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ORIGINAL RESEARCH

Quality assessments, performance, and emissions evaluation of biodiesel from citrullus lanatus oil seeds and diesel blends in compression ignition engine

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Abstract

Due to limited stock of levels of fossil fuel resources and ecological issues, biodiesel is becoming an attractive alternative choice for replacing conventional fuels. Biodiesel can be used by mixing with different fuels like citrullus lanatus seeds, camphor, cleaner fuel injector, sunflower, safflower, soybean, cottonseed, rapeseed, palm, Jatropha, and Moringa oil seeds.

This paper reviews use of biofuels blended with citrullus lanatus seeds. The citrullus lanatus biodiesel was mixed with diesel in different percentages by volume. Some physico-chemical characteristics of blends and pure diesel were investigated and it was established that it conforms to the American Society of Testing Materials (ASTM) standards. The exceptions were the viscosity and specific gravity of the pure biodiesel B100 which were 0.09 and 0.018 mm^2/s above the ASTM standard, respectively. All blends were run on a stationary 4-cylinder diesel engine at 70% loading and speeds of 1500, 2000, and 2500 rpm. It was deduced that B10 gave the best brake power, thermal efficiency, and optimum specific fuel consumption at a speed of 2500 rpm. B15 gave the highest brake mean effective pressure. B25 and B100 gave the least values of brake power and brake thermal efficiency across the speeds. B100 gave the highest brake specific fuel consumption. Furthermore, the exhaust emission gases such as CO_2, CO, NOx, and HC in different engine conditions stated above were recorded and analyzed. It was found that B25 emitted about 53% lesser CO_2 and 37% lesser CO as compared to pure diesel with zero HC at 2500 rpm. The blends were better in terms of engine performance and also in reduction of emissions in most cases, than pure diesel fuel.

Problem statement: Various emissions from engines like unburnt hydro carbons, particulate emissions, NOx, and CO have bad effects on ecology. This work presents an overview on use of novel hybrid fuels in compression ignition engines with an aim of mitigating effects of emissions on environment. Biodiesel was blended with Citrullus lanatus oil and pure diesel in different proportions to see effects on performance of diesel engines. The presented work may pave the way for use of alternative cheap and environmentally friendly fuels in automotive systems.

1 | INTRODUCTION

The main source of Fuels supplies today is from non-renewable energy .The growing demand of the fuels is increasing due to populations rise, urbanization, standard of living, and advancement in technology and industries [1] The world over reliance on fossil fuels originated from the incessant utilization of petroleum derivatives. The combustion of fossil fuels results in greenhouse gas emissions which affect human and environment [2]. However, exploration, production and utilization of the fossil fuel is characterized with many environmental and health issues. Similarly, Nigeria flares the second largest volume of gas after Russia with an estimated of 70 million metric tons of CO2 emission per year, these account for about 11% of flared gas by volume in the world [3].

Globally, petro-diesel uses on diesel engines account for over 55% of transport fuel consumption [4]. Estimates indicated that close to 15 million electric generators are in use in Nigeria of which more than 90% of businesses are run with the aid of diesel engine generators, while 30% of households, also uses diesel engine generators.[5]. Diesel engine emission has over 40 toxic air contaminants. It was reported about 70% of cancer risk is related to inhalation of air polluted by harmful substances in the USA, which arises mostly from exhaust emission from diesel [6]. Other toxic pollutants that's effect environment include; oxide of nitrogen, recently, the most ozone-depleting gas, carbon monoxide (CO), particulate matter (PM), carbon dioxide (CO2), sulphur oxides (SOx), and unburned hydrocarbons (UHC) organic compounds [7]. These emissions have always pose a threat in air pollutions.

Many researchers indicated that the emission gathering in the atmosphere due to oil exploration, gas flaring, and diesel engine exhaust as serious issues that aggravates global warming [8, 9]. Furthermore, rise in petroleum fuels prices, and increase of environmental awareness issues, energy security concern, tight restrictions on engine or vehicle emissions, have renewed the interest of researchers to search for an alternative solution in shifting from petroleum fuels to renewable fuels and advanced vehicle technologies [10]. The feasibility of using alternative fuels has been identified since the invention of diesel engine [11]. Liquid biofuels are widely used as alternative diesel engine fuel [12–14]. Biodiesel has been shown to be a possible suitable substitute to petro-diesel for use on diesel engines. Biodiesel has an edge over the conventional diesel, by being biodegradable, non-harmful with low emissions [1, 15, 16].

Ashok et al. [16] established that adding 5% mean thermal brake efficiency gives rise to a reduction of 3.49 in peak pressure, while rate of heat dissipation reduced by 5.1% when compared to diesel fuels. When analyzing the combustion process critically prolonged ignition delay was noticed during the additions of MBTE with diesel and biodiesel blends. Kaisan et al. [16] examined the proximate mineral and vitamin A contents of Citrullus lanatus (watermelon) seeds for possible boasting of animal feeds.

Sharma et al. focussed on utilization of innovative blends of Prosopis juliflora biodiesel in the operation of diesel engines [17–21].

In the present study, Citrullus lanatus biodiesel with petroleum diesel was blended in a ratio of 5:95, 10:90, 15:85, 20:80, 25:75, pure biodiesel sample and pure petroleum diesel sample were marked as B5, B10, B15, B20, B25, B100, and B0, respectively.

The objectives of this research are to compare and evaluate the performance of the biodiesel blends with petro-diesel on a stationary multi-cylinder diesel engine, and carry out exhaust air quality analysis of the combustion products (gases) [17–30].

TABLE 1 Engine test bed (P8750) specification by Cussons Technology, Manchester, UK, 2010.

Engine type	**Four-cylinder in-line DOHC duel mass flywheel**
Number of valves	16
Block	Aluminium
Head	Aluminium
Horse power	81 kW(11OPS) at 4000 rpm
Torque	240/260*NM at 1750 rpm * with transient over boost
Displacement	1560 CC
Bore and stroke	75 mm, 88.3 mm
Compression ratio	18:1
Alignment	Transverse
Weight	107 kg
Dimensions $H \times L \times W$	600 × 500 × 580 mm

2 | MATERIALS, EQUIPMENT, AND METHODS

Samples of biodiesel blends were prepared in a given ratio by volume of 5:95, 10:90, 15:85, 20:80, and 25:75 percentages respectively, and are denated as B5, B10, B15, B20, and B25. The pure biodiesel is denated as B100 while pure diesel is denated as B0.

These tests were carried out in line with the regulations set by American Society of Testing Materials (ASTM) D6751 Standards.

The P8750 engine test bed was used for this research work, 4-cylinder CI engine available at the Mechanical Engineering Department, Bayero University, Kano with specifications shown in Table 1.

3 | RESULTS AND DISCUSSION

The results of the physico-chemical properties of water melon seed biodiesel are shown in Table 2.

The physico-chemical properties presented in Table 2 are consistent with the ASTM standards for specific gravity, viscosity, calorific value, flash point, cold flow properties, cetane number, colour, and sulphur content. This agrees with the findings of [10–15].

Table 2 illustrates the results of specific gravity versus the biodiesel blends; the values of the pure diesel and the recommended range of ASTM standard values were represented. The specific gravity of the watermelon biodiesel was found to be 0.09 above the ASTM standard value; this agrees with the findings of [16]. The flash point of the biodiesel blends was short of the ASTM minimum standard and higher than the pure diesel flash point value of 97 OC with the exception of B100 which falls within the ASTM standard value as shown in Table 3. A

TABLE 2 Physico-chemical properties of biodiesel from water melon seeds oil.

Properties	B0	B5	B10	B15	B20	B25	B100	ASTM (max)	ASTM (min)
Specific gravity	0.8691	0.87	0.87	0.87	0.87	0.88	0.9189	0.9	0.8
Kinematic viscosity	4.3	4.75	4.8	5	5.6	5.7	6.08	6	1.9
Flash point (°C)	97	142	144	144	147	154	155	170	130
Pour point (°C)	−8	−9	−9	−9	−9	−15	−12	10	−15
Cloud point (°C)	2	2	3	3	−2	−3	2	12	−3
Sulphur content	0.177	0.1679	0.15	0.15	0.14	0.14	0.02	0.275	0.178
Cetane number	53	54.73	54.92	55	55	56	58	65	48
Colour indices	2	2	2.5	2.5	2.5	3	3.5	3.5	1
Copper strip RRROSSION	1a	1a1	1a	1a1	1a	1a	1a	4c	1a
Calofiric value (MJ per kg)	45.12	45.01	44.88	44.45	43.99	43.23	42.43	46	42

ASTM, American Society of Testing Materials.

TABLE 3 ASTM values for flash point.

Fuel	Flash point (°C)
B100 Biofuel	155
Petrol	−42.8°
Fuel oil	37.8°
Motor oil	215°

ASTM, American Society of Testing Materials.

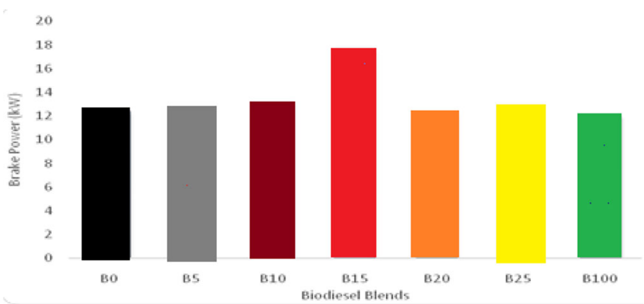

FIGURE 1 Brake horse power at 1500 rpm.

similar result was reported by [16]. The pour point was observed decreasing with the increase in biodiesel concentration and all the blends conform to ASTM specified standard; this is in compliance with the results of [16]. Table 2 shows the cloud points of both pure diesel and biodiesels blends and also the ASTM maximum and minimum values. It can be noticed that all the cloud point values are within the specified ASTM standard. B2 has the lowest values while B10 was with the highest cloud point value, as depicted in Table 3 All the blends match up with the standard values set by ASTM, the only exceptions to this which fail to meet up with this standard is B100 biodiesel sample which has a value that is less than the minimum standard value set by ASTM. Tendency of emissions of sulpur (IV) oxide to atmospheric air reduces as the sulphur content reduces.

Figures 1, 2, and 3 depict the brake powers of biodiesel blends from watermelon seed oil. It can be seen that most of the

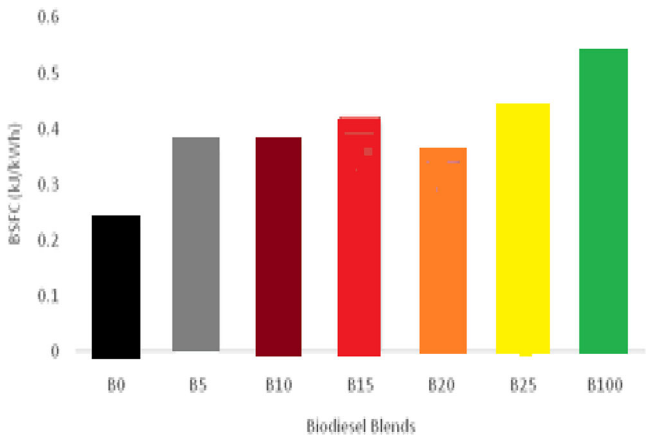

FIGURE 2 Brake horse power at 2000 rpm.

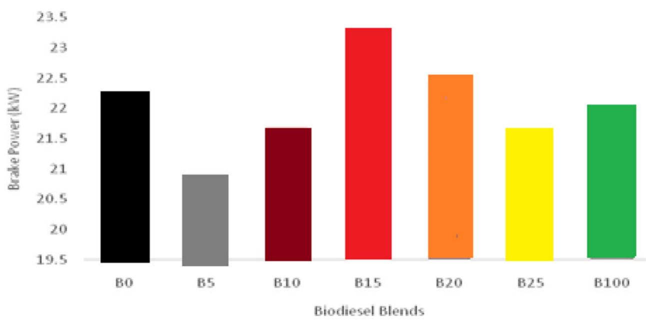

FIGURE 3 Brake horse power at 2500 rpm.

biodiesel blends have a higher brake power than pure diesel at all engine speeds; this is in line with the results of [12]; they established that maximum increase in brake power was at 50% Jatropha biodiesel blend with diesel. From Figure 1, at a constant speed of 1500 rpm, B15 has the maximum brake power followed by B10 and B100 having the minimum value. Similarly, B15 gave the highest brake power followed by B20 at the constant speed of 2000 rpm while the lowest was B25 at the same speed, as shown in Figure 2. This is tallied with the results

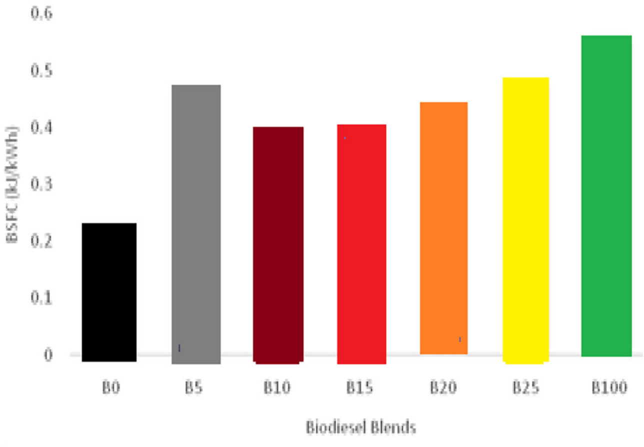

FIGURE 4 Brake specific fuel consumption at 1500 rpm.

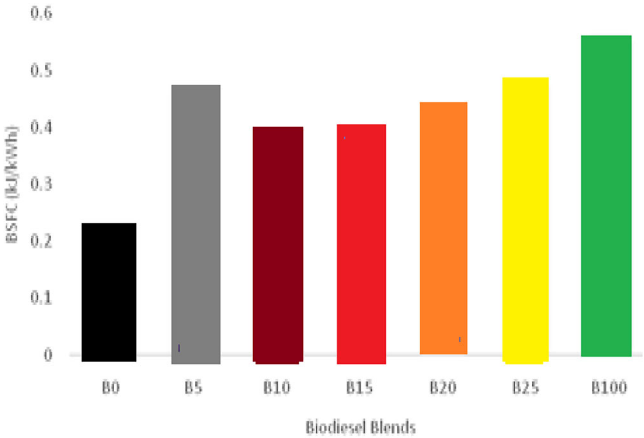

FIGURE 5 Brake specific fuel consumption at 2000 rpm.

of [13], but contradicts the findings of [14] who reported that fossil fuel has a higher brake power than sunflower and canola biodiesel at all engine speeds. However, other blends have brake power values within a very close substantial range. At the speed of 2500 rpm as depicted in Figure 3, B10 has the highest value of 38.483 kW followed by B15 and B100 having the lowest values of brake power.

The maximum brake power values were achieved by the combustion of B15, B10, and B15 at 2500, 2000, and 1500 rpm, respectively. This is opposing the findings of [15] where the petro-diesel has higher brake power than the palm biodiesel blends on combustion in CI engines, but, similar to the findings of same authors [15] where brake power was established to have increased steadily with increase in engine speed as depicted in Figures 1, 2, and 3, respectively.

Variation in specific fuel consumption with the speed of 1500, 2000, and 2500 rpm is shown in Figures 4, 5, and 6. It is observed that the specific fuel consumption increases with increase in speed and blending ratio in most cases which is consistence with the findings of [16]. The reason was that biodiesel and blends have lower calorific value, high flash point, density, and viscosity as compared to pure diesel; this leads to poor

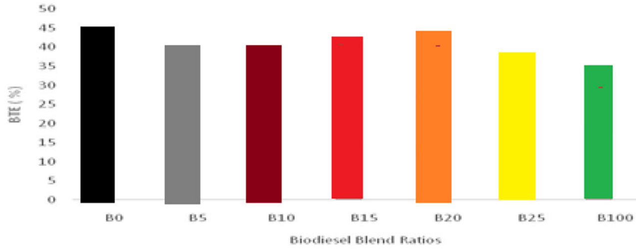

FIGURE 6 Brake specific fuel consumption at 2500 rpm.

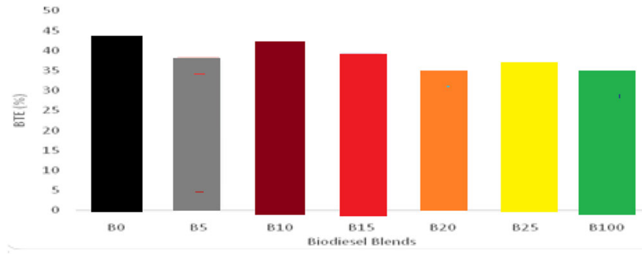

FIGURE 7 Brake thermal efficiency 1500 rpm.

atomization as supported by [16]. Therefore, for the oxygenated fuels (biodiesels), decrease in their heating value gives rise to an increase in brake effective fuel consumption because more fuel has to be injected in in order to have same power output. B5 has the least BSFC at 1500 rpm followed by B10 at 2000 rpm and B15 at 2500 rpm as depicted in Figures 4, 5, and 6.

From Figure 4, B5 has the least BSFC value of 0.3 kg/kWh followed by B15 with BSFC value of 0.34 kg/kWh at the speed of 1500 rpm. However, B20 and B5 were the least values in terms of BSFC at the speed of 2000 rpm with 0.36 and 0.37 kg/kWh respectively as depicted in Figure 5 while at the speed of 2500 rpm, B10 has the least BSFC as shown in Figure 6. It can be concluded from the result obtained that B5 was the best blend in respect of BSFC at low and medium engine speeds while B10 was the best at higher engine speed. Similarly, B100 has BSFC of about 59%, 67%, and 40% higher than B5, B10, and B0 respectively and therefore, the blends are much economical than the pure biodiesel to be considered for use in CI engines. The brake thermal efficiency values are presented in Figures 7, 8, and 9. The general outlook of the figures was that pure diesel (B0) has the highest brake thermal efficiency and pure biodiesel (B100) has the lowest brake thermal efficiency at the speeds of 1000, 1500, and 2500 rpm. The major reason for this, is the higher density, viscosity, and lower calorific of biodiesel fuel which result in poor atomization and improper spray pattern; this is close to the findings of [16].

It can be observed from Figure 7 that B10 biodiesel blend has the highest brake thermal efficiency (BTE) followed by B15 blend, while B20 was the least in terms of BTE at the speed of 1500 rpm. However, at a higher speed of 2000 rpm, B20 blend appeared to have the maximum BTE as shown in Figure 8 while B10 blend has the highest BTE at the speed of 2500 rpm as depicted in Figure 9. From this study therefore, it can be established that the thermal efficiencies of the watermelon biodiesel

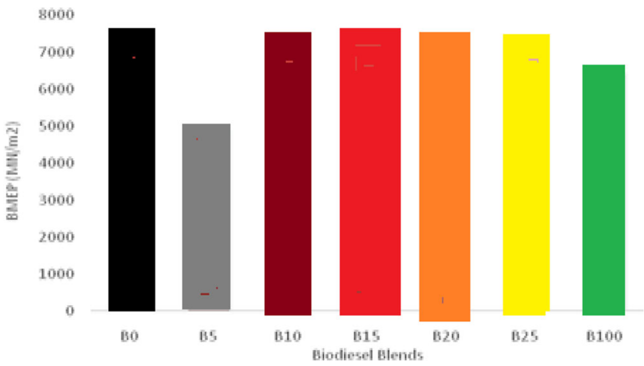

FIGURE 8 Brake thermal efficiency at 2000 rpm.

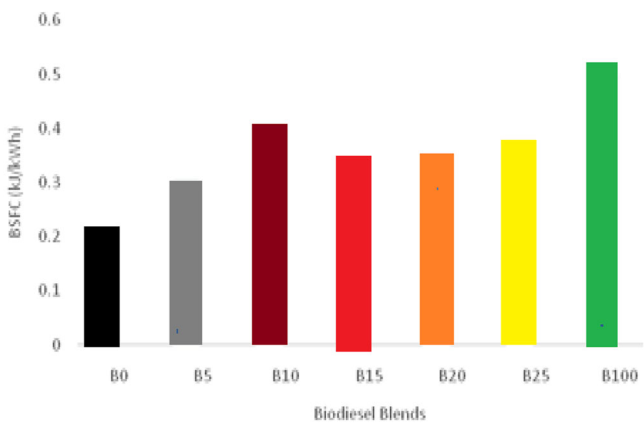

FIGURE 9 Brake thermal efficiency at 2500 rpm.

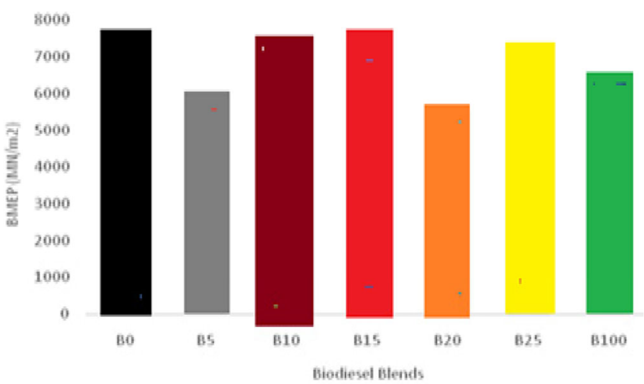

FIGURE 10 Brake mean effective pressure at 1500 rpm.

and blends are comparable with that of diesel; this agrees with the research results of [12] and B10 appeared as the best blend to be adopted in terms of BTE at low and high speeds.

Figures 10, 11, and 12 depict the variation of brake mean effective pressure to blend ratio at the engine speeds of 1500, 2000, and 2500 rpm and constant torque. It can be observed generally that pure diesel has a higher value of brake mean effective pressure than pure biodiesel at all speeds. However, the overall best in terms of the brake mean effective pressure value at the speeds of 1500, 2000, and 2500 rpm was B15, B15, and

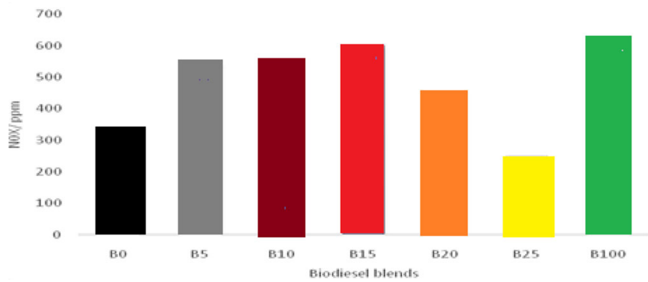

FIGURE 11 Brake mean effective pressure at 2000 rpm.

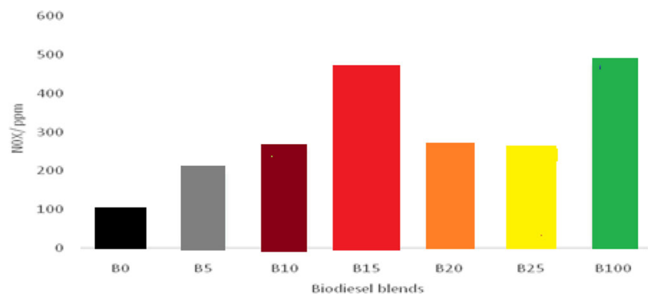

FIGURE 12 Brake mean effective pressure at 2500 rpm.

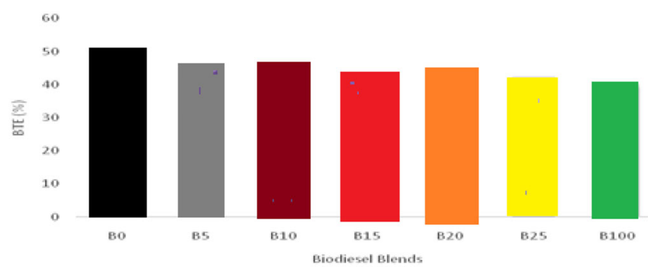

FIGURE 13 Nitrogen oxide emissiojns at 1500 rpm.

B20 with 7604.18, 7548.34, and 8179.45 MN/m^2, respectively, as shown in Figures 4.18, 4.19, and 4.20.

The exhaust emissions results were obtained using gas analyzer through watermelon biodiesel and their multiple blends. Figures 13, 14, and 15 depict nitrous oxide (NOX) emissions percentage against the blends of watermelon biodiesel and diesel at different speeds of 1500, 2000, and 2500 rpm, respectively. It can be observed generally that NOx of biodiesel is higher than that of pure diesel in most cases as depicted in

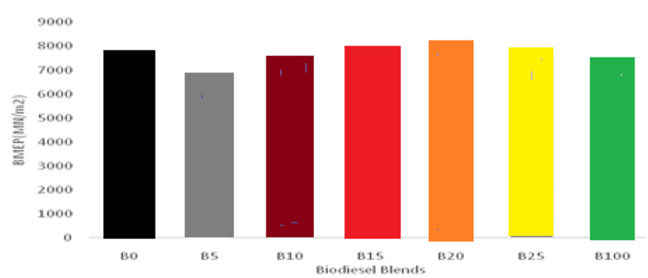

FIGURE 14 Nitrogen oxide emissions blends at 2000 rpm.

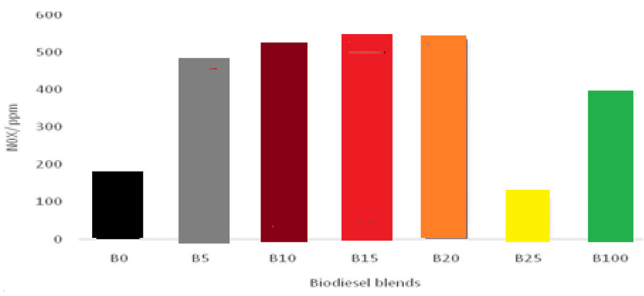

FIGURE 15 Nitrogen oxide emissions at 2500 rpm.

Figures 13, 14, and 15, respectively. Therefore, NOX emission increases with increase in engine speed for most of the biodiesel blends. This is mainly due to the fact that methyl esters (biodiesel) are oxygenated fuel, more oxygen is available for the formation of NOX and have higher cetane number [17–21, 31–56].

At a constant speed of 1500 rpm, B100 has the highest NOx emission followed by B15 with 483 and 456/ppm, respectively, while pure diesel (B0) was the lowest NOx emitter with 95/ppm, as shown in Figure 13. However, the variation of NOx emission was not always constant with speed; it can be observed in Figure 14 that B15 was the highest in NOx emission and the least was B25. The emission of NOx increases remarkably at the speed of 2500 rpm as compared with the speed of 1500 rpm; this is consistence with the findings of [54]. The maximum NOx emissions of 620/ppm occur at 2500 rpm by B100 followed by B15 with 600/ppm at the same speed as depicted in Figure 15. This might be probably due to high combustions temperature in the cylinder with increased speed at high load.

4 | CONCLUSIONS

The results of physico-chemical analyses of the biodiesel and blends established that it conforms to the ASTM standards. The exceptions were the viscosity and specific gravity of the pure biodiesel B100 which were 0.09 and 0.018 mm^2/s above the ASTM standard, respectively.

The overall performances in terms of brake power at the highest speed of 2500 rpm were recorded by B10 followed by B15 and B5, respectively. B25 has the least values of brake power. In regard to brake specific fuel consumption, B10 gave the optimum values at all speeds; the least values were obtain by B0 while highest specific fuel consumption was obtain by B100 at all engine speeds. At the maximum speed, B15 and B0 gave the highest and the lowest values of brake mean effective pressure respectively while B20 gave the minimum value at lowest speed. B10 gave the highest values of brake thermal efficiency at all speeds while the lowest values were recorded by B100 at all engine speeds.

Engine exhaust emissions results showed that NOX emission increases as engine speed increases for most of the blends. This was inline with previous works [20, 56]. The overall highest value of NOX emission was exhibited by B100 at the maximum speed of 2500 rpm. While B0 has the lowest NOx emission percentages. B25 gave the optimum NOX emission at all speed.

AUTHOR CONTRIBUTION

Sunny Narayan provided original concept. Faisal O. Mahroogi prepared manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

FUNDING INFORMATION

None.

DATA AVAILABILITY STATEMENT

All the data used for this paper is freely available online.

PUBLIC INTEREST STATEMENT

This work deals with investigation of use of novel fuels in engines, Various properties like emissions and engine performance were investigated for different blends of fuels.

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