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Shea Butter Oil Biodiesel Synthesized Using Snail Shell Heterogeneous Catalyst: Performance and Environmental Impact Analysis in Diesel Engine Applications

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Abstract: The implementation of biodiesel in internal combustion engines has been observed to enhance engine performance and mitigate the discharge of toxic gaseous emissions from the engine. In this research, Shea Butter Oil Biodiesel (SBOB) was used to operate a diesel engine to analyze the performance and emissions characteristics. Shea Butter Oil Biodiesel (SBOB) was blended with petroleum diesel in ratios 0:100 (B0), 25:75 (B25), 50:50 (B50), 75:25 (B75), and 100:0 (B100). The torque, brake power (BP), and brake thermal efficiency (BTE) of the engine were determined. Gaseous emissions from the engine's combustion were characterized using the BOSEAN BH-4S portable multi-gas detector, while the organic emissions compositions were detected and quantified using Gas Chromatography-Mass Spectrometry (GC-MS). The fuel properties of SBOB and its blends were found to be within the range of acceptable standards. However, the carbon content, sulphur content, heating value, and ash content of the blends decreased from 0.68 to 0.12 wt %, 0.04 to 0.00 wt %, 44.2 to 34.2 MJ/kg, and 0.020 to 0.010 wt %, respectively. The engine torque, brake power, BTE, and engine vibrations were found to reduce when the biodiesel blends were used. Besides the diesel fuel, the biodiesel blend, B25, produced the best engine performance characteristics with 8.50 Nm torque, 1780.95 W BP, and 90.29% BTE. The B100 produced the lowest concentrations of carbon emissions, viz. 520 ppm CO and 1.0% CO_2. The NO and NO_2 concentrations were found to increase for all the biodiesel blends used. The NO and NO_2 concentrations were measured as 230 ppm and 210 ppm for B0, respectively, and 250 ppm and 235 ppm for B25, respectively. The research showed that SBOB has improved engine performance and lowered the emissions profile of CO and CO_2 compared with petroleum diesel. The GCMS analysis confirmed that some harmful organic compounds were present in the emissions profile obtained from the exhaust samples of the diesel engine at various compositions.

Keywords: biodiesel blend; combustion; engine performance; fuel properties; gaseous emissions; internal combustion engines

1. Introduction

The use of renewable fuels in engines reduces environmental pollution compared to fossil fuels [1]. Oil extracted from groundnut, soybean, and castor seeds have similar physical, chemical, and thermodynamic properties to petroleum diesel [2,3]. However, Jaichandar and Annamalai [4] discouraged using raw vegetable oils as fuel in diesel engines because of their high viscosity to prevent an increase in specific fuel consumption and emissions (carbon monoxide and unburnt hydrocarbon). Various fuel technologies can be employed to lower the viscosity of raw vegetable oil, enabling its effective utilization as an engine fuel. These methods encompass blending raw vegetable oil with petroleum diesel, emulsification, pyrolysis, and transesterification. Among these techniques, transesterification has gained significant prominence in commercial processes due to its extensive usage in the production of environmentally friendly biodiesel [4,5].

Heavy trucks are powered by petroleum diesel, and the use of this fuel by the trucks leads to a high emission profile of CO, CO_2, and hazardous organic compounds from their exhaust [6]. Dwivedi et al. [6] reported that accumulating fossil fuel emissions could lead to human health problems such as cancer. Moreover, the issue of global warming and the fact that fossil fuels are non-renewable make the development of alternative renewable fuels, which are environmentally friendly, of global interest. Owing to the increasing global shift towards renewable and environmentally friendly fuels such as biodiesel, using vegetable oils and animal fats to produce biodiesel has to be intensified globally to mitigate environmental degradation, reduce dependency on petroleum-based fuels, and improve energy productivity [7,8].

Heterogeneous catalysts are generally preferred over homogeneous catalysts in industrial biodiesel production due to their practical applications and lower operational costs. The use of heterogeneous catalysts provides an alternative solution to the problems associated with homogeneous catalysts in biodiesel production [9]. The shells of African giant snails (*Archachatina marginata*) were discovered to contain calcium carbonate ($CaCO_3$), a raw material used to produce calcium oxide (CaO) that is both cost-effective and environmentally friendly [10–12]. According to Benzekri et al. [13], snail shell powder is a heterogeneous biocatalyst with good catalytic performance. Laskar et al. [12] reported that raw snail shell powder consists of 97.14% $CaCO_3$, while the sample calcined snail shell at 900 °C for 4 h consists primarily of 98.017% CaO. Using calcined snail shells as a catalyst, they achieved a high biodiesel yield of 98% from soybean oil. Ogunkunle et al. [14] obtained CaO from *Archachatina marginata* via calcination at 900 °C for 3.5 h. They reported 81% biodiesel yield from Thevetia peruviana oil when catalyst concentrations of 3.0 wt % of calcined snail shell were used during the transesterification reaction. Based on relatively high biodiesel yields achieved under moderate reaction conditions, calcium oxide (CaO) is found to be one of the most widely used heterogeneous catalysts for biodiesel production [14–17].

Alamu et al. [18] reported that biodiesel production and its use in CI engines could improve its economic development and poverty alleviation. It provides new jobs and business opportunities in production, transportation, and trading. Bozbas [19] reported that diesel engines could operate on 100% biodiesel, although it could thicken at an absolute temperature (273 K). The study revealed that blending biodiesel fuel with petroleum diesel fuel lowers the blend's pour and cloud points and also suggested that a heater can be retrofitted to the engine fuel tank to keep the fuel flowing in cold weather. The fuel is renewable, biodegradable, has low emission profiles, has high energy efficiency when burnt, and is easy to store, transport, and handle [20]. Biodiesel can be used either in pure form or blended with other energy resources like oil in existing oil heating systems and diesel engines without any modifications. These will positively impact the country because many people will be offered jobs and business opportunities in production, transportation, trade, and uses. Thus, this attracted interest in this study.

A literature review shows that some researchers have carried out the performance evaluation of diesel engines fueled with methyl ester of shea butter. Still, none have evaluated the performance and emission characteristics of the biodiesel synthesized via heterogeneous catalyst derived from snail shells. Shea butter was chosen for this study owing to its abundance in Nigeria and its underutilization in the biodiesel industry [21]. The details of its abundance and oil yields are reported in the article. The shells of African giant snails were chosen for the heterogeneous catalyst synthesis based on their ability to produce cost-effective and environmentally friendly calcium oxide (CaO) for transesterification catalysis [21]. More details can be found in the reports of Ogunsola et al. [21].

Enweremadu et al. [22] studied a single-cylinder diesel engine's performance and emission properties using blends of shea butter biodiesel to compare the biodiesel with fossil diesel. The results showed that adding biodiesel to diesel fuel decreases the brake thermal efficiency (BTE) and increases the brake specific fuel consumption (BSFC). The NOx emissions increased with biodiesel content in the fuel blends, while carbon monoxide (CO), unburnt hydrocarbon (UHC), and smoke opacity emissions decreased. Towoju et al. [23] studied the effect of shea butter biodiesel on a CI engine's performance and emission characteristics. There was an improvement in the performance and emission characteristics of the CI engine with the piston modification.

The limitation of their studies is that none of them studied biodiesel production using heterogeneous catalysts synthesized from biomass. Additionally, there is no evidence of scientific findings on the compounds that characterize the emission profile from the combustion of shea butter biodiesel and its blends in a CI engine. The authors' minimum time for biodiesel production was 60 min, which was a considerable amount of time, leading to a shorter time of 10 to 15 min using calcined snail shells as a catalyst in biodiesel production from shea butter oil. The research also evaluated its blends' performance and emission profile with petroleum diesel in compression ignition (CI) engines.

This research aimed to produce low-emission Shea Butter Oil Biodiesel (SBOB) and evaluate its performance in Compression Ignition Engine (CIE) running on its blends with petroleum diesel. The biodiesel production involved the purification of shea butter oil using snail shells as a heterogeneous catalyst. Blends of the fuel with petroleum diesel were developed and used to power a compression ignition engine. The SBOB was blended with petroleum diesel in ratios 0:100, 25:75, 50:50, 75:25, and 100:0. The suitability of these blends was determined based on the performance characteristics (torque, brake power, brake thermal efficiency, vibration, and emission) of the diesel engine running on the blends. The research showed that SBOB has a lower emissions profile of CO and CO_2 compared with petroleum diesel. The implementation of this research on a large scale will drive the adoption of the combustion of SBOB blends in internal combustion engines to reduce gaseous pollutants that are responsible for global warming and adverse health conditions in humans.

2. Materials and Methods

The major agro-material used in this study was raw shea nut, processed into oil. Reagents used in this study include analytical grade of tetraoxosulphate (vi) acid (H_2SO_4), dam's reagent, ethanol, aqueous potassium iodide, shea butter oil, sodium thiosulphate, phenolphthalein, distilled water, sodium hydroxide (NaOH), buffer solution, neutralized isopropanol, snail shells, dry benzoic acid, petroleum diesel, carbon tetrachloride (CCl_4), shea butter oil, and snail shell. The equipment used includes TQTD114 IC engine instrumentation (England), TQTD115 hydraulic dynamometer (England), Yoshita 165F compression ignition engine of maximum power 2.94 kW, rated power 2.67 kW, net weight 42 kg, model number 40303959 (China).

2.1. Biodiesel Production Using Heterogeneous Catalyst Developed from Snail Shell

The authors recently reported the biodiesel production results from the transesterification of shea butter oil using calcined snail shells. The catalyst preparation, characterization, esterification, and transesterification details of biodiesel production from shea butter are reported in Ogunsola et al. [21]. The XRD and SEM analyses reported in the article confirmed the presence of CaO, which makes it suitable for the transesterification of shea butter oil. More details can be found in the article.

2.2. Development of Blend Ratio and Determination of SBOB Blends Properties

An amount of 25 mL of Shea Butter Oil Biodiesel (SBOB) was mixed with 75 mL of petroleum diesel and then agitated vigorously to form a homogeneous blend. The ratio of the SBOB in the blend was adjusted inversely to that of petroleum diesel, thus leading to blend ratios B0, B25, B50, B75, and B100, respectively, based on the literature. The determined fuel properties of SBOB blends are specific gravity, kinematic viscosity, flash point, cloud point, pour point, heating value, cetane number, iodine value, pH value, ash content, sulphur content, and carbon content determined for the blends developed according to ASTM standards.

2.3. Evaluation of the Performance Characteristics of the Compression Ignition Engine

The CI engine (Yoshita 165F model of 2.94 kW maximum power, 2.67 kW rated power, 42 kg net weight manufactured in the Republic of China in May 2014 with number 40303959) was coupled to the hydraulic dynamometer test rig. The rig was powered with the following fuel blends: B0 (100% Petroleum diesel), B25 (25% v/v of shea butter biodiesel (SBOB) + 75% v/v of petroleum diesel), B50 (50% v/v of shea butter biodiesel (SBOB) + 50% v/v of petroleum diesel), B75 (75% v/v of shea butter biodiesel (SBOB) + 25% v/v of petroleum diesel), and B100 (100% Shea butter biodiesel (SBOB)). All tests were conducted at full throttle, and the engine speed was regulated by varying the water flow rate (to increase the load) into the hydraulic dynamometer test rig. The engine loads were increased for all the fuel blends until an engine speed of 2000 rpm was attained. Three experimental replicates for 2000 rpm engine speed were carried out, and the average values of these replicates were recorded. The engine's performance characteristics were evaluated with respect to the engine torque, brake power (BP), brake thermal efficiency (BTE), and vibration.

2.3.1. Determination of the Torque of the CI Engine

The torque of the CI engine was determined using to Equation (1):

$$T = mga \tag{1}$$

where T is the applied torque (Nm), m is the mass hung on the torque arm in kilogram (including that of the load carried) in kg, a is the torque arm in meter (m), and g is the acceleration due to gravity in meter per second square (m/s^2).

2.3.2. Determination of the Brake Power of the CI Engine

The B_P of the CI engine was computed as follows:

$$P_B = T\omega \tag{2}$$

where P_B is the BP of the engine, ω is the angular speed in radians per second (rads/s).

The values of P_B and ω were determined from Equations (3) and (4), respectively.

$$\omega = \frac{2\pi N}{60} \tag{3}$$

Thus,

$$P_B = \frac{2\pi N}{60} T \tag{4}$$

2.3.3. Determination of the BTE of the CI Engine

The BTE of the CI engine was computed according to Equation (5):

$$\eta_b = \frac{P_B}{m_f \cdot CV} \tag{5}$$

P_B is the BP in watts, m_f is the mass flow rate of the fuel used by this engine in kg/s, and CV is the heating value of the fuel used by this engine in J/kg.

2.3.4. Determination of the Vibration Level of the CI Engine

The vibration of the compression ignition engine developed when it runs on the SBOB blends was measured using the vibration meter VB-8206SD model by making the sensitive tip of this vibrometer touch the rotating output shaft of the dynamometer. The vibrometer displayed the level of vibration developed by the engine for a particular blend ratio.

2.4. Determination of Gaseous and Organic Emissions Level from the CI Engine

The concentrations of CO, CO_2, NO, and N_2O from the exhaust pipe of the compression ignition engine were measured by collecting and analyzing the gases coming out from the exhaust pipe of the compression ignition engine when it runs on a particular blend ratio of a 5 kg gas cylinder. The BOSEAN BH-4S portable multi-gas detector was used to detect the gaseous emissions present in the exhaust samples. The organic emissions were characterized and quantified using the Shimadzu GC-MS QP2010 with a fused silica capillary column of 30 m × 0.25 mm × 0.25 µmol film thickness.

3. Results and Discussion

The results of catalyst preparation from snail shells and characterization are reported by Ogunsola et al. [21]. The biodiesel results, their properties, performance, and emission analyses are discussed in this section.

3.1. Physicochemical Properties of SBOB and Its Blends

The physicochemical properties of the SBOB were all found to be within acceptable standards for biofuels. The physicochemical attributes of the SBOB (Straight Vegetable Oil Biodiesel) and its blends exhibited strong alignment with the established criteria outlined by the American Society for Testing and Material (ASTM D 975 and D 6751) [24], as well as the European standard for biodiesel (EN 14214) [25] (Table 1). In contrast to prior investigations [11,13,14,20], the characteristics exhibited by biodiesel fuel establish that heterogeneous catalysts derived from snail shells can be effectively synthesized and employed as catalysts in transesterification reactions, thus demonstrating their feasibility. Properties, such as specific gravity, viscosity, pH, iodine value, cetane number, flash point, fire point, cloud point, and pour point, of the blends increased from 0.836 to 0.895 kg/m^3, 3.849 to 5.794 mm^2/s, 4.00 to 5.50, 0.32 to 0.51, 48.8 to 56.0, 76 to 121 °C, 88 to 130 °C, −7 to 10 °C, and −15 to 14 °C, respectively, as the percentage volume of the SBOB increased in the blends. However, the carbon content, sulphur content, heating value, and ash content of the blends decreased from 0.68 to 0.12 wt %, 0.04 to 0.00 wt %, 44.2 to 34.2 MJ/kg, and 0.020 to 0.010 wt %, respectively, as the percentage volume of the SBOB increased in the blends. A reduction in the heating value of SBOB blends was found to be responsible for the reduction in the output power of the blend, which was reported and supported by the findings of Kaisan et al. [26] and Bamgboye and Oniya [27].

Table 1. Physicochemical properties of SBOB blended with petroleum diesel [24,25].

Fuel	SBOB Blends					Standards		
Properties	B0	B25	B50	B75	B100	Diesel ASTM D 975	Biodiesel ASTM D 6751	Biodiesel EN 14214
Specific gravity at 15 °C (kg/m^3)	0.84	0.85	0.86	0.88	0.90	0.84	≤0.90	≤0.90
Viscosity at 40 °C (mm^2/s)	3.85	4.30	4.83	5.09	5.79	1.3 to 4.1	1.4 to 6.0	3.5 to 5.0
pH value	4.00	4.50	5.00	5.20	5.50	-	-	-
Iodine value (mg/kg)	0.32	0.38	0.41	0.47	0.51	-	-	-
Cetane number	48.80	53.00	54.20	55.50	56.00	48 to 50	≥47	≥51
Flash point (°C)	76.80	82.80	94.80	115.80	121.80	60 to 93	100 to 170	≥120

Table 1. *Cont.*

Fuel	SBOB Blends					Standards		
Properties	B0	B25	B50	B75	B100	Diesel ASTM D 975	Biodiesel ASTM D 6751	Biodiesel EN 14214
Fire point (°C)	88.00	98.00	108.00	110.00	130.80	-	≥120	≥120
Cloud point (°C)	−7	−2	5	8	10.80	−3 to 12	−3 to 12	−3 to 12
Pour point (°C)	−15	−4	6	10	14.80	−35 to 15	−15 to 16	−15 to 16
Carbon content (wt %)	0.68	0.60	0.32	0.19	0.12	0.86	≤0.2	≤ 0.3
Sulphur content (wt %)	0.04	0.03	0.02	0.01	0.00	≤0.05	≤0.05	≤10.00
Heating value (MJ/kg)	44.20	40.80	38.70	36.10	34.20	43 to 46	≤37.12	≤37.12
Ash content (wt %)	0.02	0.01	0.01	0.01	0.01	0.02	≤ 0.02	≤0.02

3.2. Engine Performance Characteristics

The performance characteristics of the CI engine powered with diesel and SBOB blends are captured in Table 2.

Table 2. Performance characteristics of the CI engine powered with diesel and SBOB blends.

Fuel	Torque (Nm)	BP (W)	BTE (%)	Vibration (m/s^2)
B0	9.00	1885.71	96.71	18.10
B25	8.50	1780.95	90.29	17.80
B50	8.40	1760.00	89.69	17.50
B75	8.20	1718.09	88.16	14.40
B100	8.00	1676.19	85.05	12.80
Std. Dev.	0.38	78.95	4.27	2.38
Uncertainty	0.17	35.31	1.91	1.06

3.2.1. Engine Torque

It was observed that the speed of the engine decreased when all the SBOB blends (B0, B25, B50, B75, and B100) were used to run the engine at full throttle. The motive force (engine torque) available to drive the diesel engine was reduced from 9 Nm for B0 to 8 Nm for B100. This decrease may be attributed to the biodiesel's lower heating value and higher viscosity compared to that of petroleum diesel [28]. These values agree with the results of Liaquat et al. [29]. Using coconut oil biodiesel blends, they reported a decrease in engine torque from 22.5 Nm to 21.5 Nm when B0, B5, and B15 were used to operate a diesel engine at full load and an engine speed of 2200 rpm without any engine modification. In addition, the results are consistent with the findings of Ilkilic et al. [28], who reported a decrease in engine torque from 32.5 Nm to 29.0 Nm at full load and an engine speed of 1500 rpm when B0, B5, B20, and B50 of safflower biodiesel blends were used to power a diesel engine.

3.2.2. Brake Power

From the application of B0 to B100, the BP of the diesel engine decreased from 1885.714 W to 1676.191 W. This decrease is related to the reduced heating value of the blends when compared to that of fossil diesel, as reported by Ilkilic et al. [28] and Liaquat et al. [29]. The result further agreed with the trend of the results of Mohammadi et al. [30], who reported a decrease in BP of the engine from 51.0 kW to 48.5 kW when B0 (diesel) and B5 of cooking oil biodiesel–diesel blend, added to expanded polystyrene (EPS) waste, was used to run the engine at full load conditions.

3.2.3. Brake Thermal Efficiency

The brake thermal efficiency of the compression ignition engine powered with SBOB blends (B0, B25, B50, B75, and B100 at the speed of 2000 rpm and full load) decreased from

96.71% to 85.05%. The decrease in BTE of the blend, other than petroleum diesel, may be due to a reduction in heating value and an increase in the fuel consumption rate of these blends, as also reported by El-Kasaby and Nemit-Allah [31]. The result is consistent with the results of Mohammadi et al. [29], who reported a decrease in BTE from 34.5% to 35.2% when B0 (diesel) and B5 blend of cooking oil biodiesel–diesel, mixed with expanded polystyrene (EPS) waste, were used to power a diesel engine at full load.

3.2.4. Engine Vibrations

The mechanical vibrations of the diesel engine, when powered with SBOB blends of B0, B25, B50, B75, and B100 at full load, decreased from 18.1 m/s^2 to 12.8 m/s^2. This decrease may be because biodiesel is an oxygenated fuel, which enhances the air-to-fuel stoichiometric ratio, thus improving the smooth running and stability of the engine as the percentage ratio of biodiesel increases in the blends. This result contradicted the results of Manorathna and Nanayakkara [32], who used waste cooking oil biodiesel blended with petroleum diesel at the ratios of B5, B10, B15, B20, and B25 to power conventional diesel engines and reported an increase in engine vibration as the percentage of biodiesel increased in the blends.

3.3. Gaseous and Organic Emissions Detected in the Exhausts of CI Engine Operated with Shea Butter Oil Biodiesel Blends

Concentrations of NO, NO_2, O_2, CO_2, and CO in the exhaust of the blend samples ranged from 230 to 330 ppm, 210 to 300 ppm, 4 to 16%, 1.0 to 3.40%, and 630 to 520 ppm, respectively. The analysis of gaseous emissions from the CI engine showed that CO_2 and CO concentrations reduced from 3.40% to 1.00% and 650 to 520 ppm, respectively. The results agree with the report of Chauhan et al. [33], who observed a reduction in CO_2 and CO emissions as Karanja biodiesel content increased in the fuel blends. SBOB has a lower carbon content (0.12%) than petroleum diesel (0.68%). Therefore, increasing SBOB's blend with petroleum diesel lowered CO_2 and CO gaseous emissions. The findings align with the findings reported by the United States Environmental Protection Agency (USEPA) [34], which indicates that biodiesel fuels lead to reductions in emissions of hydrocarbons (HC), carbon monoxide (CO), and sulfur (S), while concurrently resulting in increased emissions of nitrogen oxides (NOx) and oxygen (O_2).

The NO and NO_2 emissions increased as biodiesel content increased in the blends (Table 3). The concentrations of NO_x increased as the percentage composition of the SBOB increased in the blend. The spike in NOx formation is linked to the amount of biodiesel added to the blends. Biodiesel contains more oxygen than diesel due to its biological nature. The increase in NOx was caused by an increase in heat released by the combusted fuel at high torques when the combustion fuel temperature is high, resulting in atmospheric nitrogen combusting with oxygen at the exhaust pipe to form oxides of nitrogen [35–37]. In contrast, the concentration of CO_2 and CO decreased because SBOB has a higher oxygen content (16%) and higher cetane number (56.0). The presence of a higher iodine value (0.51) significantly increased the formation of NO_x [38], thereby increasing the emission levels of NO, NO_2, and O_2 as the SBOB composition increased in the blend compared to the oxygen content (4%), cetane number (48.8), and iodine value (0.32) of the petroleum diesel.

Table 3. Gaseous emissions from the combustion of SBOB.

Sample Label	Gaseous Emissions				
	NO (ppm)	NO_2 (ppm)	O_2 (%)	CO_2 (%)	CO (ppm)
B0	230.00	210.00	4.00	3.40	650.00
B25	250.00	235.00	8.00	2.50	630.00
B50	270.00	250.00	12.00	1.80	600.00
B75	300.00	280.00	14.00	1.20	560.00
B100	330.00	300.00	16.00	1.00	520.00
US NAAQS	-	0.05	-	-	9.00
Std. Dev.	39.75	35.71	4.82	0.98	52.63
Uncertainty	17.78	15.97	2.15	0.44	23.54

Although, the values obtained for NO_2 and CO in this study are higher than those specified by the United States Environmental Protection Agency, which may be due to the climatic condition of the engine, the result obtained followed the trend of the findings of Lin and Li [38], who produced biodiesel from waste parts of mixed marine fish species and used it to operate a diesel engine at the speed of 2000 rpm and full load. The study reported an increase in NO_x (450 ppm) and O_2 (13.9%) compared to that of petroleum diesel of NO_x (400 ppm) and O2 (13.0%). In contrast, they reported a decrease in CO (510 ppm) compared to petroleum diesel (530 ppm) in the characterization emission of biodiesel produced.

The GCMS analysis confirmed that some organic compounds were present in the emissions profile obtained from the exhausts of the diesel engine operated with petroleum diesel and SBOB blends. The GCMS analysis of the exhaust emissions of B0, B25, B50, B75, and B100 indicated that some compounds were detected only in the gaseous exhausts from petroleum diesel, the shea butter oil biodiesel, and the shea butter oil biodiesel blends. Furthermore, it was observed that some compounds were detected in all the exhaust samples at various compositions.

3.3.1. Compounds Detected in Exhaust Emissions from Petroleum Diesel and Blends but Not from SBOB

The compound 2-methyl-1-phenyl-benzimidazole-5-carboxylic acid was detected in the exhaust from the combustion of petroleum diesel and blends but not in SBOB (Table 4). The percentage composition increased from 0.85% in petroleum diesel to 1.42% in B25, and 1.55% in B50. However, the concentration was reduced to 1.141% in B75 but not B100. This compound can cause respiratory tract, skin, eye, and allergic reactions on exposure and inhalation [39]. This shows that adopting SBOB wholly in engine applications promises to be beneficial in creating a clean and sustainable human environment.

Table 4. Compounds detected in exhausts from petroleum diesel and blends but not from SBOB.

Sample	2-Methyl-1-phenyl-benzimidazole-5-carboxylic Acid (%)
B0	0.85
B25	1.42
B50	1.55
B75	1.14
B100	ND

ND—Not Detected.

3.3.2. Compounds Detected in Exhaust Emissions from Petroleum Diesel, SBOB, and Blends

The presence of 2-(1-methyl-2-oxohydroazino)-acetic acid was detected in the exhaust emissions from the combustion of petroleum diesel, SBOB, and their blends (Table 5). The percentage composition ranges from 0.731% in B0 to 0.745% in B100. The order of its composition in the blends is given as B50 (2.25%) > B75 (1.34%) > B25 (1.30%), respectively. This compound can damage the liver and irritate the nose and throat in human beings when inhaled. 2,3,5-Trichloro-6-[1,4] diazepam-1-yl-isonicotinonitrile was also detected with a percentage composition of 0.94% in B0 and 0.98% in B100. The order of its composition in the blends is given as B100 (0.98%) > B0 (0.94%) > B25 (2.02%) > B75 (1.66%) > B50 (1.55%), respectively. It can cause eye and skin irritation during exposure and inhalation [40].

2-(1,3-dimethyl-1H-pryazol-4–yl-methylene)-Indan-1,3-dione was detected with a percentage composition of 0.98% in B0, which is higher than that of B100 (0.80%). The order of its composition in the blends is given as B50 (1.64%) > B75 (1.61%) > B25 (1.38%), respectively. It can cause eye, skin, and respiratory tract irritation in human beings on exposure and inhalation. 2,4-dibromo-phenol was detected in B0 with a percentage composition of 1.31%, higher than that of B100 (1.14%). The order of its composition in the blends is given as B75 (1.84%) > B50 (1.55%) > B25 (1.46%), respectively. It can cause cancer in human beings when inhaled. M-(trimethyl siloxy)-Cinnnamic acid was detected with a percentage composition of 0.98% in B0, higher than B100 (0.92%). The order of composition of 4-[5-(4-Methoxyphenyl)-2-oxazo1yl] pyridine in the blends is given as B75 (2.22%) > B50 (1.73%) > B25 (1.19%), respectively. It can cause cancer in human beings when inhaled [40].

Table 5. Compounds detected in exhaust from petroleum diesel, blends, and SBOB.

Sample	Compounds						
	2-(1-methyl-2-oxohydroazino)-acetic acid %	2,3,5-Trichloro-6-[1,4]diazepam-1-yl-isonicotino nitrile %	2-(1,3-dimethyl-1H-pryazol-4-ylmethylene)-Indan-1,3-dione %	2,4-dibromo-phenol %	M-(trimethyl siloxy)-Cinnnamic acid %	4-[5-(4-Methoxyphenyl)-2-oxazo1yl]pyridine %	5-bromo-2,4-bis(methylthio)-Pyrimidine %
B0	0.73	0.94	0.98	1.31	0.98	0.85	1.23
B25	1.30	2.02	1.38	1.46	1.19	1.34	2.34
B50	2.25	1.55	1.64	1.55	1.73	1.59	2.15
B75	1.34	1.66	1.61	1.84	2.22	1.64	1.69
B100	0.75	0.98	0.80	1.14	0.92	0.87	1.11

Sample	4-iodo-1-methyl-Pyrazole-3-carboxylic acid %	N′-[(E)-(2-hydroxyphenyl) methylidene] hydrazide %	[(1,2-.eta.)-1,3-butadiyn][1,3-propanediylbis[bis(1-methylethyl) phosphine]-p,p′]-Nickel %	2-(2-cyano-5-nitrophenylthio)-acetic acid %
B0	1.31	0.73	1.02	0.92
B25	1.50	1.30	1.30	1.11
B50	2.03	2.25	2.00	1.59
B75	1.27	1.39	1.66	1.27
B100	1.07	0.74	1.36	1.14

5-bromo-2,4-bis(methylthio)-Pyrimidine; 4-iodo-1-methyl-Pyrazole-3-carboxylic acid was detected with a percentage composition of 0.85% in B0, which is lower than that of B100 (0.87%). The order of its composition in the blends is given as B75 (1.64%) > B50 (1.59%) > B25 (1.34%), respectively. It can irritate the respiratory tract, skin, eyes, and cause allergic reactions in human beings. N′-[(E)-(2-hydroxyphenyl) methylidene] hydrazide was detected with a percentage composition of 0.73% in B0, lower than that of B100 (0.74%). The order of its composition in the blends is given as B50 (2.253%) > B75 (1.391%) > B25 (1.30%), respectively. It can cause cancer in human beings by exposure and inhalation. [(1,2-.eta.)-1,3-butadiyn] [1,3-propanediylbis [bis(1-methylethyl) phosphine]-p,p′]-Nickel was detected with a percentage composition of 1.023% in B0, lower than that of B100 (1.36%). The order of its composition in the blends is given as B50 (1.997%) > B75 (1.66%) > B25 (1.30%), respectively. It can damage the liver and irritate the nose and throat in human beings when inhaled. 2-(2-cyano-5-nitrophenylthio)-acetic acid was detected with a percentage composition in B0 (0.92%) lower than that of B100 (1.14%). The order of its composition in the blends is given as B50 (1.59%) > B75 (1.27%) > B25 (1.11%), respectively. It can cause cancer in human beings through exposure and inhalation [41].

3.3.3. Compounds Detected in Exhaust Emissions Petroleum Diesel but Not from SBOB and Blends

The GCMS analysis indicates the presence of some compounds in exhaust from petroleum diesel but not in blends and SBOB (Table 6). These include Ethyl chloride: 2-{[3-(2-Methoxyphenyl)-4(3H)-oxoquinazolin-2-ylmethyl] thio}-N-(2-naphthyl) acetamide with a percentage composition of 0.93% in B0. It can cause cancer and liver damage in human beings when inhaled. 2-cyano-2-(3,4-dichloro-5(2H)-oxo-2-furyl) acetamide was detected with a percentage composition of 0.80% in B0. It can damage the liver and irritate human beings' noses and throats on exposure and inhalation. 2,3-dihydro-2-thioxo-3-diallyl aminomethyl-Benzoxazol was found to have a percentage composition of 0.92% in B0. It can cause cancer and liver damage in human beings when inhaled [41].

N, N-dimethyl-3-Cyclohexylpropylamine was detected to have a percentage composition of 4.38% in B0. It can cause eye, skin, and respiratory tract irritation in human beings on exposure and inhalation. 4-(4-Methylpheny1amino) pyrido[3,2-c]pyridazine was detected to have a percentage composition of 0.86% in B0. It can cause cancer and liver damage in human beings when inhaled.

Table 6. Compounds detected in exhaust from petroleum diesel but not from blends and SBOB.

Sample	Compounds						
	2-{[3-(2-Methoxyphenyl)-4(3H)-oxoquinazolin-2-yl-methyl]thio}-N-(2-naphthyl)acetamide %	2-cyano-2-(3,4-dichloro–5(2H)-oxo-2-furyl) acetamide %	2,3-dihydro-2-thioxo-3-diallylamino methyl-Benzoxazol %	N, N-dimethyl -3-Cyclohexyl propylamine %	4-(4-Methylpheny1 amino) pyrido [3,2-c]pyridazine %	1,2-Dithiolane %	1,1-dioxide %
B0	0.93	0.80	0.92	4.38	0.86	0.98	0.98
B25	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B50	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B75	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B100	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Sample	2-(1-adamantyl)-Imidazo[1,2-a] pyridine %	1,3-Diphenyl-2,4-imidazo lidinedion %	1-Methoxy-3,4-dimethyl-1-phenyl-1-germacyclopent-3-ene %	tetrahydro-N-methyl-N-nitroso-3-Thiophenamine %	(2-Acetyl-1-naphthyloxy) difluoroborane %	6-Methoxy-3-oxo-2-p-tolyl-2,3-dihydro-1H-isoindole-1-carboxylic acid %	1,2,4,5-Tetrathiane %
B0	1.23	0.85	0.91	0.98	0.80	0.82	1.29
B25	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B50	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B75	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B100	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Sample	4-(4-Bromophenyl) pyridine %	N′,N′-Dimethyl sulfamide %	5-(1-phenyl-5-tetrazolyl)-1,3,4-Oxadiazol-2-amine %	3,3′-dichloro-[1,1′-Biphenyl]-4,4′-diamine %	Dimethyl bicyclo [2.2.1]-2,5 heptadiene-2,3-dicarboxylate %
B0	0.76	1.29	0.92	0.98	0.86
B25	N.D	N.D	N.D	N.D	N.D
B50	N.D	N.D	N.D	N.D	N.D
B75	N.D	N.D	N.D	N.D	N.D
B100	N.D	N.D	N.D	N.D	N.D

N.D—Not Defined.

1,2-Dithiolane was detected to have a percentage composition of 0.98% in B0. It can damage the liver and irritate humans' noses and throats on exposure and inhalation. 1,1-dioxide was detected to have a percentage composition of 0.98% in B0. It can irritate humans' eyes, skin, and respiratory tract on exposure and inhalation. 2-(1-adamantyl)-Imidazo [1,2-a] pyridine was detected to have a percentage composition of 1.230% in B0. It can irritate human beings' eyes, skin, and respiratory tract on exposure and inhalation. 1,3-Diphenyl-2,4-imidazolidinedion was found to have a percentage composition of 0.85% in B0. It can cause cancer and liver damage in human beings when inhaled.

1-Methoxy-3,4-dimethyl-1-phenyl-1-germacyclopent-3-ene was detected in B0 with a percentage composition of 0.91%. It can cause cancer in human beings through exposure and inhalation. Tetrahydro-N-methyl-N-nitroso-3-Thiophenamine was detected with a percentage composition of 0.98% in B0. It may cause respiratory tract irritation, skin irritation, and eye irritation in human beings when inhaled. 2-Acetyl-1-naphthyloxy (difluoroborane) was found to have a percentage composition of 0.80% in B0. It can cause cancer and liver damage in human beings when it is inhaled. 6-Methoxy-3-oxo-2-p-tolyl-2,3-dihydro-1H-isoindole-1-carboxylic acid was detected in B0 with a percentage composition of 0.82%. It can cause eye, skin, and respiratory tract irritation in human beings on exposure and inhalation. 1,2,4,5-Tetrathiane was found to have a percentage composition of 1.29% in B0. It can cause eye, skin, and respiratory tract irritation in human beings on exposure and inhalation. 4-(4-Bromophenyl) pyridine was detected in B0 with a percentage composition of 0.76%. It can cause cancer and liver damage in human beings when inhaled.

N′, N′-Dimethylsulfamide was detected with a percentage composition of 1.29% in B0. It causes unconsciousness when inhaled. 5-(1-phenyl-5-tetrazolyl)-1,3,4-Oxadiazol-2-amine was found in B0 with a percentage composition of 0.92%. During exposure and inhalation, it can irritate human eyes, skin, and respiratory tract. 3,3′-dichloro-[1,1′-Biphenyl]-4,4′–diamine was found to have a percentage composition of 0.98% in B0. It can cause cancer and liver damage in human beings when inhaled. Dimethyl bicyclo [2.2.1]-2,5 heptadiene-2,3-dicarboxylate was detected in B0 with a percentage composition of 0.86%. During exposure and inhalation, it can irritate human eyes, skin, and respiratory tract.

3.3.4. Compounds Detected in Exhaust Emissions from SBOB but Not from Petroleum Diesel and Blends

The GCMS analysis indicates the presence of some compounds in SBOB exhaust emissions, but not from the combustion of petroleum diesel and the blends (Table 7). 3-(2-Hydroxy-6-methylphenyl)-4(3H)-quinazolinone had a percentage composition of 0.713% in B100. It can cause cancer in human beings by exposure and inhalation. Pregna-5,8-diene-3β, 11α-diol-20-one diacetate was detected with a percentage composition of 1.36% in B100. It can cause eye, skin, and respiratory tract irritation in human beings on exposure and inhalation. 1,4-Phthalazinedione was detected with a percentage composition of 1.46% in B100. During exposure and inhalation, it can irritate human eyes, skin, and respiratory tract [42].

Table 7. Compounds detected in exhaust from SBOB but not from petroleum diesel and blends.

Sample	Compounds						
	3-(2-Hydroxy-6-methylphenyl)-4 (3H)-quinazolinone %	Pregna-5,8-diene-3. beta., 11. alpha.-diol-20-one diacetate %	1,4-Phthalazinediamine %	1,5-diphenyl-Imizazole-2-thiol %	7-trifluoromethyl 2,5-dimethyl-Pyrazolo [1,5-a]pyrimidine-3-carbonitrile %		1,3,5,7-Tetrathiocane %
B0	ND	ND	ND	ND	ND		ND
B25	ND	ND	ND	ND	ND		ND
B50	ND	ND	ND	ND	ND		ND
B75	ND	ND	ND	ND	ND		ND
B100	0.71	1.36	1.46	2.98	1.46		0.96
	1,3,5,2,4,6-Trithia(5-SIV)triazine %	1,1,3,3-tetraoxide %	2-(4-Bromophenyl)-5-hydroxypyrimidine %	4,4′-Thiodi benzenethiol %	N-methoxy-aziridine-2-carboxamide %	4-(N, N-Dimethyl aminomethyl enamino)-7-nitrobenzo furazan %	2-(diphenyl phosphino)-1H-Imidazole %
B0	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B25	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B50	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B75	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B100	0.96	0.96	0.75	0.75	1.46	0.92	0.60
	4,4′-(3-ethenyl-1-propene-1,3-diyl)bis-phenol %	Tricyclo[10.2.2.2(5,8)] octadeca-5,7,12,14,15,17-hexaen-6-ol %	3,5-di(4-nitro-1,2,5-oxadiazol-3-yl)-4H-1,2,4-Triazole %	[1-(Hydroxy-phenyl-methyl)-cyclopropyl]-phenyl-methanone %	9-(4-diethyl aminobenzylideno)-Fluorene-2,7-diacetyl %	2-amino-4-(4-biphenyl) Thiazole %	3,7-dihydro-8-chloro-1,3-dimethyl-7-(2-propynyl)-1H-Purine-2,6-dione %
B0	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B25	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B50	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B75	N.D	N.D	N.D	N.D	N.D	N.D	N.D
B100	0.71	4.58	0.63	7.34	0.65	1.02	1.02
	2,2′-Benzylidenebis (5-methylfuran) %		1,1′-(9H-fluorine-2,7-diyl)bis-Ethanone %	6-methoxyanthracene-2-carboxylic acid %		2,4-Dihydroxy-5-iodo-6-methylpyrimidine %	
B0	N.D		N.D	N.D		N.D	
B25	N.D		N.D	N.D		N.D	
B50	N.D		N.D	N.D		N.D	
B75	N.D		N.D	N.D		N.D	
B100	0.60		2.02	0.76		0.87	

N.D—Not Defined.

1,5-diphenyl-Imizazole-2-thiol was found to have a percentage composition of 2.98% in B100. It can cause cancer in human beings through exposure and inhalation. 7-trifluoromethyl 2,5-dimethyl-Pyrazolo [1,5-a] pyrimidine-3-carbonitrile was detected in B100 with a percentage composition of 1.46%. It can irritate human eyes, skin, and respiratory tract on exposure and inhalation. The presence of 1,3,5,7-Tetrathiocane was found in B100 with a percentage composition of 0.96%. It can irritate the human eye, skin, and respiratory tract in human beings on exposure and inhalation.

1,3,5,2,4,6-Trithia (5-SIV) triazine was detected in B100 with a percentage composition of 0.96%. It can irritate the human eye, skin, and respiratory tract in human beings on exposure and inhalation. 1,1,3,3-tetraoxide was found with a percentage composition of

0.96% in B100. It can damage the kidney and can also irritate the eye, skin, nose, and throat in human beings when exposed and inhaled. 2-(4-Bromophenyl)-5-hydroxypyrimidine detected in B100 with a percentage composition of 0.747%. It can cause cancer and skin, eye, and respiratory tract irritation in human beings when exposed and inhaled.

The presence of 4,4′-Thiodibenzenethiol was found in B100 with a percentage composition of 0.75%. It can cause eye irritation in human beings when exposed and inhaled. N-methoxy-aziridine-2-carboxamide with a percentage composition of 1.46% was found in B100. It can irritate human beings' skin, eye, and respiratory tract when exposed and inhaled. 4-(N, N-Dimethylaminomethylenamino)-7-nitrobenzofurazan was detected with a percentage composition of 0.92% in B100. It can cause skin, eye, and respiratory tract irritation in human beings when exposed and inhaled.

2-(diphenylphosphino)-1H-Imidazole was found to have a percentage composition of 0.60% in B100. It can cause chemical burn to the respiratory tract and cause eye and skin burns [41]. 4,4′-(3-ethenyl-1-propene-1,3-diyl)bis-phenol was detected in B100 with a percentage composition of 0.71%. When inhaled, it can cause cancer in human beings. Tricyclo[10.2.2.2(5,8)]octadeca-5,7,12,14,15,17-hexaen-6-ol was found to have a percentage composition of 4.58% in B100. 3,5-di(4-nitro-1,2,5-oxadiazol-3-yl)-4H-1,2,4-Triazole was detected with a percentage composition of 0.63% in B100. It can cause eye, skin, and respiratory tract irritation in human beings on exposure and inhalation.

[1-(Hydroxy-phenyl-methyl)-cyclopropyl]-phenyl-methanone was found to have a percentage composition of 7.34% in B100. When inhaled, it can cause cancer in human beings. 9-(4-diethylaminobenzylideno)-Fluorene-2,7-diacetyl was found in B100 with a percentage composition of 0.65%. It can cause eye irritation in human beings when exposed and inhaled. 2-amino-4-(4-biphenyl)Thiazole was found in B100, with a percentage composition of 1.02%. It can cause cancer in human beings when exposed and inhaled. 3,7-dihydro-8-chloro-1,3-dimethyl-7-(2-propynyl)-1H-Purine-2,6-dione was found to have a percentage composition of 1.02% in B100. It can cause eye irritation in humans when inhaled.

2,2′-Benzylidenebis (5-methylfuran) was detected with a percentage composition of 0.60% in B100. It can cause cancer, irritate the eye, skin, nose, and throat and also damage the liver and kidney in human beings when exposed and inhaled. 1,1′-(9H-fluorine-2,7-diyl) bis-Ethanone was found to have a percentage composition of 2.02% in B100. It can cause irritation to the eye, skin, and respiratory tract in human beings when exposed and inhaled. 6-methoxyanthracene-2-carboxylic acid was detected with a percentage composition of 0.76% in B100. When inhaled, it can irritate human skin, eye, upper respiratory tract, and mucous membranes. 2,4-Dihydroxy-5-iodo-6-methyl pyrimidine was found to have a percentage composition of 0.87% in B100. It can cause nausea and vomiting and irritate the respiratory tract, skin, and eyes in human beings when inhaled.

3.4. Engine Performance—Environmental Impact Analysis of the Biodiesel Blends Combustion

Blend B25 (25% *v*/*v* of shea butter biodiesel (SBOB) + 75% *v*/*v* of petroleum diesel) was chosen as the optimum blend amongst the five biodiesel blends developed from the mixture of shea butter oil biodiesel and petroleum diesel because of the improved performance characteristics. Nevertheless, it is important to acknowledge and evaluate the environmental impact of the combustion of these fuel blends in relation to their potential for reducing greenhouse gas emissions [43]. As per the USEPA [44], CO_2 is identified as the predominant greenhouse gas released as a result of human activities. Its capacity to trap heat in the atmosphere contributes significantly to the phenomenon of global warming, which leads to an overall increase in atmospheric temperatures [45,46]. According to Wang et al. [47], global climate change is being driven by two major factors, viz. atmospheric warming and nitrogen deposition. The primary source of CO_2 emissions from humans is the use of fossil fuels (coal, natural gas, and oil) for energy and transportation. Any alternative renewable fuel with greenhouse gas reduction potential is considered to be sustainable for the human–environment scenario [1].

The percentage reduction of CO_2 and CO emissions compared with diesel is shown in Figure 1. The exhaust from the CI engine, when operated with B100 blend, demonstrated a significant reduction in CO, CO_2, and other organic compounds that can adversely affect human health. Although its BTE of 85.05% was lower than that of B0, B25, B50, and B75 blends, environmental sustainability and the well-being of people are considered valuable assets in the energy–human sustainable scenario. The B100 produced the lowest concentrations of carbon emissions, viz. 520 ppm CO and 1.0% CO_2. The concentration of oxygen in the exhaust emissions was found to be 16% for B100 combustion, which was more than the concentrations obtained from the remaining fuel samples. The increased oxygen concentrations were occasioned by the oxygenated nature of biodiesel in comparison with diesel fuel. Biodiesel possesses a higher oxygen content in its chemical composition compared to conventional diesel fuel. This elevated oxygen content plays a crucial role in facilitating thorough combustion within diesel engines [35,36]. This is consistent with the findings of Wu et al. [48], who investigated the emission characteristics of a waste cooking oil biodiesel blend in a marine diesel propulsion engine and discovered that increasing the biodiesel content in the blend with petroleum diesel inhibits the formation of particulate matter (PM), reduces the formation of unburned hydrocarbon (HC), and reduces harmful gaseous emission.

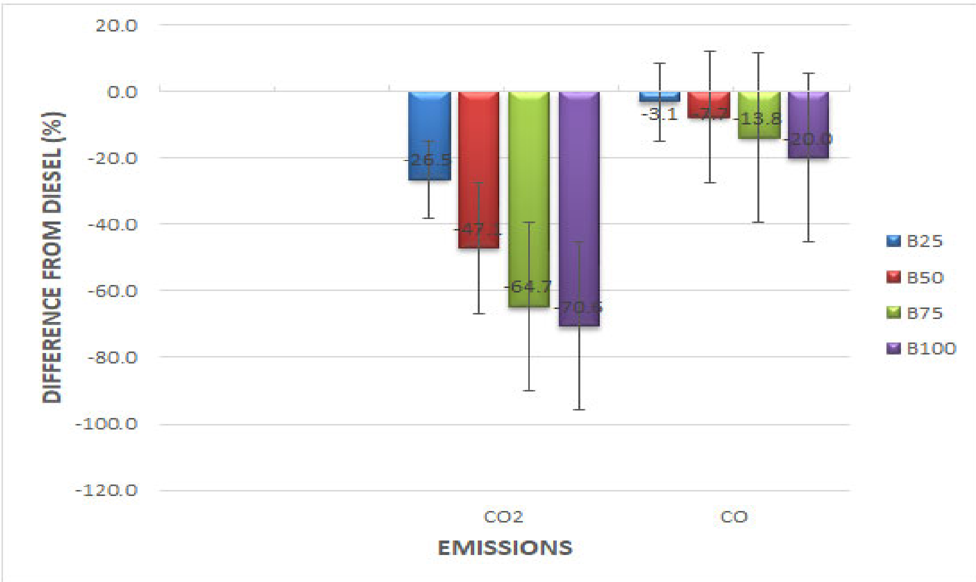

Figure 1. Percentage reduction of CO_2 and CO emissions compared with diesel.

The utilisation of B75 as an alternative fuel blend offers a promising solution for reducing greenhouse gas emissions while simultaneously yielding enhanced performance attributes. The B75 blend demonstrated notable engine performance characteristics, including 8.20 Nm of torque, 1718.09 W of BP, and a BTE of 88.16%. Moreover, when compared to diesel fuel, B25, and B50, the B75 blend exhibited lower carbon emissions with levels of 560 parts per million (ppm) of CO and 1.20% of CO_2. Notably, the exhaust gases from B75 combustion exhibited an oxygen concentration of 14%, surpassing the levels observed in the exhaust gases of diesel fuel, B25, and B50.

4. Conclusions

This study established the application of low-emission shea butter biodiesel in a CI engine. The research showed that SBOB has a lower emissions profile of CO and CO_2 compared with petroleum diesel. The optimum blend developed from the mixture of shea butter oil biodiesel and petroleum diesel was found to be B25 relative to the combined engine performance characteristics. The exhaust from the compression ignition engine operated on this blend had a reduction in CO, CO_2, and other organic compounds emitted into the atmosphere.

From the results obtained, the following conclusions were drawn from this study:

i. The carbon content, sulphur content, heating value, and ash content of the blends were found to decrease from 0.68 to 0.12 wt %, 0.04 to 0.00 wt %, 44.2 to 34.2 MJ/kg, and 0.020 to 0.010 wt %, respectively.
ii. The engine torque, brake power, BTE, and engine vibrations were found to reduce when the biodiesel blends were used.
iii. Biodiesel to petroleum diesel ratio of 75:25 gave the best engine performance with 8.2 Nm torque, 1718.09 W BP, 88.16% BTE, and 560 ppm CO, as well as 1.20% CO_2 emission.
iv. The B100 produced the lowest concentrations of carbon emissions, viz. 520 ppm CO and 1.0% CO_2.
v. The NO and NO_2 concentrations were found to increase for all the biodiesel blends used. The NO and NO_2 concentrations were measured as 230 ppm and 210 ppm for B0, respectively, and 250 ppm and 235 ppm for B25, respectively.
vi. The GCMS analysis confirmed that some organic compounds were present in the emissions profile obtained from the exhausts of the CI engine operated with petroleum diesel and SBOB blends. These organic emissions can cause respiratory tract, skin, eye, and allergic reactions on exposure and inhalation.

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