American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-4, pp-80-94
www.ajer.org
Research Paper Open Access

Biodiesel Production and Exhaust Emission Analysis for Environmental Pollution Control in Nigeria

Adeyanju A.A. and Manohar K.
Mechanical and Manufacturing Engineering Department, University of the West Indies, St. Augustine, Trinidad and Tobago

ABSTRACT: *One of the major challenges of the modern world in recent times has been how to effectively control the environmental pollution from the combustion of fossil fuels in internal combustion engines. In this study, the use of biodiesel (soybean methyl ester) as an alternative fuel in a four stroke, four cylinder diesel engine was explored and analyzed. The biodiesel was produced experimentally through trans-esterification process from soybean oil and blended at 2%, 5% and 10% volume ratio with standard diesel fuel. The emission characteristics of the diesel engine fuelled with biodiesel blends was examined and compared with the exhaust emission of the diesel engine when it was fuelled with standard diesel fuel. The emission concentration of Carbon monoxide (CO), Carbon dioxide (CO_2) and total nitrogen oxides (NO_x) for the fuel blends and for standard diesel fuel was monitored with a portable emission measuring system called Autoplus Automotive exhaust gas analyzer. The results showed a reduction in CO_2 emissions by 8%, 8% and 20% for B2, B5 and B10 fuel blends respectively compared to standard diesel fuel. CO emissions was also found to reduce by 5.89%, 11.76% and 35.3% for B2, B5 and B10 blends respectively, compared to standard diesel fuel. However, there was an increase in NO_x emission by 0.83%, 1.24% and 1.84% for B2, B5 and B10 fuel blends respectively compared to standard diesel fuel.*

Keywords: *Biodiesel, Exhaust Emission, soybean oil, Environmental Pollution.*

I. INTRODUCTION

The continuous utilization of fossil fuel in internal combustion engines poses serious threats to the health and welfare of humans, animals, plants and the environment. This is due to the effects of the exhaust emissions released into the atmosphere during their use. Internal combustion engines can either be spark ignition or a compression ignition engine, depending upon the nature of combustion and the type of fuel burnt within the combustion chamber. The spark ignition engines utilizes petrol fuel while the compression ignition engines uses diesel fuel. Petrol and diesel fuel are the most common forms of fossil fuel and internal combustion engines are considered to be the major consumer of fossil fuel around the globe. Internal combustion engines find a wide range of application in the productive sectors of the world as they are predominantly used in the manufacturing and the transport sectors for power generation, production and the transportation of goods and services. Majority of today's vehicles, power generators and plant machineries uses internal combustion engines. Due to the vast utilization of internal combustion engines in the modern world, there are growing concerns over the impact of the exhaust emissions from internal combustion engines on human health and the welfare of the environment. These concerns has lead researchers into a search for a suitable alternative to fossil fuel usage in internal combustion engines.

Generally, when fossil fuels are burnt, pollutants such as Carbon monoxide (CO), Carbon dioxide (CO_2), Total nitrogen oxides (NO_x), Sulphur oxides (SO_x), Hydrocarbons (HC), and Particulate matter (PM) are released. These pollutants have become present in the atmosphere in such concentrations that they can affect man and his environment. Fossil fuel consumption contributes a huge amount of greenhouse gas to the atmosphere, and thus is a leading cause of global warming and climate change. The three greenhouse gas typically released during fossil fuel combustion are methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). An obvious consequence of fossil fuel consumption evident from machinery and vehicle emission is air pollution, resulting in smog and low-level ozone formation which can severely degrade human health and plant growth. Pollution related diseases range from mild to severe and can significantly affect one's quality of life. Air pollution can result in asthma, chronic obstructive pulmonary disorder (COPD) and lung cancer. Long-term exposure may increase respiratory infections in general population. Children and the elderly are most vulnerable to fine particulate matter and other airborne toxicants. Sulphur dioxide is one of the pollutant that is released when fossil fuels are burnt and is a main cause of acid rain. Acid rain can lead to destruction of monuments made up of brickwork or marbles. Even crops can be affected due to acidification of loams. Sulphur dioxide is also known to affect the respiratory system and the functions of the lungs, and cause irritation of the eyes. These adverse effects continues to drive the search for better means to control environmental pollution.

Vehicular emission is one of the greatest threat to environmental health and is expected to increase reasonably as vehicle ownership increases in the world. Over 600 million people globally are exposed to hazardous level of traffic generated pollutants (UN, 1998). Human exposure to these air pollutants due to traffic is believed to have constituted severe health problems especially in urban areas where pollution levels are on the increase. Pollution due to traffic constitute up to 90 – 95% of the ambient CO levels, 80 – 90% of NO_x, hydrocarbon and particulate matter in the world, posing a serious threat to human health (Saville, 1993). Research conducted a decade and half ago has shown that transportation sources in the USA were responsible for 77% of CO levels, 80 -90% of NO_x, 36% of volatile organic compounds and 22% of particulate matter (USEPA, 1993).

In most developing countries of the world vehicular growth has not been checked properly by environmental regulating authorities leading to increase levels of pollution. Traffic emissions contribute about 50-80% of NO_2 and CO concentration in developing countries (Fu, 2001; Goyal, 2006). This situation is alarming and is predicated on the poor economic disposition of developing countries. Poor vehicle maintenance culture and importation of old vehicles which culminate to an automobile fleet dominated by a class of vehicles known as ‘’super emitters’’ with high emission of harmful pollutants, has raised high this figure of emission concentration.

In Nigeria, the situation of increased pollution from mobile transportation source is on the increase in per capital vehicle ownership, thus resulting to high congestion on Nigeria city road and increase in the concentration of pollutants in the air, consequently, increasing health risk on human population. Studies conducted in Kaduna and Abuja cities show higher values of CO_2 concentration in heavily congested areas: 1840ppm for Sambo, Kaduna, 1780ppm for Stadium round-about, Kaduna, and 1530ppm for A.Y.A, Abuja, 1160ppm for Asokoro, Abuja (Akpan and Ndoke, 1999).

Similar work by Jimo and Ndoke (2000) at Minna, a city in Nigeria shows the maximum value of 5,000ppm for CO_2 in congested areas, which was still lower than WHO stipulated maximum value of 20,000ppm. The maximum value for CO emission obtained was 15ppm still lower than the base line of 48ppm stipulated by WHO and 20ppm stipulated by Federal Environmental protection Agency of Nigeria (FEPA). Despite the efforts made by the government through the Federal protection agency of Nigeria to control pollution, such factors as inadequate monitoring systems to check real-time emission status, inadequate funding of the agency, lack of or weak enforcement of existing environmental laws and regulations (ladan, 2012) and mismanagement of resources has made the agency largely ineffective. In a bid to improve efforts, FEPA was replaced with the National Environmental Standards and Regulation Enforcement Agency (NESREA) in 2007 and is now charged with the protection of Nigeria’s environment. Despite these change, there are serious concerns about the effectiveness of the new agency in protecting the Nigeria environment from dangerous pollutants.

Recently, one of the greatest concerns has been the exhaust emission of heavy duty vehicles plying Nigeria roads. As Nigeria continues to grow industrially, the number of heavy duty vehicles continues to be on the rise as goods are regularly being transported with trucks around the country to meet up with demands. Heavy duty vehicles are generally powered by diesel engines and therefore gives off diesel exhaust emissions.

Diesel exhaust is especially dangerous, containing nearly 40 hazardous pollutants. The mixture is distinctly dangerous because it contains carbon particles known as particulate matter that are exceptionally small in size, usually less than one micron (Alderman et al., 2006). These fine particles may be deeply inhaled into the lung and carry with them a collection of attached hazardous compounds. Diesel emissions increase the severity and duration of asthma attacks and increases the risk of heart problems and premature death. Heavy truck traffic is also increasing, and older diesel engines are especially polluting. Diesel engines have exceptionally long life spans offering several millions of miles for long distance trucks and the engines are commonly rebuilt. This means that one cannot rely on improvements in new engine design to solve the problem, since the current fleet will remain on the road for a decade or more. Hence, the need for a more reasonable approach.

In the past decade, the most promising approach to solving environmental pollution problems as been to use environmental-friendly alternative fuels in place of fossil fuel to run internal combustion engines. Some of the domestic sources that have been recognized as potential alternative fuels for reduction in exhaust emission concentrations includes Biodiesel, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG), Alcohol fuels (methanol and ethanol) and Hydrogen. Biodiesel as emerged as the most promising source of renewable energy with high potential to replace petroleum-derived diesel fuel, because of similarity in chemical properties. Biodiesel, as an alternative fuel of diesel, is described as fatty acid methyl or ethyl esters from vegetable oils or animal fats. The ASTM (American Society for Testing and Materials) defined biodiesel fuel as the mono-alkyl esters of long chain fatty acid derived from renewable lipid feedstock such as vegetable oil or animal fat. It is sulphur-free, non-toxic, renewable, biodegradable and oxygenated (Xue et al., 2011).

Many studies have shown that the properties of biodiesel are very close to those of diesel fuel (Chang et al., 1996; Freedman and Pryde, 1982). Therefore, biodiesel can be used in diesel engines with few or no modifications. Other advantages of bio-diesels as to diesel fuel are the minimal aromatic content, and higher flash point, lubricity, and cetane number. On the other hand, their disadvantages include the higher viscosity and pour point, and the lower calorific value and volatility. Furthermore, their oxidation stability is lower, they are hygroscopic, and as solvents may cause corrosion in various engine components. For all the above reasons, it is generally accepted that blends of diesel fuel, with up to 20% bio-diesels, can be used in existing diesel engines without modifications.

The use of biodiesel seems to be a practical option for solving most of the environmental problems earlier mentioned. Consumption of biodiesel by vehicles results in substantial reductions of unburned hydrocarbons, carbon monoxide (CO) and particulate matter Thompson, 2005; wikipedia, 2016). Studies in Rwanda and other countries revealed that using biodiesel reduced carbon monoxide (a poisonous gas) emissions by 48% and 50% respectively compared to most petro diesel fuels (Thompson, 2005; USEPA, 2013; IRST, 2012). Studies in USA showed that production and use of biodiesel reduced carbon monoxide (CO) by 48% and carbon dioxide (CO2) emissions by 78.5% as compared with petroleum diesel (IRST, 2012). The exhaust emissions of particulate matter from biodiesel have been found to be 30-47% lower than overall particulate matter emissions from standard diesel (Thompson, 2005; IRST, 2012). The exhaust emissions of total hydrocarbons (a contributing factor in the localized formation of smog and ozone) are up to 93% lower for biodiesel than diesel fuel. The ozone (smog) forming potential of biodiesel by hydrocarbons is 50% less than the one of petroleum diesel. Sulfur emissions are essentially eliminated with pure biodiesel. Biodiesel may also reduce health risks associated with petroleum diesel.

Producing and using biodiesel in Nigeria, may result in numerous beneficial environmental and health effects including creation of employment and increased workers income, low exploitation cost, use in engine without engine modification, storage in traditional fuelling infrastructure, possibility of blending with petroleum diesel fuel, safe handling and transportation, greater engine lubrication than petroleum diesel, engine fuel mileages similar to engine using petro diesel, pleasant aroma, useful glycerin and support to domestic economy.

In recent years, considerable research has been conducted to investigate the properties of biodiesel from different sources and the performance and emission characteristics of biodiesel and various biodiesel fuel blends. However, compared to the large volume and varieties these research being conducted in developed countries, only a small fraction is conducted in Nigeria. Furthermore, majority of the research work reviewed on the emission characteristics of biodiesel blends did not involve obtaining the physicochemical properties of each of the biodiesel blends utilized during the research work, there was therefore a lack of information on the properties of each fuel blend varied compared to recognized biodiesel standards.

In this study, biodiesel (soybean methyl ester) was produced from the trans-esterification of soybean oil. Fuel blends of B2, B5, and B10 are prepared by blending 2%, 5% and 10% respectively of soybean methyl ester with standard diesel fuel. The physicochemical properties of each fuel blend was obtained and compared with those of standard diesel fuel. Finally, standard diesel fuel and biodiesel fuel blends were tested on a diesel engine and emission data was collected using an exhaust gas analyzer. The resultant data was analyzed and comparisons was made between the exhaust emission data of the biodiesel fuel blends and standard diesel fuel.

II. AMBIENT AIR QUALITY STANDARDS

The Federal Government of Nigeria established in 1988 the Federal Environmental Protection Agency (FEPA) to protect, restore and preserve the ecosystems of Nigeria. In order to improve the quality of the environment and to prevent the occurrence of environmental hazards, the Federal Environmental Protection Agency (FEPA) established environmental guidelines and standards for the abatement and control of all forms of pollution. This involved the establishment of the Nigeria Ambient Air Quality Standards (NAAQS) which is set for conventional pollutants, to protect public health and the environment (FEPA, 1999). Table 1.0 illustrates the ambient air quality standards in Nigeria.

Table 1.0: Nigeria Ambient Air Quality Standards

Pollutant	**Averaging time**	**Standard limit**
Particulates	1-hour average	250 µg/m^3
Sulphur oxides (Sulphur dioxide)	1-hour average	0.01 ppm (26 µg/m^3)
Non-methane Hydrocarbon	3-hour average	160 µg/m^3
Carbon monoxide	8-hour average	10 ppm–20ppm (11.4 µg/m^3–22.8 µg/m^3)
Nitrogen oxides (Nitrogen dioxide)	1-hour average	0.04 ppm–0.06 ppm (75.0 µg/m^3- 113 µg/m^3)
Photochemical oxidant	1-hour average	0.06 ppm

The units of measure for this standards are part per million (PPM) per volume and micrograms per cubic meter of air (µg/m^3). The Federal government replaced FEPA with the National Environmental Standards and Regulation Enforcement Agency (NESREA) in 2007 in a bid to improve environmental quality and the enforcement of environmental standards. Recently, majority of the states within Nigeria have developed ambient air quality standards under the charge of the state environmental protection agency, to regulate and control the concentration of pollutants in their environment.

Studies on the concentration of pollutants in the atmosphere shows that concentration of some pollutants in certain areas of Nigeria exceeds the acceptable limits set by both the environmental protection agency of the state and the defunct federal environmental protection agency (Oguntunde et al., 2014).

2.1 Fuel Standards

The fuel standards in Nigeria compared to the standards in the developed world are still very low. Currently, diesel fuel is regulated for 3000ppm of sulphur content while petrol fuel is regulated for 1000ppm. Table 2.0 illustrates some of the specifications stipulated for diesel fuel in Nigeria.

Table 2.0: Nigeria diesel fuel specifications

Properties	**Unit**	**Requirement**	**Actual from Nigeria refineries**
Sulphur content	ppm max	3000	1330
Density	Kg/m^3 max	820-870	871
Cetane number	Min	47	50
Total Acid Number	Mg KOH/g max	0.5	-
Final Boiling Point	°C max	385	385

Source: *www.unep.org/transport/pcfv/PDF/Benin-SulphurNigerianDiesel.pdf* (retrieved 2016).

Because of the adverse effects of sulphur on the welfare of human and the environment, the current focus of environmental protection agencies across the globe has been to reduce the sulphur content in diesel fuel. The United States Environmental Protection Agency (USEPA) mandated the use of Ultra-Low Sulfur Diesels starting in 2006. The diesel fuel regulation limits the sulfur content in highway diesel fuel to 15 parts per million from the previous 500ppm weight by volume (Shida et al, 2006; Laroo et al, 2005).

The American Society for Testing and Materials (ASTM) defined the consensus on fuels to help manufacturers design engines for a fuel that has certain characteristics. In Nigeria, efforts are being made by the Federal Ministry of Environment through such agencies as the Standards Organization of Nigeria (SON) and the National Environmental Standards and Regulation Enforcement Agency (NESREA) to improve the current fuel standards with a possibility of reducing the stipulated sulphur content to 100ppm in the future (Abner, 2016). Presently, the low standard of fuel in Nigeria has resulted in an equally low emission standard. With stricter emission standards being set and fossil fuel reserves running low, various fuel alternatives have been considered and tested particularly, in developed countries on vehicles to assess the concentrations of toxic pollutants released.

In December 2001, ASTM approved the full standard of biodiesel in US with a designation of D-6751 which covers pure biodiesel for blending with diesel in levels up to 20% by volume. Biodiesel has been registered with the USEPA as a fuel and a fuel additive under Section 211(b) of the Clean Air Act. The letter "B" followed by a numeral denotes the biodiesel/ULSD blend fuels according to the volume percent biodiesel in the fuel. For example, B20 is a 20% biodiesel, 80% ULSD blend whereas B100 pure biodiesel.

Biodiesel standards have also been developed in Nigeria (since 2010) with the standards also permitting the blending of pure biodiesel up to 20% by volume with diesel fuel (Abner, 2016). It is also estimated that market demand for biodiesel will be about 900 million litres by 2020 as compared to current market possibility of about 480 million litres for a 20% blend for bio-diesel. The Bio-fuel Production programme in Nigeria aspires to achieve 100% domestic production of bio-fuels consumed in the country by 2020 (Official Gazette of the Nigeria Bio-fuel policy and incentive, 2007).

2.2 Health Effects of Diesel Exhaust Emission

Diesel engines are a major source of pollution emitting particulate matter (soot), nitrogen oxides which contribute to the production of ground-level ozone (smog), acid rains, hydrocarbons and air toxics. These emissions can damage plants, animals, crops, and water resources. Emissions from diesel exhaust can lead to serious health conditions, such as asthma and allergies. They can also worsen heart and lung diseases, especially for vulnerable populations such as children and older individuals.

USEPA estimates that every $1 spent on clean diesel projects produces up to $13 of public health benefits. Studies conducted in the past have established the fact that a huge percentage of pollutant emissions in ambient air are emitted by vehicles (USEPA, 2002a). They have numerous effects on human health as well as on the environment. A study in the Journal of the American Medical Association cited that people who live in the most heavily polluted areas have a 12% higher risk of getting lung cancer than people in the least polluted areas (Burnett et al., 2002). Table 3.0 illustrates some of the health concerns due to different diesel pollutants.

Table 3.0: A summary of health concerns due to different diesel pollutants

Pollutant	**Health concern**
Nitrogen oxides (NO_x)	Lung irritation, respiratory illness, premature death
Carbon monoxide (CO)	Headaches and reduces mental alertness
Particulate matter	Increase in existing heart disease, breathing difficulties and respiratory illness
Sulphur dioxide	Increase in existing heart disease, breathing difficulties, respiratory illness
Ozone	Breathing difficulties, respiratory infections, lung and tissue damage

III. Methodology

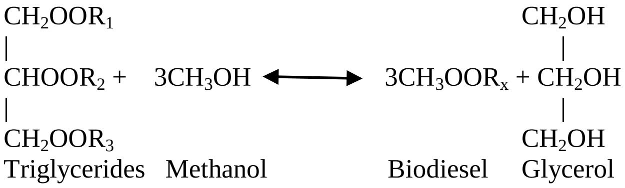
This section explains the stepwise process involved in carrying out this study. It explains the procedures involved in producing the biodiesel used in this study. Details about blending of biodiesel with standard diesel fuel and how the physicochemical properties of each fuel sample examined during this study was obtained is provided in this chapter. It also contains the experimental setup involved in the study and the procedures used to carry out the emission test.

3.1 Production of Biodiesel

Biodiesel was produced through the trans-esterification of soybean oil. The biodiesel produced in this study is known as soybean methyl ester (SME). Trans-esterification is the general term used to describe the important class of organic reactions, where an ester is transformed into another ester through interchange of alkyl groups and is also called alcoholysis. Trans-esterification is an equilibrium reaction and the transformation occurs by mixing the reactants. In the trans-esterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. In the base-catalyzed process, the trans-esterification of vegetable oils proceeds faster than the acid-catalyzed reaction. The trans-esterification reaction is represented by the general equation;

RCOOR’ + R”OH = RCOOR”+ R’O

Since methanol was used as the alcohol during this research, the process can be described as methanolysis. The reaction of triglyceride with methanol is represented by the general equation given below;



$$\begin{array}{llcll} CH_2OOR_1 & & & & CH_2OH \\ | & & & & | \\ CHOOR_2 + & 3CH_3OH & \longleftrightarrow & 3CH_3OOR_x + & CH_2OH \\ | & & & & | \\ CH_2OOR_3 & & & & CH_2OH \\ \text{Triglycerides} & \text{Methanol} & & \text{Biodiesel} & \text{Glycerol} \end{array}$$

Materials Used

The following raw-materials were used during the trans-esterification process;

i. Vegetable oil - Soybean oil
ii. Alcohol - Methanol (CH_3OH)
iii. Catalyst - Sodium Hydroxide (NaOH)

Procedures

The biodiesel was obtained from soybean oil in the following steps;

i. The soybean oil was heated to 100°C temperature and maintained for 15 minutes. It was allowed to settle for one day for removal of water.
ii. Sodium hydroxide (NaOH) was added to methanol and stirred thoroughly to produce sodium methoxide.
iii. The prepared sodium methoxide was poured into the mixture, the mixture was heated to 55°C and the whole reaction was maintained.
iv. Soybean methyl ester and glycerol was obtained from the reaction and appeared as two immiscible fluids.
v. After heating for one hour, the oil was poured into a decanter for the removal of the glycerol.
vi. Glycerol was removed and water wash was done with Phosphoric acid.
vii. After washing, the neat bio diesel was heated to 100°C to remove the traces of water. Figure 1.0 describes the trans-esterification process of soybean oil.

(i) Raw soybean oil (ii) After adding methoxide

(iii) Separator funnel for decantation. (iv) During decantation to remove glycerol.

Figure 1.0: Trans-esterification process of soybean oil.

3.2 Preparation of Biodiesel Fuel Blends

Biodiesel fuel blending involves the process of mixing biodiesel with a base fuel usually diesel fuel. Biodiesel blends are usually denoted with the alphabet “B” followed by a numeral which indicates the percentage by volume of biodiesel present in a mixture of biodiesel and petro-diesel fuel. For example, B5 denotes that 5% of biodiesel and petro-diesel is present in a blend. The B100 is used to represent 100% (pure) biodiesel fuel while B0 represents pure standard diesel fuel. In this research, B2, B5 and B10 fuel blends were prepared.

Apparatus Used

i. Conical flask
ii. Volumetric flask
iii. Beaker
iv. Electric mixer
v. Plastic keg

Blends Prepared

The following fuel blends were prepared;

i. 2% soybean methyl ester (biodiesel) and 98% Diesel fuel blend known as B2.
ii. 5% soybean methyl ester (biodiesel) and 95% Diesel fuel blend known as B5.
iii. 10% soybean methyl ester (biodiesel) and 95% Diesel fuel blend known as B10.

Procedure

Soybean methyl ester (SME) and diesel fuel were heated in separate conical flask to around 40°C for few minutes as shown in Figure 2.0. A volumetric flask of 2000mL was used for measuring the proportion by volume of biodiesel and conventional diesel fuel for each blend. B2 blend was prepared by using a beaker to pour 40ml of biodiesel into the volumetric flask and another beaker to pour 1960ml of conventional diesel into the same volumetric flask. The mixture was thoroughly mixed using a hand electric mixer for a few minutes. The mixture was then poured into a plastic keg which was thereafter labelled as Sample A.

A similar procedure was used to prepare B5 blend. Separate beakers were used to introduce 100ml of biodiesel and 1900ml of conventional diesel into a 2000ml volumetric flask. The mixture was thoroughly mixed with an electric mixer and the resultant blend was poured into a plastic keg which was thereafter labelled Sample B. Finally, B10 blend was prepared using the same technique, with separate beakers used to introduce 200ml of biodiesel and 1800ml of conventional diesel into a 2000ml volumetric flask. The plastic keg containing the B10 blend was designated as Sample C.

Figure 2.0: Biodiesel Fuel Blends process

3.3 PHYSICOCHEMICAL PROPERTY TEST

The physicochemical property test for each fuel sample (that is, B0, B2, B5 and B10) was carried out in the Laboratory. The following properties were tested for each sample;

1. Volatile matter content
2. Ash content
3. Specific gravity
4. Refractive index
5. Cloud point
6. Pour point
7. Flash point
8. Kinematic Viscosity
9. Fire point
10. Moisture content
11. Heating Value
12. Fixed Carbon content

The procedure used to obtain some of these properties are explained as follows;

i. Volatile Matter Content Determination:

This was done by the gravimetric method according to AOAC (1990). Weight of a previously washed and dried empty evaporating dish was determined using a mettle balance as (W_1). 10g of the sample was weighed into the evaporating dish (W_2). The dish and sample were then placed in the oven and dried for 8hrs at 70°C. After drying, the dish and sample was then placed in the desiccator to cool to room temperature after which it was then weighed. This process was continued until a constant weight was obtained, (W_3), (i.e., drying, cooling and weighing were done repeatedly at 30mins interval until a constant weight was obtained). A picture of the mettle balance and oven used for the test is illustrated in Figure 3.0. The volatile matter was calculated and expressed as a percentage of weight of the sample analyzed. This was given by the expression below:

$$\%\ \text{Volatile matter content} = \frac{W_2 - W_3}{W_2 - W_1} \times \frac{100}{1} \qquad (1)$$

Where; W_1 = weight of empty evaporating dish
W_2 = weight of sample + evaporating dish
W_3 = weight of sample + evaporating dish after drying at 70°C

(i) Mettle balance for weighing samples. (ii) Oven used for drying samples.

Figure 3.0: The mettle balance and oven used during test.

ii. Determination of Ash Content:

This was done by the gravimetric method according to AOAC (1990). Weight of a previously washed and dried empty crucible was determined using a mettle balance as (W_1). 5g of the sample were then placed in crucible (W_2). The crucible and sample were then placed in muffle furnace set at 550°C and was ashed for 4hrs. After ashing, the crucible and sample was then placed in the desiccator to cool to room temperature after which it was then weighed (W_3). Figure 4.0 shows the furnace used during the test. The percentage ash content was then calculated thus:

$$\%\ \text{Ash} = \frac{W_3 - W_1}{W_2 - W_1} \times \frac{100}{1} \tag{2}$$

Where; W_1 = weight of empty crucible
W_2 = weight of sample + crucible
W_3 = weight of sample + crucible after ashing at 55°C

Figure 4.0: Ashing process in Carbolite furnace

iii. Specific Gravity:

he specific gravity of the sample was determined using a 25ml density bottle. The bottle was washed thoroughly with detergent solution and rinsed with water and final with distilled water. It was then dried a 105°C on an oven for 30mins. This was cooled in a desiccator and weighed and the weight noted. The bottle was then filled with distilled water and weighed on a mettle balance. The weight was also noted. The bottle was then washed and dried in the oven, cooled in a desiccator and filled with the sample. This was then weighed and the weight noted. The specific gravity of the sample solution was then calculated. Thus;

$$\text{Specific Gravity} = \frac{Weight\ of\ sample}{Equal\ weight\ of\ water} \tag{3}$$

iv. Refractive Index:

The refractive index of the sample was determined at 25°C using the Abbe refractometer equipment. A picture of the refractometer is illustrated in Figure 5.0.

Figure 5.0: Refractometer

v. Cloud Point:

Cloud point is defined as the temperature at which a cloud of wax crystals first appears in a liquid form when the liquid is cooled under certain conditions. The cloud point was measured using an equipment manufactured by Koehler Instrument Company. A picture of the equipment used for measuring the cloud and pour point is illustrated in Figure 6.0.

Figure 6.0: Cloud and pour point measuring equipment.

vi. Pour Point:

Pour point is defined as the lowest temperature at which a liquid can flow. Each sample was homogenized and poured into the test jar to a required level. The pour point was determined for each sample using the device in Figure 6.0 according to the ASTM D97 standard method.

3.4 Experimental Setup for Emission Test

The main aim of this study was to investigate the impact of biodiesel blends on the exhaust emissions of diesel engines as it compares to standard diesel fuel. A SIFANG S115, four-stroke, four-cylinder diesel engine was used for the experiment. The basic specifications of the engine are listed in Table 4.0. A picture of the diesel engine is illustrated in Figure 7.0.

Table 4.0: Basic specifications of SIFANG S115 diesel engine.

Brand	SIFANG
Model	S115
Type	four- stroke, water cooled
Number of cylinders	four
Net mass	205kg
Rated speed	2200 rev/min
Rated output	16.18KW (22hp)

Figure 7.0: A SIFANG S115 diesel engine.

The fuel samples used during the test are described in Table 5.0. The fuel samples were tested on the engine at no load and under steady-state conditions. The engine was allowed to reach its optimum operating temperature before the emission data was collected.

Tables 5.0: Description of Fuel Samples Tested.

Fuel samples	**Description**
B0	Pure Diesel fuel
B2	2% biodiesel and 98% Diesel fuel blend
B5	5% Biodiesel and 95% Diesel fuel blend
B10	10% Biodiesel and 90% Diesel fuel blend

Emission data was collected using a portable emission measuring system (PEMS) called Autoplus Automotive exhaust gas analyzer. The Autoplus Automotive exhaust gas analyzer consists of non-dispersive infrared sensors that can continuously measure up to six gases namely; oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitric oxide (NO), hydrocarbon (HC) and Lambda (Λ). It also provides readings for calculated carbon monoxide (CO) and calculated total nitrogen oxides (NO_x). The unit of measurement for all the above gases except NO is given in percentage (%) volume. NO is measured in parts per million (ppm). For diesel engines, the Autoplus exhaust gas analyzer only provides data for NO, $O_{2,}$ CO, CO_2 and calculated NO_x emissions. Figure 8.0 shows a picture of the exhaust gas analyzer and its probe. Table 6.0 illustrates the measuring range, resolution and the accuracy of the exhaust gas analyzer.

(i) Exhaust Gas analyzer (ii) Exhaust gas probe of the gas analyzer

Figure 8.0: Autoplus Automotive exhaust gas analyzer and its probe.

Table 6.0: The measuring range and accuracy of the Autoplus Automotive exhaust gas analyzer.

Parameter	**Resolution**	**Accuracy**	**Range**
Carbon Monoxide (Infrared)	0.01 %	+/- 5% of reading +/- 0.06% of volume	0-10% Over-range 20%
Oxygen (fuel cell)	0.01 %	+/- 5 % of reading +/- 0.1% of volume	0-21% Over-range 25%
Hydrocarbon (Infrared)	1 ppm	+/- 5% of reading +/- 12 ppm volume	0-5000ppm Over-range:10,000ppm
Carbon Dioxide (Infrared)	0.1 %	+/- 5% of reading +/- 0.5% of volume	0-16% Over-range: 25%
Nitric Oxide (fuel cell)	1 ppm	0-1500ppm +/-5% or 25ppm	0-1500ppm Over-range: 5000ppm
Carbon monoxide Corrected ($CO_{k)}$	0.01%	Calculated	0-15%
Total Nitrogen oxides (NO_x)	1 ppm	Calculated	0-1575ppm Over-range: 5350ppm
Lambda AFR (petrol)	0.001 00.01		0.8-1.2 11.76-17.64 12.48-18.72

The Autoplus exhaust gas analyzer was calibrated by purging it with fresh air before the test began as illustrated in Figure 9.0. During this process, the analyzer pumps in fresh air and causes the gas sensors to be set to the ambient average values of the monitored parameter in fresh air. The process is completed in 90 seconds. Once the process is completed, the analyzer zeroes the CO, HC, $CO_{2,}$ NO sensors and sets oxygen 20.9 %. This calibration process was repeated between each fuel sample test so as to clear the electrochemical sensors for any gas residues that might affect the accuracy of the data obtained. The exhaust gases recorded during this study were $O_{2,}$ CO, CO_2 and calculated NO_x emissions.

3.4.1 Emission test procedure

The fuel hose linking the fuel tank of the SIFANG diesel generator to its injector was detached and a hose was passed directly from the injector to a fuel vessel so as to facilitate the easy disposal of fuel samples after each test. It also helped ensure that residual fuel from a concluded test does not affect the outcome of the next fuel sample test. Pure diesel fuel (B0) was poured into the fuel vessel and the engine was started and made to run for 30minutes before the emission test commenced. The probe of the exhaust gas analyzer was attached to the exhaust outlet of the generator for sampling of the exhaust emissions. The probe was connected for a period of 15minutes and emission data was collected for pure diesel fuel. At the end of the test, the probe was detached and the generator turned off temporarily. The B0 fuel sample was disposed and B2 fuel blend poured into the fuel container. The exhaust analyzer was re-calibrated and the procedure used for B0 emission test was repeated. This procedure was also performed for B5 and B10 fuel blends and the results were recorded. The test was performed twice for each sample and the average values of the emission data obtained was used to analysis the results.

Figure 9.0: Exhaust gas emission test

IV. RESULTS AND DISCUSSION

The results of the physicochemical and emission test for pure conventional diesel (B0), pure Biodiesel (B100) and B2, B5 and B10 blends are illustrated comparatively in Tables 7. 0, 8.0, 9.0 and 10.0.

Table 7.0 illustrates the physicochemical properties of each fuel sample while Tables 8.0 and 9.0 shows the emission characteristics obtained from the emission test of B0, B2, B5 and B10 after the first and second period of test. Tables 10.0 shows the average value of the emission data obtained during the emission test and the percentage change in the values of the regulated pollutants measured during the test for each fuel blend as it compares to pure diesel fuel.

4.1 Physicochemical Test Results

The result obtained during the physicochemical test for each fuel sample is illustrated in Table 7.0.

Table 7.0: Physicochemical properties of fuel samples

S/N	PROPERTY	UNIT	B0	B2	B5	B10	B100
1.	**Refractive index (@ 30°C)**		1.460±0.000	1.474±0.002	1.472±0.001	1.453±0.002	1.460±0.000
2.	**Specific Gravity**	g/cm^3	0.882±0.002	0.8552±0.001	0.8561±0.002	0.8435±0.001	0.882±0.002
3.	**Kinematic Viscosity**	Pas/sec	5.890×10^{-3}	5.044×10^{-3}	5.066×10^{-3}	5.188×10^{-3}	5.516×10^{-3}
4.	**Ash Content**	%	0.101±0.001	0.245±0.010	0.402±0.003	0.586±0.005	0.738±0.002
5.	**Flash point**	°C	105.00±0.00	130.00±0.20	133.00±0.10	140.00±0.00	170±0.200
6.	**Volatile Matter**	%	22.404±0.012	1.861±0.021	2.217±0.010	3.165±0.004	0.749±0.017
7.	**Cloud point**	°C	-4.000±0.000	1.000±0.000	-2.000±0.000	-4.000±0.010	-4.000±0.001
8.	**Pour point**	°C	14.000±0.000	11.000±0.000	10.000±0.000	7.000±0.000	4.000±0.000
9.	**Fire point**	°C	118.00±0.05	178.00±0.20	158.00±0.10	144.00±0.05	242.00±0.10
10.	**Moisture content**	%	0.560±0.010	0.380±0.003	0.425±0.003	0.568±0.002	0.633±0.002
11.	**Heating value**	KJ/Kg	33917.225±0.220	34101.603±0.302	34029.272±0.202	33909.069±0.156	29401.920±0.033
12.	**Fixed Carbon**	%	76.935±0.110	97.517±0.210	96.956±0.058	95.699±0.100	98.880±0.021

Keys:

i. B0 represents pure Diesel fuel.
ii. B2 represents 2% Biodiesel and 98% Diesel fuel blend.
iii. B5 represents 5% Biodiesel and 95% Diesel fuel blend.
iv. B10 represents 10% Biodiesel and 90% Diesel fuel blend.
v. B100 represents pure Biodiesel fuel.

4.1.2 Emission Test Results

The emission data obtained for B0, B2 and B5 and B10 fuel samples are given in the Tables 8.0, 9.0 and 10.0 shows the average values in percentage volume concentration of the exhaust gases obtained after each sample was tested, as well as the percentage change in the values of the measured pollutants for the fuel blends as compared to those of standard diesel fuel.

Table 8.0: Result of the emission test for B0, B2 and B5 and B10 fuel samples after the first test period**.**

Constituent	**Unit**	**B0**	**B2**	**B5**	**B10**
CO_2	%Vol.	1.3	1.2	1.2	1.0
CO	%Vol.	0.09	0.08	0.08	0.06
O_2	%Vol.	18.66	17. 39	19.34	19.38
NO_X	ppm	605	607	610	615

Table 9.0: Result of the emission test for B0, B2 and B5 and B10 fuel samples after the second test period.

Constituent	**Unit**	**B0**	**B2**	**B5**	**B10**
CO_2	%Vol.	1.2	1.1	1.1	1.0
CO	%Vol.	0.08	0.08	0.07	0.05
O_2	%Vol.	19.39	19.51	19.50	19.10
NO_X	ppm	600	608	610	612

Table 10.0: Average values and percentage change of engine emissions for regulated pollutants.

Constituent	**Unit**	**B0**	**B2**	**B5**	**B10**
CO_2	%Vol.	1.25	1.15	1.1	1.0
Change in CO_2	%		+8	+8	+20
CO	%Vol.	0.085	0.080	0.075	0.055
Change in CO	%		+5.89	+11.76	+35.3
O_2	%Vol.	19.03	18.45	19.42	19.24
NO_x	ppm	602.5	607.5	610	613.5
Change in NO_x	%		-0.83	-1.24	-1.84

Keys:
i. Ppm denotes parts per million.
ii. %Vol. denotes concentration in percentage volume.
iii. Plus (+) sign denotes decrement.
iv. Minus (-) sign indicate increment.

4.2.1 Physicochemical Properties of Fuel Samples

The results of the physicochemical properties test in Table 8.0 shows a higher value of flash point, ash content, fire point, moisture content and fixed carbon content for pure biodiesel fuel (B100) compared to pure standard diesel (B0). The table shows that these properties increased in value as the percentage volume of biodiesel in the blends (that is, B2, B5 and B10) increased, except the fire point and the fixed carbon content which decreased with an increasing volume of biodiesel although the values of fire point and carbon content for each blend was still higher than that of pure standard diesel. The values of properties such as refractive index, specific gravity, heating value, volatile matter, pour point and kinematic viscosity was found to be higher in pure standard diesel fuel compared to pure biodiesel fuel. The values of these properties reduced as the content of biodiesel in the blended fuel samples increased (that is, from B2 to B10).

4.2.2 Emission Characteristics

The exhaust emissions data obtained for pure diesel fuel (B0), B2, B5, and B10 fuel samples are discussed below. Comparisons are made between the Carbon dioxide (CO_2), Nitrogen oxides (NO_x), and Carbon monoxide (CO) emissions of pure diesel fuel and those of the blended fuel samples (B2, B5 and B10).

4.2.2.1 Comparison of carbon dioxide (CO_2) emissions

The CO_2 emissions levels percentage volume concentration for the fuel samples (B0, B2, B5 and B10) are shown in the Figure 10.0. All the biodiesel fuel blends emitted lesser CO_2 compared to pure diesel fuel (B0). The CO_2 emission level for B2 and B5 blend were similar. Compared to pure diesel fuel, the CO_2 emissions of B2 and B5 were both reduced by 8%. The highest reduction in CO_2 emission was found for B10 blend which was 20%. This reduction was found to be statistically significant. The percentage reduction in CO_2 emissions for the fuel blends is shown in Figure 11.0.

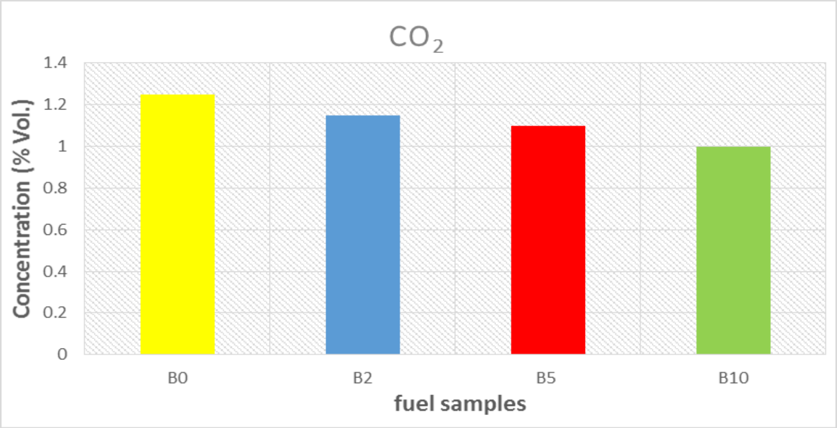


Figure 10.0: Comparison between the CO$_2$ emissions of B0, B2, B5 and B10 fuel samples.

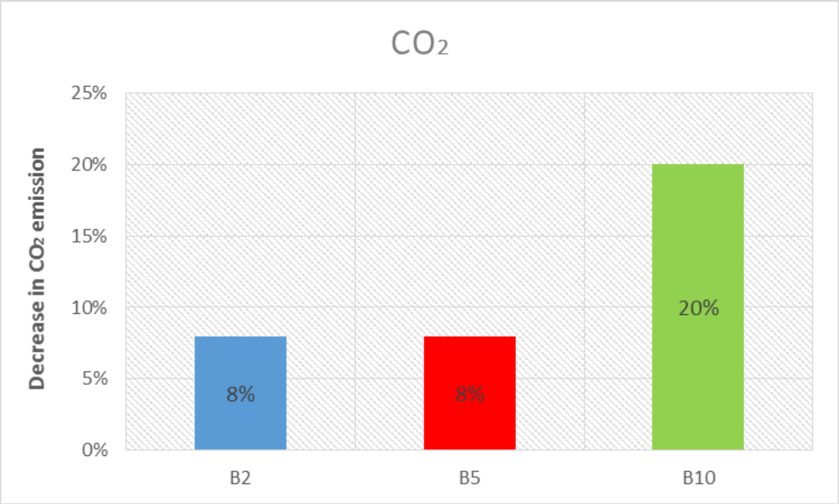


Figure 11.0: Percentage reduction in CO$_2$ emissions for B2, B5 and B10 fuel blend compared to pure Diesel fuel (B0)

4.2.2.2 Comparison of carbon monoxide (CO) emissions

The CO emission levels in percentage volume concentration for B0, B2, B5 and B10 are shown in the Figure 12.0. Compared to Diesel fuel (B0), CO emissions of the B2, B% and B10 were lower. CO emission levels reduced in B2 and B5 blends by 5.89% and 11.7% respectively. These reduction was found to be statistically significant. The most significant reduction in CO emissions was found for B10 blend. Figure 13.0 shows the percentage reduction in CO emissions for the fuel blends compared to pure diesel fuel.

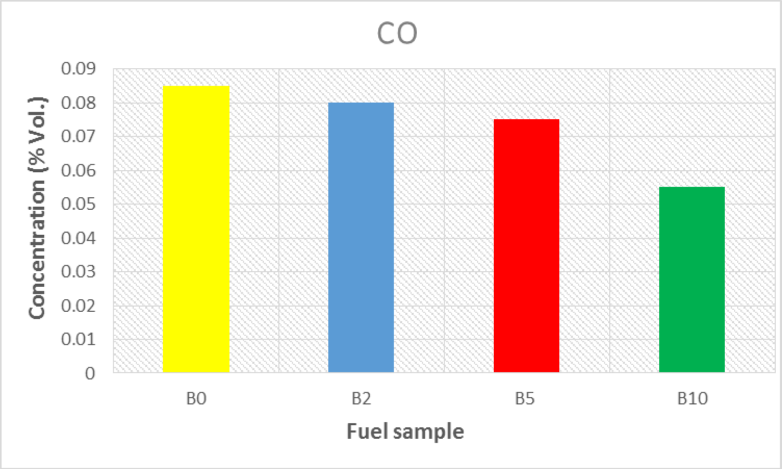


Figure 12.0: Comparison between the CO emissions of B0, B2, B5 and B10 fuel samples.

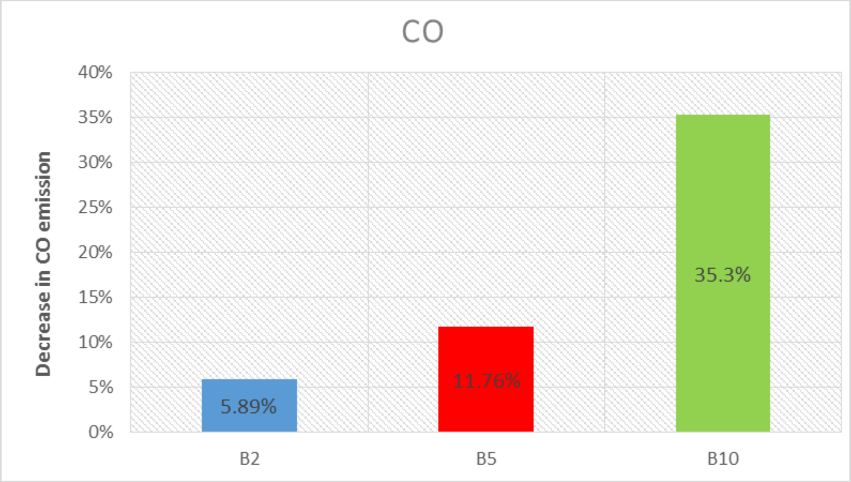


Figure 13.0: Percentage reduction in CO emissions for B2, B5 and B10 fuel blend compared to pure Diesel fuel (B0).

4.2.2.3 Comparison of Nitrogen oxides (NO_x) emissions

The NO_x emission levels in parts per million for B0, B2, B5 and B10 are shown in the Figure 14.0. All the biodiesel fuel blends emitted more NO_x compared to pure diesel fuel (B0). The percentage increase in NO_x emissions for B2, B5 and B10 compared pure diesel fuel was found as 0.83%, 1.24% and 1.84% respectively. The percentage increase in NO_x emissions for the fuel blends is shown in Figure 15.0.

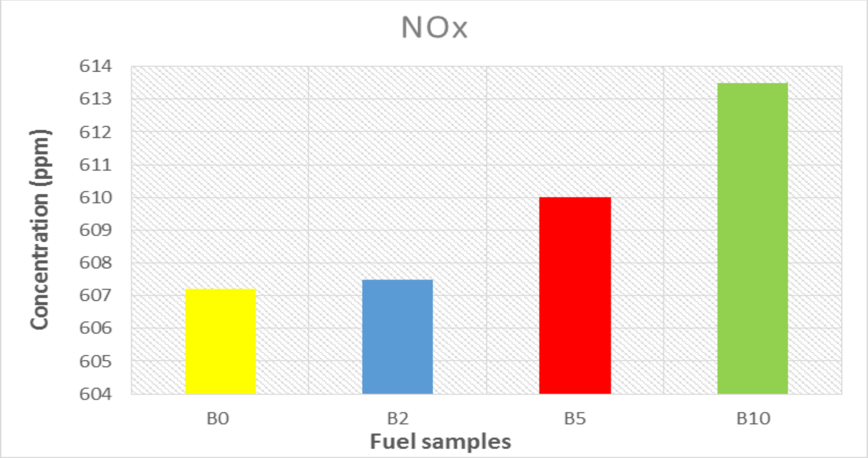


Figure 14.0: Comparison between the NO_x emissions of B0, B2, B5 and B10 fuel samples.

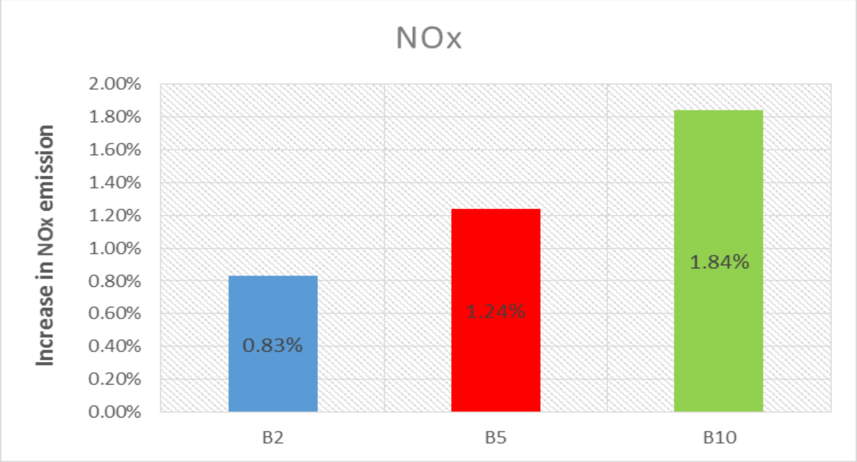


Figure 15.0: Percentage reduction in NO_x emissions for B2, B5 and B10 fuel blend compared to pure Diesel fuel (B0).

V. CONCLUSION

From the results of this study, the following were the conclusions:

(i) The properties of soybean methyl ester biodiesel (SME) are similar to those of standard diesel fuel.

(ii) SME blends up to 10% with standard diesel fuel can be used in diesel engines without any engine modification.

(iii) B2, B5 and B10 fuel blends produced statistically significant reduction in CO_2 emissions by 8%, 8% and 20% respectively, compared to pure standard diesel fuel thus indicating that there is a commendable reduction in CO_2 emissions as the concentration of biodiesel in a blend increases.

(iv) There was also a statistically significant reduction in CO emissions by 5.89%, 11.76% and 35.3% for B2, B5 and B10 blends respectively, compared to pure diesel fuel probably because biodiesel is much oxygenated hence, there is reduction in the occurrence of incomplete combustion with an increase in biodiesel concentration.

(v) NOx emissions are higher for SME blends compared to pure diesel fuel. The increase in NOx emission is not statistically significant especially for B2 fuel sample. NO_x emission increases with an increase in the concentration of SME in a blend. The increase in NOx emission for B2, B5 and B10 was found to be 0.83%, 1.24% and 1.84% respectively.

(vi) SME blends up to 10% with standard diesel fuel is a superior fuel to pure standard diesel fuel.

The data obtained from this study has proven that biodiesel fuel is environmental friendly and emits lesser pollutants compared to standard diesel fuel. It has also proven that biodiesel blends up to 10% can be used in diesel engines without modification hence, to achieve the much desired environmental pollution control in Nigeria, the study recommends the use of biodiesel blends up to 10% in diesel engines.

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