[5]Department of Industrial Technical Education, Tai Solarin University of Education, Ijagun, Nigeria

Abstract: In view of the multiple issues associated with fossil fuels, an environmentally friendly and economically feasible alternative energy source is required. While sufficient research has been conducted on diesel and single biodiesel blends, only a few studies on dual blended biodiesel have been conducted in this respect. The significance of blending waste cooking oil and rubber seed oil mixed with diesel at different proportions is investigated in the present research. At different braking power levels, the impacts of dual biodiesel (DB) performance and exhaust fumes on the stationary single-cylinder four-stroke air-cooled diesel engine with electrical loads were evaluated. The engine speed was held constant at 2800 rpm all through the testing. Each load was tested three times. Blend A had relatively better thermal and mechanical efficiency than diesel, based on experimental investigation results. Blends B and C were almost identical to the diesel values. Specific fuel consumption statistics for dual biodiesel blends were similar to diesel. The influence of different mixes on CO, CO2, HC, NOx, and smoke opacity were studied using emission tests. In contrast to diesel, the dual biodiesel blends produced more fumes, hydrocarbons, and nitrogen oxides. Dual biodiesel blends, on the other hand, have lesser emissions temperatures than diesel.

Keywords: Alternative fuel, biodiesel, dual biodiesel, emission analysis, diesel engine.

*Corresponding author: Azeeztemitayo221@abuad.edu.ng

1 Introduction

The energy available from various sources, including alternative energy sources, drives the world's domestic and industrial needs. Global energy consumption is rising at a higher rate than population growth and energy demands due to rapid development in both developed and emerging nations [1]. To meet this requirement associated with the growing demand for energy, efforts are being made to find another renewable alternative. Environmental and health issues caused by exhaust gas emissions from the use of fossil fuels also motivate the search for a more environmentally friendly alternative. More emphasis is being placed on the feasibility of biodiesel and ethanol biofuels because they are renewable, and it is expected that they will address energy self-sufficiency, environmental concerns, and an increase in rural economics. Trans-esterified biodiesel shares many of the same characteristics as regular biodiesel [2]. Reducing the viscosity of vegetable oil is expected to be accomplished effectively through transesterification [3]). Oils from palm, soy, rapeseed, and peanuts could be used to make biodiesel. Food security gives non-edible oils like Castrol, jatropha, Karanja, mahua, rubber, cottonseed, calabash, and many others a competitive advantage over edible oils. It should be emphasized that cost and availability are the primary considerations when choosing a feedstock for the manufacturing of biodiesel [4].

Biodiesel's low heating value reduces engine power and increases fuel consumption. However, when a biodiesel blend with diesel is used, these problems are greatly reduced [5-9]. Fewer biodiesel blends boost braking thermal performance, reduce fuel intake and produce fewer engine emissions than pure diesel, according to [10]. Meanwhile, a blend of diesel fuel, bioethanol, and sunflower methyl ester serves as a diesel engines fuel, the proportion of CO content in emissions drops as the proportion of bioethanol in the blends increases. Muralidharan. K et al.(2011) showed that whenever biodiesel made from pongamiapinnata oil by transesterification is utilized in a C. I engine, blend B5 exhibits decreased engine emissions of unburnt hydrocarbon, carbon monoxide, oxides of nitrogen, and carbon dioxide at full load [11]. According to Srivastava and Verma (2008), the greatest thermal performance of Karanja oil with methyl ester was roughly 24.9% at maximum power output, whereas diesel had a maximum thermal efficiency of 30.6% [12]. According to Lawrence et al. (2011), utilising prickly poppy methyl ester combined with diesel in a diesel engine boosted brake thermal performance and output while decreasing specific fuel usage. The pattern seen is because bioethanol has fewer carbon particles than diesel [13]. When contrasted with petroleum diesel, biodiesel lessens CO and HC emissions owing to its high oxygen proportion and lower carbon-to-hydrogen concentration. Biodiesel reduces a considerable quantity of CO_2 based on CO_2 life cycle study. Biodiesel, as contrasted with petroleum diesel, will decrease CO_2 emissions by 50-80% [14]. Ramadhas et al. (2008) explored dual fuel mode operating employing coir-pith developed producer gas and rubber seed oil as pilot fuel and came to the conclusion that non-edible oils are not suitable as pilot fuel, hence removing the necessity for petroleum diesel [15]. Srithar et al. (2017) tested two biodiesels blended with diesel as a replacement fuel for a single-cylinder high-speed diesel engine, which ran effectively during testing on dual biodiesels and their mixes [16].

According to Wang et al. (2006), vegetable oils have roughly the same thermal values as diesel fuel. He also discovered that vegetable oil and its blends have approximately equal fuel consumption and engine power output to diesel. Several research have been

undertaken on the usage of biodiesel and its blends in engines. The bulk of studies, however, concentrated on mono biodiesel and its blends [17]. Based on past study, engine efficiency and emissions for biodiesel-only diesel engines are adequate. Yet, just a few tests utilizing dual biodiesel and diesel as a fuel have been conducted [18]. In accordance with a study on the manufacture of biodiesel from diverse resource sources [19], the cost of feedstock alone accounts for roughly 75% of the overall cost of biodiesel production. As a result, cheaper, readily accessible raw materials are necessary to minimize the expenses of biodiesel manufacturing. In contrast, the usage of edible vegetable oil boosts the cost of biofuel manufacturing. Because of the presence of free fatty acids (FFA), frequent frying for food preparation makes edible vegetables oil not edible [20]. As a result, waste cooking oil (WCO) causes numerous disposal issues all over the world by polluting water bodies such as rivers and clogging drainage systems, among other things. Therefore, one of the best methods to use it effectively and inexpensively while avoiding disposal difficulties is to produce biodiesel from used cooking oil [21]. The majority of research on rubber seed oil (RSO) biodiesel came to the conclusion that it makes a great raw material for transesterification-based biodiesel synthesis [22]. The characteristics of performance, combustion, and emission of mixed waste cooking oil (WCO) and rubber seed oil (RSO) biodiesel with petroleum diesel are not mentioned in any of the literature we consulted. The current study aims to investigate the effects of combining WCO and RSO biodiesel with a diesel blend on a conventional single-cylinder four-stroke compression ignition diesel engine that is unmodified.

2.0 Materials and Methods

2.1 Materials

A mechanical press is used to extract rubber seed oils (RSO). The extracted RSO and WCO oil were then refined to obtain oils suitable for biodiesel production. To produce biodiesel from each oil category, the refined vegetable oils were trans-esterified with the help of a potassium hydroxide (KOH) catalyst. Following that, the physicochemical properties of each biodiesel (WCOD and RSOD) were investigated, as well as those of their combined oil mixture and blend with petroleum diesel. The dual biodiesel blends were developed with the given ratios: Blend A 90% petroleum diesel + 5% WCOD + 5% RSOD, Blend B 80% petroleum diesel + 10% WCOD + 10% RSOD, Blend C 70% petroleum diesel + 15% WCOD + 15% RSOD, Blend D 60% petroleum diesel + 20% WCOD + 20% RSOD, Blend E 30% petroleum diesel + 35% WCOD + 35% RSOD, Blend F 20% petroleum diesel + 40% WCOD + 40% The obtained results were compared to ASTM biodiesel specifications and petroleum diesel.

2.2 Determination of biodiesel physical properties and blend with pure diesel

The ASTM procedure was used to evaluate the density, flash point temperature, calorific value, specific gravity, kinematic viscosity, and acid values of WCOD, RSOD, and two biodiesel mixed blends, which were then contrasted with biodiesel standards. To assess the flash point, the American Society for Testing and Materials suggested employing a Pensky Martens closed cup tester. The specific gravity was determined using a precision hydrometer and a specific gravity bottle. Canon Fensky viscometers were used to determine the viscosities of the various samples. The calorific value of fuel is determined using a digital bomb calorimeter and ASTM D

240 procedures was followed. Table 1 shows the WCOD, RSOD, used diesel, and biodiesel variables.

Table 1. Characteristics of WCOD, RSOD, diesel used and biodiesel specifications

Property	WCOD	RSOD	ASTM limit
Acid Value (mgKOH/g)	0.46	0.44	<0.50
Calorific value (MJ/Kg)	41.25	40.12	
Density (g/cm^3)	0.86	0.83	
Flashpoint (^0C)	139	119	>120
Kinematic Viscosity (cSt)	4.72	5.4	1.9 -6.0
Specific gravity (g/cm^3)	0.86	0.81	0.82 – 0.9

2.3 Experiments involving performance and emission

For the experiment, a single-cylinder, four-stroke, air-cooled diesel engine that was fixed and charged with electricity was employed. The efficiency of combustion, and emission properties of dual mixed diesel were contrasted to pure diesel fuel. The experiments were run at a steady speed but with variable weights for all mixed biodiesel blends. The engine speed was kept constant during all investigations at 2800 rpm. For each load, three tests were run to assess fuel usage, energy use, mechanical performance, exhaust gas temperatures, carbon monoxide, carbon dioxide, hydrocarbon, nitrogen oxide emissions, and exhaust smoke. An Andros 6241A 5-gas analyzer was employed during testing. The analyzer collects instantaneous readings of the exhaust gas and may detect carbon monoxide, carbon dioxide, and hydrocarbons using a non-dispersive infrared (NDIR) sensor. To monitor oxygen and nitrogen oxides, the EGA analyzer employs an electrochemical sensor. It can also detect ambient parameter indications such as temperature. An AVL smoke meter was used to test the smoke opacity of the exhaust gases. The parameters for the test engines are shown in Table 2.

Table 2. Parameters for test engines

Items	Engine Parameters
BHP	4.5
Bore · stroke	68 mm · 76 mm
Compression ratio	18:1
Model	Kirloskar engine
Speed	3000 rpm
Type	Single cylinder
Type of cooling	Air cooling

3 Physical properties of produced and its blend with pure diesel

3.1The fuels calorific Values

The different fuels consumption calorific value (CV) is shown in Figure 1. As can be observed, the CA value of raw vegetable oils is lower than that of equivalent biodiesel. The calorific value of biodiesels increases after the transesterification process compared to their raw oils. In comparison to RSOD, WCOD40.01 has a larger calorific value. The Blends A and B calorific values moved closer to those of diesel when the two biodiesels were combined with diesel. Blend A and Bare have higher calorific values than standalone biodiesel blends. Mixes C and D almost have the same calorific values as the individual biodiesel blends. Blends E and F have lower calorific values than single biodiesel blends. As a result, dual biodiesel blends A, B, C, and D are used to conduct an experimental performance and emission analysis.

.

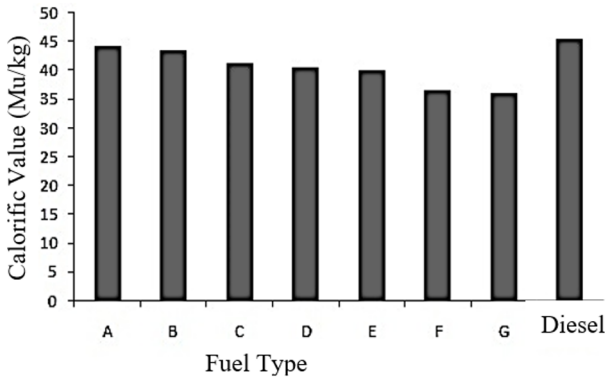

Fig. 1. The fuels calorific values

3.2 Fuel specific gravity

Dual biodiesel blends A, B, C, and D have specific gravities of 0.82, 0.83, 0.84, and 0.85, respectively, compared to 0.81 for diesel. The other blends fall in the 0.86 to 0.89 range.

3.3 Viscosity of fuels

Biodiesel has a lower viscosity than raw vegetable oils. After transesterification, biodiesel has a lower viscosity than raw oil. RSOD and WCOD have different viscosities. As the blend ratio rises, the viscosity of the blends also rises, and dual biodiesel blends are more viscous than diesel fuel. Diesel-like viscosity is present in dual biodiesel mixes A and B. Compared to Blend A and Blend B, which have viscosities of 4.12cSt and 4.24cSt, respectively, Diesel has a viscosity of 3.91cSt.

4 Results and discussion

Fuel and energy consumption, mechanical efficiency, exhaust gas temperatures, C0, N0, $C0_2$, hydrocarbon emissions, and exhaust smoke are among the factors that are assessed. Figure 2 depicts the impact of braking power on specific fuel consumption. Increasing brake power reduces SFC for all dual biodiesel blends. Blend A has an SFC of 0.32 kg/kWh at maximum load, Blend B has an SFC of 0.35 kg/kWh, and Blend C has an SFC of 0.37 kg/kWh, whereas diesel fuel has an SFC of 0.31 kg/kW h. The blends lower calorific value contributes to the higher SFC for dual biodiesel fuel consumption. The patterns of this curve accord with the established conclusions that, biodiesel had a greater fuel usage due to its reduced energy level and higher density [23]. Based on the findings, introducing biodiesel increases fuel use. The outcomes obtained conforms with the discoveries that as the amount of biodiesel advances, correspondingly rises the brake-specific fuel usage [24].

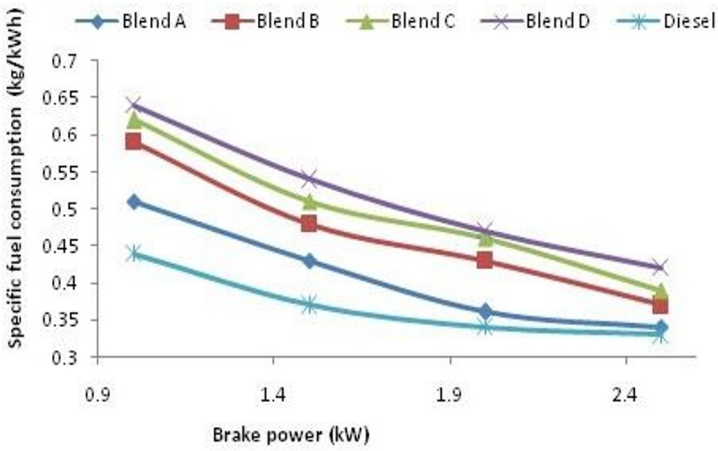

Fig. 2. The effect of brake power on specific fuel consumption

Due to the varied heating values of the fuel mixtures, brake-specific energy consumption (BSEC) is the ideal criterion for assessing the engine's cost effectiveness. In the study by Srithar et al. (2017), BSEC is an excellent factor as it is influenced by the calorific value of the fuel [25]. Figure 3 displays the brake-specific energy consumption of dual biodiesel, its mixes, and diesel. It reveals that the BSEC for all dual biodiesel blends is higher than that of mineral diesel. As consequently, when contrasted with diesel, the brake-specific energy use of dual biodiesel blends rises. The lesser energy value of the ester accounts for the higher specific energy consumption. The BSEC of blends is equivalent to diesel at maximum brake power. The similarity of results could be due to biodiesel's lower heating value, higher density, and viscosity relative to diesel.

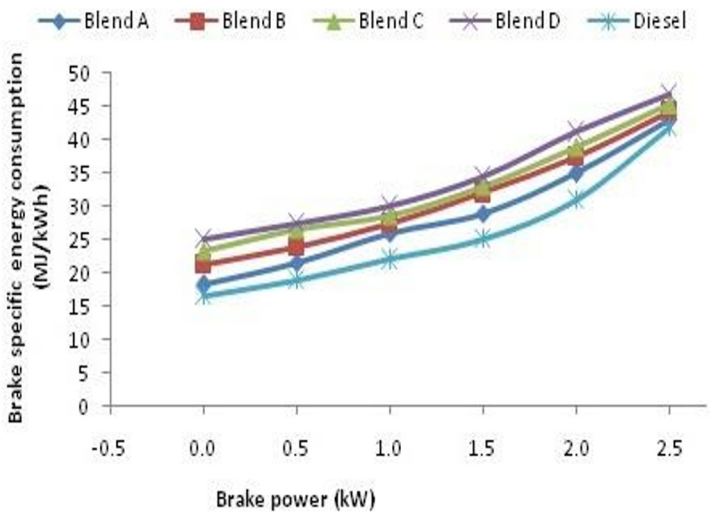

Fig. 3. Brake power's impact on brake-specific energy usage

Calculating the engine's mechanical efficiency requires both indicated power and engine friction. Efficiency is the ratio of the machine's measured performance to its ideal performance. Mechanical efficiency assesses how well a machine converts the force and movement that is applied as an input to the device into energy and power. Therefore, an engine's mechanical efficiency shows how well it converts the specified output to usable power. Figure 4 depicts how brake power affects mechanical effectiveness. The diesel has 78.2% mechanical efficiency at the maximum brake power, compared to Blend A's maximum mechanical efficiency of 79.3%. The mechanical efficiency of the other blends is less than that of diesel. According to Chauhan et al. (2013), some researchers came to the conclusion that biodiesel fuels have lower brake thermal efficiency than diesel fuel [26].

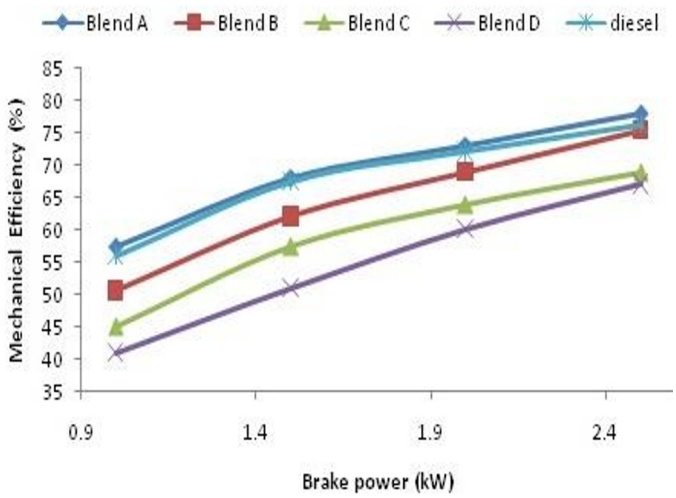

Fig. 4. Mechanical efficiency and brake power

Figure 5 depicts the influence of exhaust gas temperature on braking efficiency. In any circumstance, as the braking force goes up, so does the exhaust temperature. The temperature of exhaust gas represents the condition of combustion in a chamber. The upsurge in exhaust gas temperature with engine load is clear since the engine consumes more fuel to provide the additional power necessary to manage the extra loading. All blends have reduced exhaust temperatures than diesel values for any braking power due to their lower heating values and the enhanced oxygen content provided by the dual biodiesel, which promotes combustion [27]. When exhaust temperature is taken into account, dual biodiesel blends are preferred to diesel.

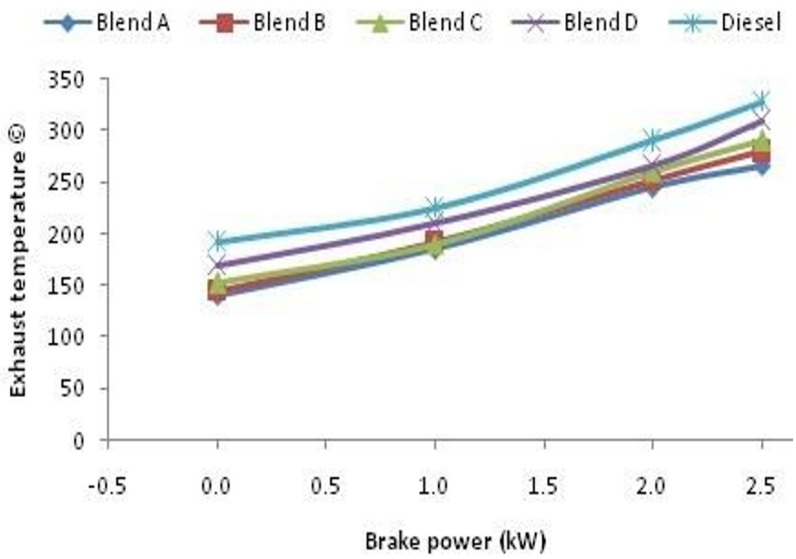

Fig. 5. Brake power varies with exhaust gas temperature

Figure 6 shows that as the brake power increases, the percentage of smoke increases as well. Diesel produced 60% of the smoke at the maximum load, while Blend A and Blend B produced 64% and 68% of the smoke, respectively, at the same maximum load. The diesel smoke value is closer to that of Blend A. Other mixes have a higher smoke percentage than diesel with the same stopping power. This might be explained by the biodiesel's high oxygen concentration, lack of aromatic and sulfur components, and lower boiling point. When compared to neat diesel, the higher viscosity and density may also contribute to higher smoke emissions. Pure biodiesel's high viscosity reduces fuel atomization and increases exhaust smoke. The results obtained agree with those obtained by Pai et al [28].

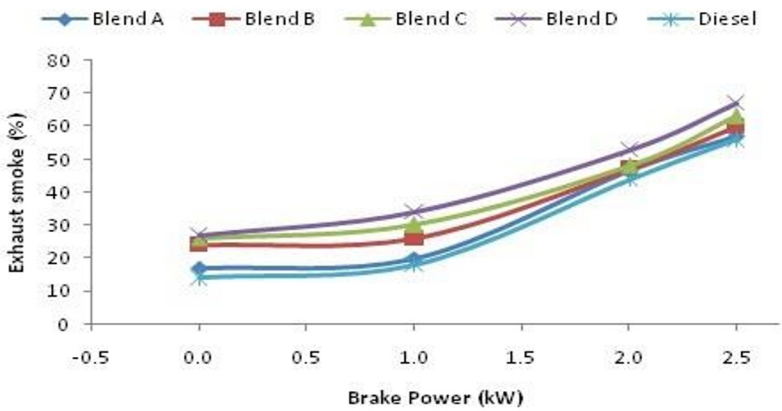

Fig. 6. The impact of braking on exhaust smoke

Figure 7 demonstrates the effects of carbon monoxide on brake power. Carbon monoxide (CO) level grows in direct proportion to braking power. Blends A and B contain less CO than diesel. Carbon monoxide is a poisonous gas that is colorless and odorless. A higher cetane number and more oxygen present will minimize CO emissions, leading in CO2 conversion [29]. The resulting result is consistent with Chauhan et al. findings [30]. The same pattern can be seen in Figure 8 for carbon dioxide (CO2) emissions. Blend A and Blend B produce less CO and CO2 than diesel at full load. This is owing to the high oxygen concentration of biodiesel, which allows it to burn at higher temperatures in the cylinder. The remainder of the blends differ from diesel. Because of the high viscosity, the challenges in atomizing and vaporizing dual biodiesels has an effect on the air-fuel mixing process. When the engine load is raised, a richer fuel-air mixture is burnt, resulting in greater CO and CO2. Blend A and Blend B produce less CO and CO2 than diesel at full load.

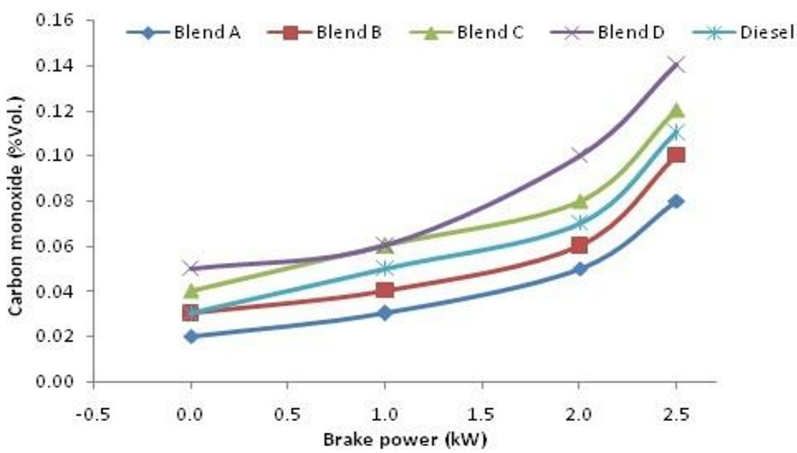

Fig. 7. Brake power variation and carbon monoxide emissions

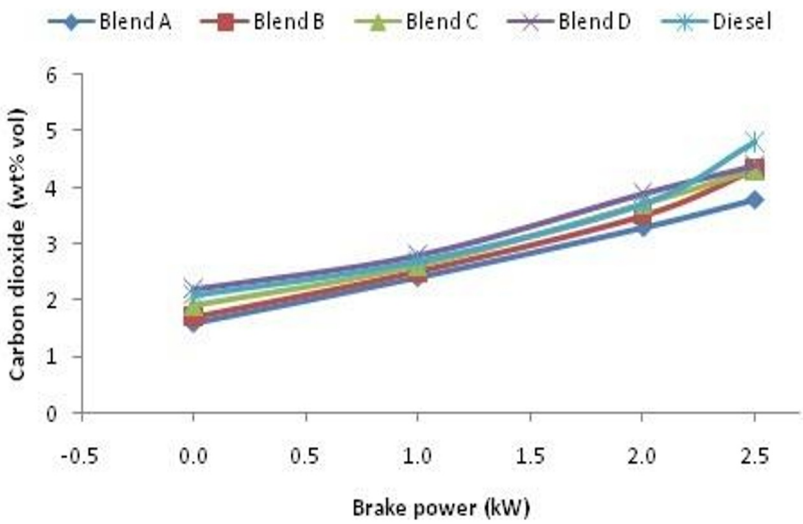

Fig. 8. Brake power variation and carbon dioxide emissions

One of diesel's most hazardous emissions is NOx [31]. Figure 9 depicts the impact of brake power on nitrogen oxides. By increasing the load for each blend, the nitrogen oxides (NOx) increased. Diesel produces 150 ppm for the maximum load, while Blend A produces 166 ppm, Blend B 180 ppm, and Blend C 190 ppm for the same maximum load. According to the findings, diesel emits less NOx than dual biodiesel mixes. Blend A emits less NOx than other dual biodiesel mixes, nevertheless. Biodiesel made from vegetable oil contains a trace of nitrogen. This contributes to the production of NOx. All of the blends emit higher NOx than diesel. greater NOx emissions were induced by greater average petrol temperature, the presence of fuel oxygen, and residence time under higher braking power circumstances with the mix combustion. Gumus and Kasifoglo got equivalent NOx emissions values when running a diesel engine with a different biodiesel blend [32].

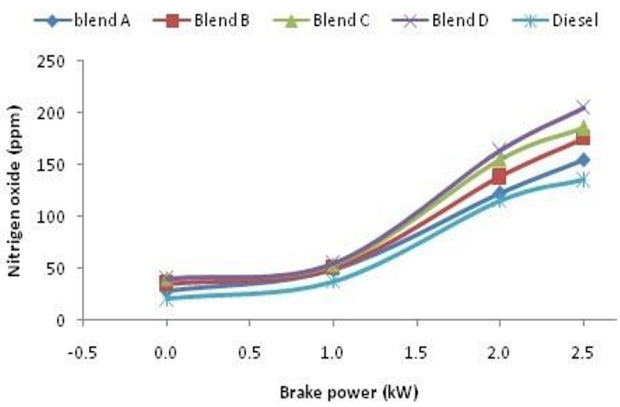

Fig. 9. Nitrogen oxide emissions and brake power

According to Figure 10, increasing the load for each blend enhanced the correlation between brake power and hydrocarbon (HC). All of the Blends contain more HC than diesel. Based on the findings, Blend A produces less HC than the other blends. In broad terms, dual biodiesels and blends emit less HC at lower engine loads and more at higher loads. This is because there is less oxygen available for the process when more gasoline is put into the engine cylinder at a greater engine load. Due to its lesser calorie content and greater viscosity, biodiesel oil emits the most HC.

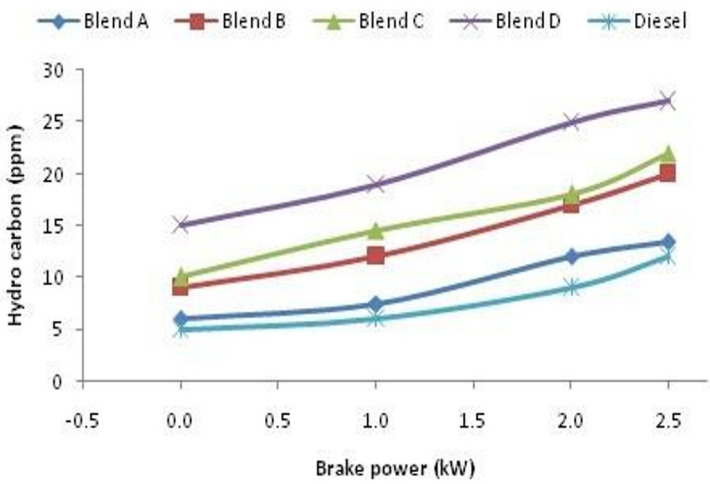

Fig. 10. Hydrocarbon emissions and brake power

5 Conclusions

The current study used a single-cylinder, four-stroke air-cooled diesel engine to successfully test dual biodiesels and their mixtures. The exhaust pollution and engine rating of diesel fuel and dual biodiesels of calabash and rubber seed oil were compared and discussed. The following is a summary of the work's findings:

1. DB and its diesel fuel blends are both engine suitable with no engine alterations.
2. The trial results revealed that Blend A was substantially superior thermally and technically than diesel. Blends B and C had values that were quite close to those of diesels. DB blends had fuel usage estimates that were comparable to diesel.
3. Blends A and B emit slightly less CO and CO_2 than diesel.
4. In addition, research has shown that dual biodiesel and its blends greatly lessen smoke emissions and CO relative to diesel fuel.
5. Dual biodiesel does emit somewhat more NOx than petroleum diesel, though.

As a result, DB mixtures of Blend A, B, and C can be substituted for diesel engines. The logical conclusion is that non-edible biodiesel might replace diesel and help lower air pollution. Additionally, it would encourage the development of biodiesel using

non-cooking oil, reducing our dependency on fossil fuels without affecting engine efficiency.

All the authors hugely appreciate the managements and technologists of Afe Babalola University, Ado Ekiti Nigeria for the financial support in publication and making the workshops and laboratories accessible to enable this research. The inputs of all technologists cannot be over-emphasized. Thank you.

References

1. Sahoo, P.K., Das, L. M., Babu, M. K. G., Arora, P., Singh, V. P., Kumar, N. R. and Varyani, T. S. 2009. Comparative evaluation of performance and emission characteristics of Jatropha, Karanja and polanga-based biodiesel as fuel in a tractor engine. Fuel, **88**: 1698-1707. https://doi.org/10.1016/j.fuel..02.015 (2009)
2. Theansuwan, W. and Triratanasirichai, K. The biodiesel production from roast Thai sausage oil by transesterification reaction, Am. J. Eng. Appl. Sci., 4: 130–132. (2011)
3. Agarwal, D., Kumar, l. and Agarwal, A.K. Performance evaluation of a vegetable oil fuelled compression ignition engine. Renew. Energy. 33:1147–1156. https://doi.org/10.1016/j.renene.2007.06.017. (2008)
4. Takase, M., Zhao, T., Zhang, M., Chen, Y., Liu, H., Yang, L. and Wu. X.. An Expatriate Review of Neem, Jatropha, Rubber and Karanja as Multi-Purpose Non-Edible Biodiesel Resources and Comparison of Their Fuel, Engine and Emission Properties, Renewable and Sustainable. J.rser. 43: 495-520. https://doi.org/10.1016/j.rser.2014.11.049. (2015)
5. Murillo, S., Míguez, J.L., Porteiro, J., Granada, E. and Morán, J.C. Performance and exhaust emissions in the use of biodiesel in outboard diesel engines, Fuel, 86: 1765-1771. https://doi.org/10.1016/j.fuel.2006.11.031. (2007)
6. Hasan, M.M. Rahman, M.M., Kadirgama, K. A Review on homogeneous charge compression ignition engine performance using biodiesel–diesel blend as a fuel, Int. J. Automot. Mech. Eng.11: 2199-2211. (2015)
7. DOI: http://dx.doi.org/10.15282/ijame.11.2015.3.0184
8. Azman, S.R., Ismail, M., Kadhum, A. A. H. and Yaakob, Z. The performance ofmonolithic structured calcium oxide for biodiesel, Int. J. Automot. Mech. Eng 10:1959-1970. DOI: https://doi.org/10.15282/ijame.10.2014.13.0164. (2014)
9. Adam, I. K., Aziz, A.R. and Yusup, S. Determination of diesel engine performance fueled biodiesel (rubber seed/palm oil mixture) diesel blend, Int. J. Automot. Mech. Eng 11: 2675-2685. DOI: http://dx.doi.org/10.15282/ijame.11.2015.44.0225. (2015)
10. Abbaszadeh, A., Ghobadian, B., Najafi, G. and Yusaf, T. 2014. An Experimental investigation of the effective parameters on wet washing of biodiesel purification, Int. J. Automot. Mech. Eng. 9: 1525-1537.
11. https://doi.org/10.15282/ijame.9.2013.4.0126
12. Deepanraj, B., Dhanesh, C. and Senthil, R. Use of palm oil biodiesel blends as a fuel for compression ignition engine, Am. J. Appl. Sci., 8: 1154–1158. 10.3844/ajassp.2011.1154.1158. (2011)

13. Muralidharan, K. and Govindarajan, P. The effect of bio-fuel blends and fuel injection pressure on diesel engine emission for sustainable environment, Am. J. Environ. Sci., 7:377–382. (2011)
14. Srivastava, P.K. and Madhumita, P. Methyl ester of karanja oil as an alternative renewable source energy, Fuel, 87: 1673–1677. https://doi.org/10.1016/j.fuel.2007.08.018. (2008)
15. Lawrence, P., Mathews, K. and Deepanraj, B. "The effect of prickly poppy methyl ester blends on CI engine performance and emission characteristics", Am. J. Environ. Sci., 7: 145–149. 10.3844/ajessp.2011.145.149. (2011)
16. Xue, J., Grift, T.E. and Hansen, A.C. Effect of biodiesel on engine performances and emissions", Renewable and Sustainable Energy Reviews, 15:1098-116. https://doi.org/10.1016/j.rser.2010.11.016. (2011)
17. Ramadhas, A.S., Jayaraj, S. and Muraleedharan, C. Dual fuel mode operation in diesel engines using renewable fuels: rubber seed oil and coir-pith producer gas, Renew. Energy, 33:2077–2083. https://doi.org/10.1016/j.renene.2007.11.013. (2008)
18. Wang, Y.D., Al-Shemmeri, T., Eames, P. et al, "An experimental investigation of the performance and gaseous exhaust emissions of a diesel engine using blends of a vegetable oil", Appl. Therm. Eng., 26:1684–1691. https://doi.org/10.1016/j.applthermaleng.2005.11.013. (2005)
19. Prabhakar, S., Annamalai, K., Lalvani, K., Issac, J.R. Experimental study of hybrid vegetable oil blends in diesel engine, J. Sci. Ind. Res., 71:612–615. (2006)
20. Nantha, K. G., Pal, A., Sharma, S., Samanchi, C., Sathyanarayanan, K. and Elango, T. Investigation of emissions and combustion characteristics of a CI engine fueled with waste cooking oil methyl ester and diesel blends, Alexandria Engineering Journal, 53:281–287. https://doi.org/10.1016/j.aej.2014.02.003. (2014)
21. Basha, S. A., Raja, K., Gopal, K. and Jebaraj, S. A review of biodiesel production, combustion, emissions, and performance, Renewable and Sustainable Energy Reviews, 13(6):1628-1634. https://doi.org/10.1016/j.rser.2008.09.031. (2009)
22. Kulkarni, M. G. and Dalai A. K. Waste cooking oils, an economical source of biodiesel : A review, Ind. Eng. Chem. Res., 45:2901–2913. https://doi.org/10.1021/ie0510526. (2006)
23. Gimbun, J., Ali, S., Suri, C. C., Kanwal, C., Shah, L. A., Ghazali, N. H. M., Cheng, C. K. and Nurdin, S. Biodiesel Production from Rubber Seed Oil Using A Limestone Based Catalyst, Advances in Materials Physics and Chemistry, 2: 138-141. doi:10.4236/ampc.2012.24B036. (2012)
24. Mahgoub, B. K. M., Sulaiman, S. A, Karim, Z. A. A. Performance Study of Imitated Syngas in a Dual-Fuel Compression Ignition Diesel Engine. International Journal of Automotive and Mechanical Engineering, 11: 2282–2293. DOI: http://dx.doi.org/10.15282/ijame.11.2015.11.0192. (2015)
25. Armas, O., Hernandez, J. J. and Cardenas, M. D. Reduction of Diesel Smoke Opacity from Vegetable Oil Methyl Esters during Transient Operation Fuel, 85: 2427-2438. https://doi.org/10.1016/j.fuel.2006.04.016. (2006)
26. Srithar, K., Balasubramanian, A. K., Pavendan, V. and Kumar, B. A. 2017. Experimental investigations on mixing of two biodiesels blended with diesel as an alternative fuel for diesel engines, Journal of King Saud University – Engineering Sciences, 29: 50–56. https://doi.org/10.1016/j.jksues.2014.04.008. (2017)

27. Chauhan, B. S., Kumar, N., Cho, H. M. and Lim, H. C. A Study on the Performance and Emission of a Diesel Engine Fueled with Karanja Biodiesel and its Blends. Energy, 56:1-7. https://doi.org/10.1016/j.energy.2013.03.083. (2013)
28. Kumar, S., Velraj, K. and Ganesan, R. Performance and exhaust emission characteristics of a CI engine fueled with methyl ester (PPME) and its blends with diesel. Renew. Energy, 33: 2294–2302. (2008)
29. Pal, A., Verma, A., Kachhwaha, S. S. and Maji, S. 2010. Biodiesel Production through Hydrodynamic Cavitation and Performance Testing. Renewable Energy, 35: 619-624. https://doi.org/10.1016/j.renene.2009.08.027
30. Guru, M., Koca, A., Can, O. C., Cinar, C. and Sahin, F. Biodiesel production from waste chicken far-based sources and evaluation with Mg-based additives in a diesel engine. Renew. Energy, 35: 637-643. https://doi.org/10.1016/j.renene.2009.08.011. (2010)
31. Kumar, M. V., Veeresh, V., Babu, P. and Kumar, R. The impacts on combustion, performance and emission of biodiesel by using additives in the direct injection diesel engine. Alexandria Engineering Journal, 57: 509-516. https://doi.org/10.1016/j.aej.2016.12.016. (2018)
32. Gumus, M. and Kasifoglu, S. Performance and Emission Evaluation of a Compression ignition engine using biodiesel (apricot seed kernel oil methyl ester) and its blend with diesel fuel. Biomass Bioenergy, 34: 134-139. https://doi.org/10.1016/j.biombioe.2009.10.010. (2005)