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Original Research

Exhaust Emissions from Engines Fuelled with Petrol, Diesel and their Blends with Biodiesel Produced from Waste Cooking Oil

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Abstract

A study of exhaust emissions from engines in Enugu State, Nigeria fuelled with petrol, diesel and their blends with biodiesel was carried out. The biodiesel was produced from waste cooking oil via transesterification and both were analysed using ASTM methods. Exhaust emissions (CO, CO_2, O_2, NO and NOx) from petrol (motorcycles, tricycles, mini-buses and passenger cars) and diesel vehicles (tankers and trailers) as well as big and small capacity generators were analysed using a Bacharach portable combustion analyzer 2. Petrol and diesel were blended with biodiesel and used to fuel generators and vehicles at different blend ratios (B5 to B40). The diesel vehicles emitted much lower concentrations of CO and CO_2 but higher NOx than the petrol vehicles. Small capacity generators emitted more CO while large capacity generators emitted more NOx and CO_2. For all blends, there was a significant reduction in CO, CO_2 and NOx emitted in the small and large petrol-biodiesel generators. However in the diesel-biodiesel generator there was an increase in NOx emission and a decrease in CO and CO_2. Also, CO from all the petrol vehicles exceeded the obsolete EU 2 limit. Therefore, these emissions could enhance health and environmental hazards associated with their pollution.

Keywords: biodiesel, diesel, air, exhaust emissions, waste cooking oil

Introduction

The last century has seen an increase in the global automobile population, making the transportation sector very crucial to a nation's economy. Developing countries account for about 10% of the global automobile population and a little over 20% of the global transport energy consumption [1]. The transportation sector consumes over 50% of the global oil demand, resulting in about 25% of anthropogenic CO_2 emissions. Within the sector, emissions from motor vehicles account for approximately 75% of direct CO_2 emissions [2].

This vehicular growth has not been properly checked by approved environmental regulating bodies, leading to increased levels of pollution [3]. With the rapidly rising mobility that accompanies it, the increase in automobile emissions will be greater than in developed nations. Steady growth in vehicular populations has put environmental stress on urban centres in various forms, particularly causing poor air quality. There is growing evidence that links vehicle pollutants to human

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ill health. In a study by Wang et al., [4], decreased attention of urban children was significantly associated with traffic-related pollution. Also, motor vehicles are major emission sources for several air pollutants, including nitrogen oxides (NOx) and carbon monoxide (CO) [5]. These pollutants have significant health and ecological effects. For example, high content of atmospheric CO leads to asphyxiation, which affects the proper functioning of different organs, resulting in impaired concentration, slow reflexes and confusion [6, 7]. Wheezing and coughing are common effects of nitrogen oxide toxicity. However, dyspnea, chest pain, nose, eyes or throat irritations, headache, bronchospasm, diaphoresis, fever and pulmonary edema may also occur [8].

Mobile source pollution is increased by disorganized road networks, inefficient vehicles, fuel adulteration and traffic congestion [9]. The extent of automobile pollution is also based on the attributes of vehicular congestion movement rate, repair status and life span [10]. Particularly, poor vehicle maintenance culture and importation of old vehicles, which culminates in an automobile fleet dominated by a class of vehicles known as “super emitters” with high emission of harmful pollutants, has raised this figure of emission concentration [11]. These situations are alarming and are predicated on the poor economic disposition of developing countries.

One of the largest contributors to air pollution in urban environments are actually motor vehicles [12]. Particularly, air pollution problems in Nigeria are mainly from automobile exhaust due to the numerous and common outdoor activities. The general population stays daily on very busy roads to do their work, sell their wares or wait for public transport. Also, in Enugu state, Nigeria, the absence of a reliable public transport system has worsened air pollution because of an increased number of old second-hand cars, taxis, motorbikes, substandard petrol and other products imported into the country. There is presently no available data on the emission and impact of air pollution in Enugu, but it is anticipated that air pollution will become a major health problem if adequate mitigation measures are not employed [13]. In Nigeria, a lot of attention is given to general industrial pollution, including oil industries, with little reference to pollution caused by air pollution from transportation sources [14]. Pollution from mobile transportation is on the rise due to increases in per capital vehicle ownership, thus resulting in high congestion on Nigeria city roads and increases in the concentration of pollutants in the air, and consequently increasing health risks for the human population. With a public ban placed on motorcycles in major cities in Nigeria, towns like Nsukka have too many motorcycle operators, and no proper investigation has been made into the estimation of the level of emissions from motorcycles in comparison with that from cars and tricycles. Nigeria is also at the brink of economic meltdown cum the persistent power shortage experienced, hence purchasing and operating of small-capacity petrol generators (SCGG) seem the most viable option for most Nigerians, but the ban placed on the importation of this set of generators makes it a very difficult option. It is therefore necessary to analyse the gaseous emissions from these generators and see the difference between them and the large-capacity petrol generators (LCGG). It is also necessary to investigate ways of reducing the emissions from vehicles and generators – especially the publicly banned ones (e.g., motorcycles and SCGGs) by blending their fuels with biodiesel fuel.

Some studies have been carried out on exhaust emissions. Passenger cars were analysed for emissions on Nigerian roads. Results showed that the major types of tail pipe emission from the vehicles used in Nigeria are CO_2, NOx, CO and O_2 [10]. The impact of vehicular emissions has also been studied in Benue and Akwa Ibom States in Nigeria by assessing the levels of gaseous emissions in the air. Results from Benue were slightly higher than Nigerian air quality standards [15, 16].

Compared with the large volume and varieties of studies carried out on air exhaust emissions in the developed world [17], studies for Nigeria are quite scarce. Therefore, this study was carried out to evaluate the level of pollution from automobile and generator exhaust gases (CO, CO_2, O_2 and NOx) in Nsukka, Enugu State, Nigeria through monitoring of gaseous emissions from petrol and diesel, and analyzing the impact of biodiesel blends on exhaust emissions.

Experimental

The study was carried out at the National Centre for Energy Research and Development, University of Nigeria Nsukka. The waste cooking oil was obtained from a restaurant. Reagents used were analytical grade. Methanol and sodium hydroxide were products of Merck, Darmstadt, Germany (99.7% purity) and Loba Chemie GmbH Switzerland (85% purity). The oil was characterised for specific gravity using a specific gravity bottle; moisture content by oven (BTOV 1423) dry method; kinematic viscosity using a Ferranti portable viscometer model VL; the acid, peroxide, iodine and saponification values by titrimetry; refractive index using Abbe’s refractometer; flash point using semi-automatic Clevaland flask point tester; pour point using cooling method; acid number using ASTM D 664; percentage free fatty acid (% FFA) (as Oleic) was determined by the acid value with the factor 0.0503. Thus % FFA = 0.503 x acid value [18]. Sulphur content was determined by energy dispersive X-ray fluorescence spectroscopy, ash content by ASTM D874 and calorific value using a Hewlett adiabatic bomb calorimeter model 1242.

Biodiesel Production, Separation and Purification

The transesterification reaction was carried out by measuring 1000 ml of the sieved waste cooking oil with an excess amount of methanol (220 ml per liter of oil) into an airtight clean conical flask containing a magnetic stirrer and then heated to 55°C. A catalyst (1% NaOH) was added and made airtight immediately in order to improve the transesterification reaction. The reaction mixture was then shaken and maintained between 60-65ºC for 60 minutes [19]. At the end of the reaction, the product was allowed to settle overnight. Two distinct liquid phases: crude ester phase at the top and glycerol phase at the bottom were produced in a successful transesterification reaction.

The top ester phase (biodiesel) was separated from the bottom glycerol phase by transferring to a clean 1000 ml conical flask. The biodiesel was then purified by washing several times with warm distilled water to a neutral pH to remove all the residual by-products such as excess alcohol, excess catalysts, soap, glycerine and other impurities. The volume of distilled water added was approximately 15% of the biodiesel volume. The flask was shaken gently for 1 minute and placed on a table to allow separation of biodiesel and water layers. After separation, the biodiesel was transferred to a clean conical flask [19]. The biodiesel was characterized using the same methods as the oil.

Sample Size of Vehicles and Generators

The vehicles and the generators were selected at random based on availability and corporation of the automobile and generator operators in Nsukka, Enugu State, Nigeria. The engines analysed were diesel vehicles (6 trailers and 6 tankers), petrol vehicles (10 each of motorcycles, tricycles, buses and passenger cars) and generators (10 small (2 kVA) capacity and 10 large (7.5 kVA) capacity). In addition, petrol and diesel were blended with biodiesel in ratios ranging from B10 (10% biodiesel and 90% petrol/diesel) to B40 (40% biodiesel and 60% petrol/diesel). Blended engines were a petrol-biodiesel small capacity generator, a petrol-biodiesel large capacity generator, a diesel-biodiesel large capacity generator and a petrol-biodiesel motorcycle.

Equipment Setup and Exhaust Gas Measurement

A gas analyser (Bacharach portable combustion analyser 2) was used for the study. The gas analyser was comprised of a 5-gas analyzer meter, an exhaust probe, sample conditioning probe and a printer. The meter is fitted with water trap, a filter and a protective rubber sleeve. The equipment measures the volume percentage of CO, CO_2, O_2, NO, and NOx in the exhaust gas. The CO_2 and O_2 emissions are measured in percentages whereas CO, NO and NOx (added values of NO and NO_2) are measured in ppm. At the start of each experiment, the gas analyser was first purged to ensure there was no air trapped that could affect the results. The filter was regularly checked to ensure that it was clean and not clogged with particles. The startup time before testing was about 70 seconds. When ready for use, the analyser probe was fitted to the exhaust pipe and firmly held. The vehicle operator was required to run the engine in idle mode for five minutes and then measurements were done. The typical time for testing one vehicle/generator was five minutes. In the case of motorcycles, the operators were required to ride the motorbike through a distance of 1 km and then measurement of the emissions was done [10]. To compare the EU standard in g/km to the results obtained in ppm, the conversion employed (equations 1-3) was based on the assumptions of Alkama et al., [20] and conversions adopted by Pilusa et al., [21].

$$\text{CO (g/km)} = 9.66 \text{ x } 10^{-3} \text{ x CO (ppm)} \quad (1)$$

$$\text{NOx (g/km) } 28.56 \text{ x } 10^{-3} \text{ x NOx (ppm)} \quad (2)$$

$$CO_2 \text{ (g/km)} = 166.3 \text{ x } CO_2 \text{ (vol\%)} \quad (3)$$

Results and Discussion

The waste cooking oil and the biodiesel produced were analysed for their fuel properties in order to determine their suitability for biodiesel production and engine fuel respectively. The results are shown in Table 1. The specific gravity of the oil and biodiesel was 0.99 and 0.90 respectively. The gravity of the biodiesel

Table 1. Quality parameters of waste cooking oil and biodiesel.

Parameters	Waste cooking oil	Biodiesel
Specific gravity	0.99	0.90
Moisture Content (%)	0	0.05
Kinematic Viscosity (m^2/s)	7.52	1.90
Acid Value (mgKOH/g)	1.64	0.22
Free Fatty Acid (%)	0.82	0.11
Peroxide Value (mgKOH/g)	4.98	-
Iodine Value ($gI_2/100g$)	9.90	13.45
Refractive Index	1.47	-
Saponification Value (mgKOH/g)	257.93	-
Sulphur Content (%)	-	0.01
Flash Point (°C)	-	155
Pour Point (°C)	-	-3.00
Ash Content (%)	-	0.09
Calorific Value (KJ/Kg)	-	34,400

Table 2. Concentrations of gaseous emissions from petrol vehicles.

S/N	Motorcycles					Tricycles					Mini buses					Passenger vehicles				
	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	14.5	3011	4.7	3	3	19.5	3350	3.5	3	3	11.9	3325	6.1	32	32	13.2	1598	3.6	43	43
2	17.6	3290	5.8	2	2	20.9	1565	3.8	5	5	14.9	3563	5.1	6	6	18.1	2891	2.4	12	12
3	18.6	2919	3.4	2	2	18.5	2981	4.6	2	2	13.7	3644	5.3	8	8	7.7	2346	3.8	26	26
4	18.5	3371	-	3	3	20.2	3217	2.3	4	4	18.3	3123	6.6	34	34	12.6	2274	3.9	16	16
5	16.2	3320	-	2	2	19.3	1781	4.7	2	2	12.3	3832	4.9	13	13	9.2	2812	2.9	37	37
6	12.7	3406	4.1	6	6	14.6	3017	4.3	6	6	15.1	3428	5.1	27	27	14.6	1497	3.5	23	23
7	9.3	2273	3.3	5	5	11.1	2178	4.9	3	3	11.9	3861	7.5	9	9	11.2	2654	4.6	14	14
8	5.7	3590	4.1	24	24	19.3	1782	4.3	2	2	11.4	3520	8.4	17	17	19.4	1091	3.3	39	39
9	16.6	4031	4.9	2	2	20.4	2415	2.5	5	5	16.8	3005	6.2	24	24	20.2	1986	-	20	20
10	11.4	3650	4.6	3	3	13.8	3319	3.5	3	3	12.6	3816	5.7	30	30	15.9	2170	3.8	41	41
Mean	14.1	3286	4.4	5	5	17.8	2560	3.8	3.5	3.5	13.9	3512	6.0	20	20	14.2	2132	3.5	27	27

was within the EN 14214 standard range of (0.86-0.09) for biodiesel. This is important since fuel is delivered by the engine on a volumetric basis and biodiesel density is higher than that of diesel. Studies have shown that higher engine fuel consumption for biodiesel is partly due to its high density. Also, higher content of biodiesel in the blends results in higher emissions of particulate matter [22]. The moisture content of the waste cooking oil was 0%, which favours transesterification. Moisture in vegetable oils is a great impediment to the formation of esters due to increased tendency of soap formation and thus will have to be minimal for transesterification to occur [23]. The moisture content (0.05%) of the biodiesel produced was within the acceptable limit of 0.05% for ASTM D6751. The amount of water in biodiesel determines the calorific value and, above all, the shelf life of the fuel. Biodiesel with high water content has clearly lower oxidation stability, which favours oxidation products to be formed during long storage periods. These can cause engine problems due to deposits, particularly with the injection system. The calorific value of the obtained biodiesel was 34400 KJ/kg (34.4 MJ/kg), which is only slightly higher than that of EN14214 standard (32.9 MJ/Kg) for biodiesel.

Kinematic viscosity is a measure of fluid resistance to flow. This is one of the advantages of the use of biodiesel as an alternative fuel instead of neat vegetable oils and animal fats that cause operational problems such as engine deposits when used directly as fuels. The kinematic viscosity of the oil (7.52 m^2/s) was within the recommended standard range of 6.3 to 8.8 m^2/s, while that of the biodiesel (1.9 m^2/s) measured at 40ºC was in conformity with the ASTM D6751 standard range of 1.9-6.0. This also shows that the transesterification method employed effectively reduced the kinematic viscosity as required.

The acid value of the waste cooking oil and biodiesel were 1.64 mgKOH/g and 0.22 mgKOH/g, respectively, which was within the recommended standard of 0.50 mgKOH/g and 0.8 mgKOH/g for EN 14214 and ASTM D6751 respectively. High acid value leads to catalyst deactivation. Acid value is also a direct measure of the content and the level of free fatty acids, which has an influence on fuel aging. The presence of high free fatty acids can lead to corrosion during storage or transportation and may be a consequence of water in the fuel. The peroxide value of the waste cooking oil at 4.98 mgKOH/g was very low compared to the standard of 10 mEq/kg by FAO/WHO [24] for fresh edible oil. This was attributed to low levels of oxidative rancidity of the oils, high levels of antioxidants like propyl gallate, and susceptibility of oil to deterioration when used as a feedstock for biodiesel. Iodine value is an important characteristic that determines the degree of unsaturation of fats and oils [25]. Therefore, high iodine value indicates high unsaturation of fats and oil.

The iodine value of the oil and biodiesel used in this study were 9.9 $gI_2/100g$ and 13.45 $gI_2/100g$, respectively,

Table 3. Concentrations of gaseous emissions from diesel vehicles.

S/N	Tankers					Trailers				
	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	16.0	597	1.5	50	126	16.	928	1.9	38	102
2	12.8	705	1.2	17	103	16.3	971	1.1	55	109
3	13.7	728	1.9	37	113	16.6	729	2.3	46	104
4	15.6	840	1.5	41	106	16.7	890	1.4	33	89
5	16.1	671	1.6	53	132	17.2	551	0	49	100
6	16.2	831	1.7	28	108	18.7	583	0	50	95
Mean	15.1	729	1.6	74	115	17	745	1.1	55	100

which was comparably lower than 120 gI_2/100g EN14214 standard. The biodiesel had a flash point of 155ºC and was within the recommended range of >130ºC and >101ºC of ASTM D6751 and EN 14214 respectively. This indicates that the biodiesel is not highly inflammable and therefore poses no risk of fire outbreak – especially in case of accidents. It was also characterized by low sulphur content (0.01%), which is considered to be an advantage since the presence of sulphur in the fuel leads to the formation of acidic sulphur oxides (SO_2 and SO_3), which are corrosive gases that will corrode the engine parts and also lead to environmental pollution.

The analysis of gaseous emissions from vehicles and generators showed that O_2, CO_2, NOx, and CO were emitted during combustion of the fossil fuels. Table 2 shows the results of the analysed gaseous emissions from petrol vehicles. The mean results of CO_2 and CO emitted by minibuses were higher than those emitted by other petrol vehicles. Passenger cars emitted highest mean NOx value (27.1 ppm) while minibuses, motorcycles and tricycles emitted 20 ppm, 5.2 ppm and 3.5 ppm respectively. In comparison with the second European emission (EU 2) standard [26] adopted by Nigeria [27], as against the EU 6 standard [26] being used in Europe, motorcycles (3286.10 ppm) emitted four times the CO limit of 569.36 ppm for two-wheelers, and hence produced an excess of 2716.6 ppm CO, which could be detrimental to the environment. However, the NOx concentration of motorcycles (5.2 ppm) was below the standard value (10.50 ppm) for NOx. Tricycle CO (2560.5 ppm) emissions were 1835.64 ppm above the permissible limit of 724.64 ppm for three-wheelers but emitted an NOx value (3.5 ppm) below the permissible limit of 14.01 ppm. The CO of passenger car (2131.9 ppm) and minibus (3511.7 ppm) emissions was above the permissible limit of 227.74 ppm. There is no standard limit for the emissions of NOx and CO_2 in the EU 2 emission standard for light-duty petrol vehicles, but the emitted NOx value exceeded the EU 6 permissible limit of 2.10 ppm. Although Nigeria is using the EU 2 Standard, comparison with EU 6 is important since there is a direct correlation between concentrations of pollutants from vehicular emissions and the general health of the population. This is even more important for densely populated countries, e.g., Nigeria.

For diesel vehicles (Table 3), the mean CO and NOx emitted from tankers were below the EU 2 emission standard permissible limit of 1113.89 ppm and 1054.86 ppm, respectively, for heavy-duty diesel vehicles. But on comparison with the EU 6 emission standard, tankers emitted more CO and NOx above the permissible limit of 54.39 ppm (CO) and 60.27 ppm (NOx). Trailers on the other hand emitted 369.09 ppm less CO against the permissible limit of 1113.89 ppm and 955.03 ppm less NOx against the permissible limit of 1054.86 ppm for EU 2 standard. On comparison with the current EU 6 emission standard, trailers emitted 37.69 ppm more CO above the permissible limit of 417.11 ppm and 39.56 ppm more NOx above the permissible limit of 54.39 ppm. Gaseous emissions (CO and NOx) from trailers and tankers appear to be environmentally friendly according to the Nigeria standard, but when compared to the current EU 6 standard, they exceeded the maximum permissible limit.

Each of the petrol vehicles emitted more than twice the CO_2 of the diesel vehicles. Among the six vehicles considered, minibuses and tricycles emitted the highest (27%) and lowest CO_2 (17%) respectively, while motorcycles and passenger cars accounted for 21.5% and 19% respectively of the total CO_2. CO_2 is formed when the fuel is completely burnt. Diesel is a long-chain heavier (hexanes) compound than petrol, which means that it has a higher number of carbon atoms, resulting in greater CO_2 emissions, yet diesel vehicles emit less CO_2 than petrol engines. This could be attributed to the fact that diesel engines have more fuel efficiency than petrol engines and hence burn less carbon per kilometre [28]. Petrol vehicles emitted about three times more CO than diesel vehicles which shows that petrol vehicles had more incomplete combustion than diesel vehicles. This is due to insufficient air present to completely burn the fuel. CO emission is common in petrol engines since it always operates close to stoichiometric conditions, while diesel engines are lean-burn engines, hence the chances

Table 4. Concentrations of gaseous emissions from petrol generators.

S/N	Small Capacitor Petrol Generators					Large Capacitor Petrol Generators				
	O_2(%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2(%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	18.5	2847	2.1	29	29	15.7	2868	5.4	33	33
2	14.2	3891	4.8	26	26	5.9	4021	10.8	26	26
3	7.5	2311	7.6	19	19	7.3	3029	8.8	41	41
4	9.1	3248	5.6	33	33	16.0	3865	3.2	25	25
5	14.6	2130	6.4	23	23	12.2	1548	5.0	18	18
6	18.0	1935	1.9	37	37	9.2	1955	7.2	45	45
7	17.4	3271	4.5	16	16	13.2	3124	6.3	37	37
8	12.0	3619	5.1	41	41	14.6	2138	5.5	19	19
9	13.2	2477	6.2	20	20	11.0	3081	6.7	39	39
10	16.8	3039	2.4	32	32	8.9	2847	6.9	20	20
Mean	14.1	2877	4.7	27.6	27.6	11.4	2847	6.6	30	30

of CO emission from diesel engine is less compared to that of petrol engines [29]. The highest NOx emissions were observed in diesel engines (trailers and tankers). The NOx emitted by tankers (114.7 ppm) were twice the sum of all the NOx emitted by the petrol vehicles, while that of trailers (99.8 ppm), although lower than that of tankers (114.7 ppm), is actually higher than the sum of all the NOx emitted by petrol vehicles. Since NOx is formed when nitrogen reacts with oxygen at elevated temperatures, high cylinder temperatures lead to NOx formation as both nitrogen and oxygen in the incoming charge are usually inert at low temperature. As diesel engines operate at much higher cylinder pressure, which leads to high in-cylinder temperature, more nitrogen reacts with oxygen, hence NOx formation is dominant in diesel engines. This was also the case in other studies. For instance, Yasar et al., [28] reported that a diesel car emitted 0.1% CO and 41 ppm NOx while a petrol-used car emitted 1.8% CO and 13 ppm NOx.

Table 4 shows the results of the emissions from both SCPGs and LCPGs. SCPGs emitted less mean CO_2 (4.66%) than LCPGs (6.58%), but slightly higher CO. With the amount of CO_2 and CO emitted by both the SCPG and LCPG, it is clear that the LCPG is more efficient in ensuring complete combustion. There was no NO_2 detected in the two categories of generators measured as the volume of NOx equalled the volume of NO emitted. The LCPG emitted higher NOx than the SCPG; with its mean NOx emission value of 30.3 ppm while SCPG was 27.6 ppm. Consequently SCPGs are responsible for 47.8% of the total NOx emitted by the petrol generators, while LCPG is responsible for about 52.2% of the total NOx emissions by petrol generators. LCGGs also emitted more CO_2, which is not harmful to humans and is less harmful to the environment. SCGGs emitted more CO, which is very harmful to both human health and the environment.

Generally, both generators and vehicles contribute significantly to air pollution. With an epileptic power supply and transportation needs as a result of increasing population, the numbers of vehicles and generators can only be on the increase. Comparing the results from generators and vehicles, it is seen that each contributes significantly to the pollution problems in the environment. Tankers emitted more NOx than every other vehicle and generator used, followed by trailers, but these two had the least CO and CO_2 emissions. Inasmuch as diesel engines emit one-third the CO and CO_2 that petrol engines emit, they on the other hand emit about thrice the NOx that the petrol engines emit. Tankers and trailers accounted for about 65% of the total NOx emissions while minibuses, passenger cars, tricycles, motorcycles, small capacity petrol generators and large capacity petrol generators all accounted for only about 35% of total NOx emissions. Minibuses emitted most CO, while large capacity petrol generators emitted the highest CO_2. Tricycles had an average CO and CO_2 emissions and the least NOx emissions. While motorcycles had very low NOx emissions, they had very high CO emissions. SCGG, LCGG and small vehicles had very high NOx emissions compared to only the rest of petrol engines.

The excess CO, NOx and CO_2 emitted will directly increase the concentration of these gases in the air and hence affect air quality of the environment, which also affects human health and the environment. The severity of health effects from CO exposure depends on some factors, such as general health status and age of a person, duration of CO exposure, atmospheric concentration of CO, etc. [30]. Also, ischemia apoptosis and hypoxia are known mechanisms of underlying CO toxicity [31]. Safe CO exposure can be characterized as exposure to an air concentration of CO that is less than the U.S. EPA's [32] National Ambient (outdoor) Air Quality Standards of

9 ppm (8-hr average) or 35 ppm (1-hr average). NOx also is very harmful when inhaled beyond the permissible limit. NO_2 concentration below 0.12 ppm does not have any effect on humans. However, if exposed to high concentrations it will cause adverse health effects such as lung disease and influenza [33].

Petrol and biodiesel blended at two different ratios as shown in Table 5 were used to fuel small- and large-capacity petrol generators as well as a motorcycle. At B0, the small generators emitted 3.7% CO_2. At B5 there was no significant reduction in the CO_2 emitted as 3.7% was still recorded. However, at B10, 2.70% CO_2 reduction was recorded. For carbon monoxide emissions, at B0 a CO value of 2847 ppm was recorded, at B5 there was a 1.58% reduction in CO emitted. At B10, there was further reduction in the CO as 2730 ppm was recorded, which indicates a 4.12% reduction in CO emitted. In the case of NOx, there was also a large reduction of emissions for each blending ratio. At B0, 29 ppm of NOx was emitted. At B5, about 17.24% reduction was observed and at B10, there was still a further reduction in emissions of 44.83% reduction with only 16ppm of NOx. While for large generators, CO_2 reductions were observed at every blend ratio although the concentrations emitted were higher than small generators and this was also the case for CO and NOx.

For the motorcycle, at B0, there was 10% reduction in emission of CO_2 from B0 to B10. However, reduction in the volume of CO emitted occurred at each blend ratio, which exceeded the percentage CO_2 reduction. NOx was emitted at each blend ratio, but unlike petrol generators, there was an increase in the volume of NOx emitted. At B10, the volume of NOx emitted was 10ppm. This was the highest recorded volume of NOx. At B5, there was 80% reduction in the NOx volume recorded while a further 10% reduction occurred at B0, which confirmed that NOx emissions decreased with a decrease in the blending ratio. Therefore, for motorcycles the volume of CO_2 and CO decreased with increases in the blend ratio, while NOx increased. Blending petrol with little biodiesel reduced emissions of CO, CO_2 and NOx for petrol generators. Similar trends were found in literature, where CO reduction is linear with biodiesel concentration in the fuel [34]. Therefore, blending petrol with biodiesel is most appropriate for petrol generators.

Blends of diesel and biodiesel were also studied (Table 6). At every blend ratio, there was a significant change in the volume of emissions. For B0, the diesel generator emitted 1.5% CO_2. At B10, there was 13.33% reduction and at B20 there was 33.33% reduction. However, at B30 and B40 there was no detectable CO_2 emission. For CO, 1009 ppm was emitted at B0 with a reduction in emissions for all blending ratios, which was up to 37.46% at B40. Unlike petrol engines, NO_2 was detected at every blend ratio as NOx equals the sum of the values of NO and NO_2. The highest NOx value (88 ppm) was recorded at B40 with a reduction for decreasing biodiesel ratio, which was 12.50% for

Table 5. Concentrations of gaseous emissions from biodiesel-petrol motorcycles and generators.

Ratio	Small Capacitor Generators					Large Capacitor Generators					Motorcycle				
	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
B0	15.5	2847	3.7	29	29	12.5	3891	5.2	54	54	11.7	3566	3.0	1	1
B5	15.1	2802	3.7	24	24	13.5	3831	5.1	51	51	10.7	2842	2.9	2	2
B10	15.3	2730	3.6	16	16	14.4	3675	4.5	43	43	11.5	2218	2.7	8	10
Mean	15.3	2793	3.7	23	23	13.5	3799	4.9	49.3	49.3	11.3	2875	2.9	3.7	4.3

Table 6. Concentrations of gaseous emissions from biodiesel-diesel large-capacitor generator.

Ratio	Concentrations				
	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
B0	11.4	1009	1.5	43	77
B10	14.7	900	1.3	51	80
B20	16.2	820	1.0	53	82
B30	15.2	713	--	57	83
B40	16.2	631	--	62	88
Mean	14.7	814	1.3	53	82

B0. As the emission of NOx increased with increasing biodiesel ratio, it is also observed that the volume of NO_2 emitted decreased with increases in biodiesel. The reasons for CO reduction in biodiesel generators and motorcycles could be attributed to the additional oxygen content in the fuel that enhances a complete combustion of the fuel. Abdullah et al. [35] also observed that NOx emissions increased while the carbon monoxide (CO) emissions decreased for the studied biodiesel blends. The increase in NOx emissions from diesel generators and the motorcycle could be attributed to the higher oxygen availability in the combustion chamber when using biodiesel, which could promote NO formation while NOx reduction in petrol generators could be due to engine construction and flame profile.

Conclusions

This study shows that exhaust gas pollution in Nigeria is high and will continue to increase if left unabated. Diesel vehicles emitted more NOx than the petrol vehicles, while petrol engines emit more CO_2 and CO than the diesel engines. Large-capacity generators emitted lesser quantity of the harmful CO than small-capacity generators. The emissions from both small- and large-capacity generators are within the range of vehicular emissions, but they exceeded the outdated EU 2 standard adopted by Nigeria. This implies that persons exposed to these emissions on a daily basis are likely to develop health complications over time.

Also, waste cooking oil, which is readily available, is a good feedstock for biodiesel production. Blending petrol or diesel with biodiesel produced from waste cooking oil reduced exhaust emissions. Biodiesel-diesel blend reduced CO_2 and CO emissions in diesel generators, but there was an increase in NOx emissions. On the other hand, biodiesel-petrol blend reduced emissions of CO, CO_2 and NOx in petrol generators, but an increase in emissions of only NOx in petrol motorcycles occurred. Therefore, bodiesel-petrol blend is ideal for reducing exhaust emissions from both small- and large-capacity petrol generators.

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Conflict of Interest

The authors declare no conflict of interest.

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