EFFECTS OF BIODIESEL/PETROL-DIESEL BLENDS AND ENGINE LOADING ON THE EMISSIONS OF A DIESEL ENGINE

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DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Prof. I. A. Rufa'i and has not been presented anywhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write-up (BELLO SHEHU, SPS/11/MGY/00011) were carried out under my supervision.

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APPROVAL PAGE

This dissertation has been examined and approved for the award of Masters in (ENERGY ENGINEERING).

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DEDICATION

This dissertation is dedicated to the loving memory of Baba Shehu H. Malumfashi (Sept. 1942 - April 2014)

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NOMENCLATURE

ASTM	American Society for Testing and Materials
B_{10}	10% Biodiesel 90% Diesel
B_{12}	12% Biodiesel 88% Diesel
B_{15}	15% Biodiesel 85% Diesel
B_{17}	17% Biodiesel 83% Diesel
B_{20}	20% Biodiesel 80% Diesel
BTE	Brake Thermal Efficiency
BTDC	Before Top Dead Center
°C	Degree Celsius
CI	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRDI	Common-Rail Direct Injection
CV	Calorific Value
cSt	Centi Stroke
DI	Direct Injection
HC	Hydrocarbon
HM	Heavy Metals
IDI	Indirect Injection
kW	kilo-Watt

NARICT	National Research Institute for Chemical Technology
NO_2	Nitrogen dioxide
N_2O	Nitrous Oxide
NOx	Oxide of Nitrogen
NOx	Nitric Oxide
PM	Particulate Matter
ppm	part per million
psi	pounds per square inch
RME	Rice Bran Methyl Ester
rpm	Revolution per minute
SAE	Society for Automobile Engineering
SO_x	Oxide of Sulphur
SO_2	Sulphur dioxide
Sgf	Specific gravity of fuel
SME	Sunflower oil Methyl Ester
SOF	Soluble Organic Fraction
T	Torque
TDC	Top Dead Center
TBG	Triglycerides
V_f	Volume/flow of fuel
v/v	volume/volume

VOC	Volatile organic Compound

ABSTRACT

This dissertation presents the result of the effects of fuel composition and engine loading on the emissions of a single cylinder air-cooled four-stroke, Power Point direct injection engine run at different load capacity using biodiesel/petrol diesel fuel blends of 12% biodiesel 88% petrol diesel, 15% biodiesel 85% petrol diesel and 17% biodiesel 83% petrol diesel simply represented as B_{12}, B_{15} and B_{17} respectively. Crowcon gas sensors were used to quantify the concentration of the exhaust gas emissions of carbon monoxide (CO), Nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). The relationships between the exhaust emission, fuel composition and engine loading have been reported. Predictive model equations were developed using multiple regression analysis to predict the exhaust emissions. Among the fuel blends used (B_{12}, B_{15} and B_{17}), B_{15} gave the optimum Nitrogen dioxide (NO_2), Carbon monoxide (CO) and Sulphur dioxide (SO_2) emissions with respect to increase in loading of 0.01ppm, 2ppm and 0.1ppm respectively. For the engine performance test the results showed that, the fuel consumption of the engine decreased with an increase in amount of biodiesel in the blends, the consumption was 0.435kg/kWh at a loading of 1.120kW for B_{17} while at same load capacity it was 0.450kg/kWh for B_{12}. The brake thermal efficiency was relatively found to be stably higher with increased biodiesel in the fuel blends at all the tested load capacity, as it was 19.07% for a load of 1.120kW when using B_{17} while 18.34% for an equal load while using B_{12}.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE RESEARCH

The increase in population and advancement in technology has led to increased use of compression ignition engines in Agricultural and transport sectors. The extensive use of diesel engines in power generation in Nigeria has further increased the demand of diesel fuel significantly. The inadequate power supply from the national grid has also led to the use of diesel engines as prime movers in electricity generation. In this regard, depleting reserves, fluctuating prices of petroleum products in addition to growing concerns over global warming and environmental degradation (e,g acid rain, smog, climate change) have accentuated the scientific awareness and led to a substantial effort to develop alternative fuel sources that are at least, renewable and environmentally friendly. Biofuels have assumed a leading role since they possess the benefit of being renewable, showing thus an ad hoc advantage in reducing the unwanted emissions.

The term biofuel refers to any fuel that is derived from biomass, such as sugars, vegetable oils, animal fats, etc. Biofuels made from agricultural products (oxygenated by nature) offer benefits in terms of sustainability and reduced particulate matter (PM) emissions. Among the biofuels currently in use or under consideration, biodiesel (derived from Jatropha, karanja, palm, soybean, sunflower, rice bran etc) is considered, since it possesses similar properties with petroleum based diesel fuel. Biodiesel is miscible with petrol diesel practically at any proportion, and is compatible with the existing distribution infrastructure; moreover, biodiesel is less toxic than petro-diesel and is also bio-degradable (Demirbas, 2009; Agarwal, 2007). Jatropha plant is known as a diesel fuel plant as the seed could yield substantial quantity of oil, which can be converted to biodiesel without refining (Becker and Makkar, 2009). The use of pure vegetable oils as fuel in diesel engines causes some problems such as poor fuel atomization, low volatility due to their high viscosity, high molecular weight and density. Use of this over a long period might lead to engine failure (Hemmerlin et al., 1991). To improve engine performance, the viscosity is reduced through transesterification, heating and blending with diesel.

Although the diesel engine has for many decades been in existence, thanks to its reliability and fuel efficiency, disadvantages in the form of increased exhaust smokiness and noise have delayed its infiltration (and popularity) in the highly competitive automotive market. For many years now due to the inadequate power supply from the national grid, many Nigerian households, offices, market places and industries have resorted to using stand-by generators for their electricity supply. The combustion of fossil fuels in engines are considered a major source of air pollution in port and urban areas because of their soot, HC, NO_x, particulate matter (PM), CO, CO_2, SO_x

emissions. The disgusting odor and noise from these engines may impair human health and the natural environment, such as ozone layer destruction, greenhouse effect enhancement and acid rain production (Linak and Wendt, 1993; Lin, 2000; Lin and Pan, 2001). In search for greener energy/electricity, researchers such as Abubakar (2010), Babeji (2010), Abu-Qudais et al. (2002), Kavitha (2003), Sani and Rufai (2012) to mention a few, have investigated and documented the need, workability and performance of a diesel engine run on biodiesel, though investigations have shown there is little or no completed work on the effect of fuel composition and engine loading on the emissions of a diesel engine run on Jatropha biodiesel.

1.2 STATEMENT OF THE PROBLEM

The inadequate electricity supply in Nigeria have led to the increase use of diesel generators for electricity supply, the combustion of conventional fuel (fossil fuel) by the diesel engines causes considerable environmental pollution, diminished air quality, acidic precipitation and climate change impacts. On the other hand, biodiesel from Jatropha has been one of the viable alternatives (to fossil fuel) that has gained momentum in its use as an alternative and indeed been run successfully on diesel engines. Many research works (Kabiru, 2014; Sani and Rufai, 2012; and Abubakar, 2010) have been done on diesel engine run on biodiesel. None of this works investigate the effect of fuel composition in relation to different engine loading on the emissions of a diesel engine using

Jatropha biodiesel to find an optimum relation between engine loading and fuel composition on the exhaust emissions and engine performance. Thus, the needs for this research to find the effects of fuel composition and engine loading on the emissions of a diesel engine run on diesel/Jatropha biodiesel blends.

1.3 SIGNIFICANCE OF THE STUDY

The importance of emission reduction cannot be over emphasized, thus the outcome of this research would signal an optimum biodiesel/petrol diesel fuel mix that will lead to emission reduction and eventually promote good and healthy environment.

1.4 AIM AND OBJECTIVES

The aim of the study is to examine the effects of biodiesel/petrol-diesel blends and engine loading on the emissions of a diesel engine.

The objectives focused on, in achieving the said aim are:

I. Assessment of engine performance and exhaust emissions of a compression ignition engine using biodiesel/petrol-diesel fuel blends. These was carried out under different engine loading during the engine operation,

II. To predict the emissions of a stand-by generator at different applied loads when using biodiesel/petrol-diesel fuel blends.

1.5 METHODOLOGY

The methodology to be used in carrying out this study is as follows:

I. Study of relevant literature on previous related works

II. Running a direct Injection engine (D.I.E) under different applied load using biodiesel/petrol-diesel fuel blends

III. Characterization of the combustion products using gas analyzer

IV. Analysis of result

1.6 SCOPE OF THE STUDY

The scope of the study is to determine the effect of fuel composition and engine loading on the emissions of a diesel engine using biodiesel/petrol-diesel fuel blends of B_{12}, B_{15} and B_{17} prepared from Jatropha biodiesel. However, the investigation only considers exhaust emissions of Nitrogen Oxide (NO_2), Carbon Monoxide (CO) and Sulphur Oxide (SO_2).

CHAPTER TWO

LITERATURE REVIEW

2.1 JATROPHA AS A SOURCE OF FUEL FOR DI ENGINES

The drought resistant *Jatropha* plant which is known as Physic plant is found growing on uncultivated land in most parts of Africa and could be used as a hedge plant (http://www.unilorin.ed.ng). The plant is considered as the best source of biofuel production among the various plants based fuel resources the world over (Tint and Mya, 2009). *Jatropha curcas f*ruit is made up of a green epicarp, a fleshy mesocarp and hard endocarp. The plant is known as a diesel fuel plant as the seed could yield substantial quantity of oil, which can be converted to biodiesel without refining (Becker and Makkar, 2009). The plant can yield about 1000 barrels of oil per year per sq mile. Curcas which grows on degraded agriculture lands incurs little or no carbon debts. Hence, it offers immediate and sustained greenhouse gas advantage. The various other uses of the plant (soap, organic fertilizer, pesticide and other more) make it to stand at the top as there is no competition between the plant and man. Due to its potential, scientists in developing countries have the responsibility of militating against climate change as well as creating new sources of income for the rural farmers. This underutilized biofuel plant will help in meeting the challenges of global biofuel demand (37 billion gallon) by 2016 (http://www.jatrophaworld.org). Currently, the Nigerian government has shown great interest in Jatropha plant and other biofuel plants. The aim of the government is to gradually reduce the nation's dependence on imported gasoline, reduce environmental pollution as well as create commercially a viable industry that can precipitate domestic jobs (Federal Government of Nigeria Policy on Biofuel, 2008).

2.1.1 Jatropha Curcus Cultivation in Nigeria

In Nigeria, farmers intercrop Jatropha with other plants like maize and cassava in between the Jatropha trees, to avoid looking for another land to plant. The reasons behind the intercropping strategy are essentially risk spreading in the event of adverse weather, although crops can also benefit from plant shadowing effects, and 'natural' disease and pest control. A combination of certain selected food crops and Jatropha might have positive overall impacts on yields and farmer income. Intercropping is successful in Nigeria. Intercropping also provides farmers with a form of insurance against crop failure. The growing period of one crop is usually different from that of the other, so if the rains are late for one crop and reduce its growth they may arrive in good time for the other crop. The trees are well adapted to arid conditions and have a 'built-in' capacity to combat desertification by restoring vegetative cover. In addition, the plant is relatively drought resistant; this largely depends on the method of cultivation. It is suitable for sand dune stabilization and soil conservation areas. Jatropha has potential for controlling soil erosion and increasing the habitat for wild animals." It does not require any particular soil type for growth and can flourish on almost any soil composition. Jatropha cultivation is already popular, researched and tested worldwide. Its oil yield in Nigeria is above 40%. Nigeria has ample availability of economic, deforested and large chunks of wasteland mass which can be utilized for the Jatropha cultivation. The plate below shows typical Jatropha vegetation in the northern Nigeria.

Plate 1: Jatropha Vegetation

2.1.2 Vegetable Oil as Diesel Substitute

In pursuance of an August 2005, Nigerian government directive on automotive biofuels, the NNPC was mandated to create an environment conducive for the take-off of a domestic fuel ethanol industry. The policy mandated the NNPC to blend gasoline and diesel with bioethanol (up to 10%) and biodiesel (up to 20%), thus forming E_{10} and B_{20} blends respectively (NNPC, 2007). The policy created an immediate demand of 1.3 billion litres of bioethanol and 480 million litres of biodiesel, which could increase to 2.0 billion litres and 900 million litres, respectively, by 2020 (NNPC, 2007).

Biodiesel is an alternative fuel for diesel engine, the esters of vegetable oils and animal fats are known collectively as biodiesel. It is a domestic, renewable fuel for diesel engine derived from natural oil like Jatropha oil. Biodiesel has an energy content of about 12% less than petroleum-based diesel fuel on a mass basis. It has a higher molecular weight, viscosity, density, and flash point than diesel fuel. Jatropha oil is extracted from a renewable non-edible plant known as Jatropha curcas. The Jatropha oil has similar properties as petroleum diesel but some properties such as kinematic viscosity, solidifying point, flash point and ignition point is very high in Jatropha oil. By some chemical reactions, Jatropha oil can be converted into biodiesel. Jatropha oil can also be used directly by blending with petroleum diesel (Kazi et al., 2009). Table 2.1 below shows the standard properties of petroleum diesel and biodiesel.

Table 2.1: Standard Fuel Properties of Bio-diesel and Diesel

S/No.	Fuel Property	Bio-diesel	Diesel
1	Density, kg/m^3	870-890	840-860
2	Kinematic viscosity, cSt	3.5-5.2	1.92-4.1
3	Higher heating value, MJ/kg	Min. 39.2	Min. 45.2
4	Cetane index	Min. 50	Min. 40
5	Flash point, $^{\circ}C$	Min 100	Min. 52
6	Distillation range, $^{\circ}C$	Max 360	Max. 342

Source: (ASTM, 2008)

Thus, biodiesel presents a very promising alternative since it can be produced where there is need for a renewable, environmentally friendly form of fuel. Various crude or refined, low grade, non-edible, biodiesel have been widely used for their possible utilization either straight or as diesel fuel extender on compression ignition (CI) engines by several investigators over the decades.

2.1.3 Review of Related Past Works

Adamu (2009) studied the endurance characteristics of a compression ignition engine run on Jatropha biodiesel blends of B_{20}, B_{30}, B_{40} B_{50}, B_{60}, B_{70}. B_{80} and B_{100}. The experiment results indicated that diesel engines endure long hours of operation on using Jatropha biodiesel blends B_{20}, B_{30}, B_{40}, B_{50} B_{60} B_{70}, B_{80} and B_{100} than when run on diesel fuel. Though, B_{20}, B_{80} and B_{100} were observed to have superior endurance characteristics.

In another study carried out by Abubakar (2010), Jatropha biodiesel blends of B_{20}, B_{30}, B_{40}, B_{50}, $B_{60,}$ B_{70} and B_{80} were used to run a single cylinder two stroke engine in order to determine the operational parameters of the engine. The work shows that there was reduction in brake power values for increased percentage substitution of biodiesel in diesel, with maximum and minimum brake power obtained with Jatropha oil/diesel fuel blends B_{20} and B_{50} respectively. Engine brake thermal efficiency was observed to be maximum when B_{20} was used and as well shows the lowest specific fuel consumption at all speeds.

Also, a study carried out using soybeans biodiesel blend on a four stroke, single cylinder engine by Kabiru (2014) showed that B_{15} is having a low NO_2, CO and SO_2 compared to other fuel blends used. The study established that NO_2 emission for diesel and all blends followed an increasing trend with respect to load at all the levels of throttling while the SO_2 emission deceases.

Kyle and Spencer (1993) reported that high viscosity of pure vegetable oil causes poor atomization, larger droplets and high spray jet penetration. Viscosity of pure vegetable oil exerts a strong influence on the shape of the fuel spray and the jet tends to be a solid stream of small droplets and consequently the fuel is not distributed properly or mixed with the air, which is required for proper combustion. These result to incomplete combustion accompanied by loss of power and fuel economy. In small engines, the fuel spray may impinge upon the cylinder walls, washing away the lubricating oil film and causing dilution of the crank case oil. Kyle and Spencer (1993) also noted that the high flash point of this type of fuel is attributed to its volatility characteristics. This leads to more deposit formation, carbonization of injectors' tips, ring stricking, lubrication oil dilution and degradation. The combination of high viscosity and low volatility of vegetable oil causes poor cold engine start up, misfiring and ignition delay. Kyle and Spencer (1993) concluded that, the use of vegetable oil in its pure form gave satisfactory engine performance and power output or even slightly better than conventional diesel fuel in short term trials.

On the same note, Venkata el al. (2010) reported biodiesels are used because of their similarity to petroleum diesel, which allows the use of biodiesel-diesel blend at any proportion. The biodiesel allow the addition of more ethanol blended fuel, improves the tolerance of the blend to water and keeps the mixture stable, so that it can be stored for a long period. The large cetane number of biodiesel offset the reduction of cetane number from addition of ethanol to diesel, thus improving the engine ignition. Moreover, the addition of biodiesel increases the oxygen level in the blend. In addition, biodiesel have lubricating properties that benefit the engine and are obtained from renewable energy sources such as vegetable oils and animal fats. Similar to ethanol, biodiesel have a great potential for reducing emissions, especially particulate matter. It is further noted that diesel-biodiesel-ethanol blends can substantially reduce emissions of CO, total hydrocarbons (HC) and particulate matter (PM), (Shi et al., 2005). The mixing of biodiesel and bioethanol with diesel significantly reduces the emission of particulate matter (PM) because the blended biofuel contains oxygen (Hansen et al., 2005). Hadi rahimi et al. (2009) showed that the bioethanol and sunflower methyl ester can improve low temperature properties of diesel-biodiesel-ethanol blends due to very low freezing point of bioethanol and low pour point of sunflower methyl ester. The power and torque produced by the engine using diesel-biodiesel-ethanol blends and conventional fuel was found to be very comparable. The CO and HC emission concentration of these blends decrease compared to convention diesel. Hwanam et al. (2008) investigated the exhaust gas characteristics and particulate size distribution of PM on a CRDI diesel engine using diesel, biodiesel and ethanol blends. They observed the reduced CO, HC, smoke emission and total number of particulate emitted, but increased NO_x emission.

Scholl and Sorenson (1993) conducted a test using a four stroke naturally aspirated direct injection diesel engine with SME and found that hydrocarbon, smoke and carbon monoxide emissions were gradually lower than those of the conventional diesel. However, it was observed that NO_x emission was essentially unchanged.

A single cylinder caterpillar engine was used by Choi et al. (1997), both single and multiple injection strategies with B_{20} and B_{40} were used, and revealed that at high load using single injection, particulate and carbon monoxide were decreased. A slight increase in NO_x was noticed as the biodiesel concentration increased. However, in the case of multiple injections, a decrease in particulate emission was observed with little or no effect on NO_x.

Darodo et al. (2004) studied the exhaust emission of a direct injection diesel engine fueled with waste olive oil methyl ester at several steady state operating conditions. The result of the study revealed that the use of biodiesel resulted in lower emissions of CO, CO_2, NO and SO_2, but increased emission of NO_2.

Neto da Silva et al. (2003) in their study observed that B_5 resulted in increased torque and power output. Nitrogen Oxide emissions were lower at lowers engine speed for 5% blends and higher proportion of biodiesel in the blend.

Kumar and Sharma (2005) have reported increase in brake thermal efficiency with methyl ester as compared to pure vegetable oil. The methyl ester showed higher diffusion combustion compared to standard diesel operation.

Can et al. (2004) comprehensively reviewed the literature and observed that bio-diesel containing 10-12% oxygen on weight basis causes reduction in engine torque and power due to its lower energy content.

Faralu (2012) used a single cylinder diesel engine and a Jatropha biodiesel as fuel for electricity generation. The result revealed that blend of B15 was observed to be optimum blend as it exhibited the best specific fuel consumption and exhaust gas temperature. Though some studies have revealed that biodiesel can cause a slightly higher engine power than conventional diesel fuel. This is because of complete combustion with the fuel oxygen in the fuel rich flame zone. The complete combustion also reduces exhaust emission such as hydrocarbons, smoke and carbon monoxide.

In another study carried out using a horizontal single cylinder four stroke air cooled diesel engine to investigate the effects of fuel composition on the emission characteristics of a direct injection engine by Kabiru (2014) using soya beans-based biodiesel and conventional diesel fuel as blending fuel, the study concluded that B_{15} fuel was established to be a good alternative to diesel fuel based on the analysis, the study revealed that there was a low NO_2, CO and SO_2 emissions for B_{15} compared to other fuels used for the study. The study also established that the higher the blend ratio, the higher oxygen content and the lower the carbon and Hydrogen content of the fuel. And generally, there was an increase in Sulphur fraction as the amount of biodiesel increases in the fuel blends, while diesel fuel has the higher Sulphur fraction than any of the blends.

2.1.4 Biodiesel from Jatropha as a Fuel for Direct Injection Engine

Jatropha curcas is among tree crops that are a renewable non-edible plant. From jatropha seeds jatropha oil can be extracted, which has similar properties as diesel but some properties such as kinematic viscosity, solidifying point, flash point and ignition point are very high in jatropha oil. By some chemical reactions such as emulsification, pyrolysis (thermal cracking), and transesterification (alcoholysis), Jatropha oil can be converted into biodiesel. Jatropha oil can also be used directly by blending with diesel. The most commonly used and most economical process is called the base catalyzed esterification of the fat with methanol, typically referred to as 'the methyl ester process' (Kabiru, 2014). Essentially the process involves combining the fat/oil with methanol and sodium or potassium hydroxide. This process creates four main products- methyl ester (biodiesel), glycerin, feed quality fat and methanol that are recycled back through the system. The primary product, methyl ester, is better known as Biodiesel. The glycerin and fats can be sold to generate added income from the process. The methyl ester process is very energy efficient in that for each unit of energy required by the process approximately 3.2 unit of energy are gained. Biodiesel is thus an excellent resource fuel source. Biodiesel can be produced from any type of vegetable oil or animal fat. Some of the suitable feedstocks may require some pre-processing to remove materials that reduce the yield of biodiesel. The Jatropha biodiesel can effectively be used as fuel for direct injection engines. The choice of Jatropha curcas as source of biodiesel in this research is mainly because of its availability and it being a non-edible plant.

2.1.5 Biodiesel Fuel as a Blending Stock for Diesel

Many characteristics of bio-diesel are similar to that of petroleum derived diesel. It is a light, dark yellow liquid, practically immiscible with water, and has a high boiling point as well as low vapour pressure (Kabiru, 2014).

Biodiesel can be use as an additive in formulation of diesel to increase the lubricity of pure ultra- low sulphur diesel (ULSD) fuel. Although care must be taken to ensure that the bio-diesel used does not increase the sulphur content of the mixture above l5ppm, most of the world uses a system known as the B factor to state the amount of bio-diesel in any fuel mix. For example, fuel containing 20% bio-diesel is labeled B_{20}. Pure bio-diesel is also referred to as B_{100}. Bio-diesel also has the best energy balance amongst all liquid fuels.

Blends of 20 percent bio-diesel with 80 percent petroleum diesel (B_{20}) can generally be used in unmodified diesel engine. Bio-diesel can also be used in its pure form (B_{100}), but may require certain engine modification to avoid maintenance and performance problems. Biodiesel has higher cetane number (49-62) as compared to petroleum diesel (Sheehan et al., 1998). This explains its ability to improve diesel combustion. Biodiesel also has superior lubricity which reduces wear in the engine and can increase the life of fuel injection systems as well as other engines components.

2.1.6 Biodiesel as Energy Carrier in Nigeria

Although Nigeria is a major world crude oil producer, the energy situation in the country is both complex and worrisome. Nigeria is exporting crude oil, while refined fuels are imported at international prices and sold with subsidies. In January 2012, strikes were organized as a protest against the abolishing of gasoline subsidies, criticized for being costly and distorting the market. Currently, Oil and Gas account for over 90% of both foreign exchange benefits and total government revenues. However, continuous reliance by the country on only one sector is unsustainable, especially considering the fact that the current proven reserves for oil (36.22 billion barrel) and gas (181 trillion cubic feet) could only last for the next 35 to 40 years (Enibe and Odukwe, 1990). This could be attributed to the rapid increase in population and energy consumption as well as the associated development in science, technology and socio-economic activities (Enibe and Odukwe, 1990). At the same time, pollution is a serious problem in the larger cities and widespread use of stand-by diesel generators for electricity generation due to the epileptic power supply from the national grid in the country, kerosene and firewood for cooking is harmful for indoor air quality. Production of biofuels such as bioethanol, biodiesel and biogas may alleviate these problems. Biofuel development in Africa is believed to offer some prospect of local energy supply with potential economic, environmental and security-of-supply benefits, among others. Nigeria is a West African country with a total land area of 910,770 square kilometers out of which 16%, 34%, 23% is occupied by forests, crops and grassland, respectively, and the remaining 27% consist of rivers and lakes (Olufolaji, 2012). Nigeria is the largest emitter of the undesirable gases from sub-sahara Africa, and particularly, the second worlds' biggest gas flarer, contributing immensely to the global atmospheric pollution (Olufolaji, 2012).

The oil and gas exploration and production being dominant in only a certain part of the country, accounted for only few job opportunities to less than 1% of the over 160million inhabitants of the country. This can also be connected with the continuous rise in poverty levels among rural communities and the persistent rural-urban migration over the years. In an attempt to mitigate these problems, Nigerian government has indicated the incorporation of biofuels production, particularly bioethanol and biodiesel to be a good option. The production of these fuels could enhance fuel use in automotive industry, electricity power generation and rural development, including agricultural mechanization and light industrial goods development, and in ensuring that the common man is fully benefitting from the country's economy (Azih, 2007). These issues therefore prompted the Biofuels Policy (2007), which tailors the necessary measures to be applied in ensuring successful biofuels production and utilization. The policy's main target is to reduce the country's dependence on imported petrol, and environmental pollution while creating an industry that is commercially viable to both investors and consumers and provide stainable job opportunities that could reach the common man. It also aims at ensuring an integration of the downstream petroleum industry with agricultural activities (NNPC, 2007).

2.2 EFFECTS OF BIODIESEL ON ENGINE PERFORMANCE

Diesel engine is primarily designed and developed to operate on liquid fuel. The desirable properties of the fuel to be used on diesel engine includes: ignition quality, volatility, viscosity, specific gravity. However, the ignition quality is one of the most significant factors governing the suitability of the use of any fuel in diesel engines.

Cetane number which is the index of ignition quality of fuels should be higher for a better performance in diesel engines. These engines have been designed to run over a wide range of heavy to light range of hydrocarbon fuels. Heavier grades of petroleum fuel known as light oil are suitable for low speed engines but unsuitable for higher speed diesel engines.

Relatively high viscosity, lower volatility and reactivity of unsaturated hydrocarbon chains of these oils cause problem of high emissions and low break thermal efficiency (Vellgulh, 1983). Pure vegetable oil is too viscous and creates difficulties over prolonged use in the direct injection engines (Ziejewski et al., 1996).

2.3 THE BENEFITS OF BIODIESEL AND BIODIESEL BLEND

Biodiesel is increasingly considered very important in addressing energy security problems, poverty reduction, decreasing the dependency on fossil fuels, and reducing greenhouse-gas (GHG) emissions and lower PM emissions.

The benefits of biodiesel include reduced net CO_2 emissions, reduced HC and CO emissions and lower visible smoke. Biodiesel also has a higher cetane number and contains no aromatics. It has low sulfur content and improves lubricity. Biodiesel is also nontoxic and biodegradable. The concerns most often expressed by the diesel engine and vehicle manufacturers include several topics; there are concerns about materials compatibility, biodiesel may cause corrosion of certain metals. These include zinc, copper-based alloys, tin, lead and zinc.

Certain elastomers and seal materials may also harden or swell. This effect may be more pronounced on older vehicles or equipment and may increase with biodiesel concentration in the blend. There is also concern with the potential for the increased water contamination, which could increase corrosion as well as the potential for microbial contamination. Biodiesel may also increase NOx emission, especially at higher blend levels.

2.4 FUEL INJECTION IN DIESEL ENGINES

Fuel injection is a system for admitting fuel into an internal combustion engine. It has become the primary fuel delivery system used in automotive engines, having replaced carburetors during the 1980s and 1990s. A variety of injection systems have existed since the earliest usage of the internal combustion engine. The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on suction created by intake air accelerated through a venturi tube to draw the fuel into the airstream. Fuel injectors must produce a fine spray that will vaporize rapidly to ensure fast mixing of the fuel vapor and air. Placement of the injector in the cylinder head is carefully calculated to determine the best position and angle to enhance fuel vapor and air mixing. The design of piston top and intake port can help create a swirling motion of the air/fuel mixture in the cylinders. The fact that, the fuel is injected into an environment hot compressed air, it must be injected late in the compression stroke, just before the piston reaches the top dead center (TDC). This necessitates injection under very high pressures, as much as 2000bar.

There are two basic fuel injection designs, each with various subcategories. In a direct-injection (DI) system, the fuel is introduced directly into the cylinder. DI engines usually have compression ratios in the range of 15:1 to 18:1. Indirect-injection (IDI) engines inject the fuel into small pre-chamber between the injector and the cylinder (Robert, 2007). IDI engines typically operate at higher compression ratios, in the range of 20:1 to 24:1. IDI systems create a more rapid mixing of the fuel and air. However, there are some drawbacks, IDI systems lose more heat during compression and this is why IDI engines have higher compression ratios to reach the necessary air temperature. This usually results in fuel economy that is significantly lower than in a DI engine. IDI engines may also be hard to start, that is why glow plugs are installed in the pre-chamber. The primary interest in IDI systems is their ability to operate at higher engine speeds when there is less time to inject and mix the fuel per engine cycle.

2.5 OVERVIEW OF EMISSION CHARACTERISATION

Compression ignition engines are employed particularly in the field of heavy transportation and agriculture on account of their higher thermal efficiency and durability. The diesel engine is widely used for its high fuel efficiency, low emission of CO_2, and unburned hydrocarbons (HCs) and CO. However, one problem of the diesel engine is that it has a high emission of NO_x and particulate matter (PM), and it is difficult to reduce both emissions simultaneously because of the tradeoff between NO_x and PM emissions. Although application of high-pressure injection and common rail system can reduce both NO_x and PM emissions. The expense is also very high and unaffordable for many engine producers and consumers, especially for diesel engines widely applied for agricultural machinery (Ruijun et al., 2008).

Reduction of exhaust emissions is extremely important for diesel engine development in view of increasing concerns regarding environmental protection and stringent exhaust gas regulations. Diesel engines are the most fuel-efficient combustion engines in human history. However, diesel engines are also considered a major source of air pollution in port and urban areas because of their soot, HC, NO_x, particulate matter (PM), CO, CO_2, SO_x emissions. The disgusting odor and noise from these engines may impair human health and the natural environment, such as ozone layer destruction, greenhouse effect enhancement and acid rain production (Linak and Wendt, 1993; Lin, 2000; Lin and Pan, 2001). The primary reason that the quantity of NO_x pollutants emitted from diesel engines is greater than those from gasoline engines is the difference in the burning processes inside the cylinders. The high compression ratio of diesel engines produces higher gas temperatures inside the combustion chamber and on the cylinder surface, leading to greater NO_x formation based on the extended Zeldovich thermal NO mechanism (Ferguson and Kirkpatrick, 2001).

The amount of particulate matter emission depends on the quality of the fuel oil and the completeness of burning in the combustion chambers. Particulate matter is generated from incomplete hydrocarbon burning when the fuel oil is injected into a cylinder and mixes with its surrounding air imperfectly. Particulate matter is generally composed of three compounds:

1. Solid carbon particles produced from the burning process.
2. Soluble organic fractions (SOF); and
3. Sulfides, additives for fuel oil. etc. (Mayer et al., 1980).

Controlling diesel engine exhaust emissions through fuel modification seems to be promising because it would affect both the new and old engines. Modification of diesel fuel to reduce exhaust emission can he performed by increasing the cetane number, reducing fuel sulphur, reducing aromatic content, increasing fuel volatility and decreasing the fuel density. However, the potential of conventional diesel fuel for emission reduction has already been to a large extent exploited and the most important fuel parameters mentioned above, can nowadays be changed in a narrow range only.

Moreover, the shortfall in NO_x and PM emissions control in diesel engines is so great that much more drastic fuel change will be needed (Stoner and Litzinger, 1999).

Studies show that the composition of diesel engine exhaust gas varies considerably, depending on the engine type, operating conditions, fuel, lubricating oil, and whether an emission control system is present (Ouenou-Gamo et al., 1998). Three basic approaches are generally used to reduce diesel gas emissions:

i. Design Parameters: Cylinder head and combustion chamber design, number of valves, bore-stroke ratio, compression ratio and inlet and exhaust port shape;

ii. Operational Parameters: Engine management, mixture formation and control, modification of fuel composition, supercharging, valve timing, internal and external exhaust gas recirculation (EGR), etc, and

iii. Exhaust gas after treatment: Catalytic converter systems, secondary air injection, thermal reactors, particulate traps, etc. (Schafer and Van, 1995).

With the increasing concern on environmental protection and more stringent emission regulations, reduction of diesel engine exhaust emissions has become a recurrent issue in engine development. It is difficult to reduce particulate and nitrogen oxide (NOx) emissions at the same time. On the other hand, modification of fuel composition through the addition of oxygenate fuel to diesel fuel can reduce exhaust gas emissions from diesel engines (Song et al., 2003).

2.5.1 Emissions from Biodiesel and Its Blend with Diesel

Research works such as that of Kabiru (2014), Faralu (2011), Lapuerta et al. (2008), Kegl (2008), Barwal and Sharma (2005), Raheman and Phadatare (2004), Mirandol et al. (2004), Senthil et al. (2006), Vellguth (1983) have reported that CO, CO_2 and unburnt hydrocarbon (UBHC) emissions are less with bio-diesel and its blends, because bio-diesel has oxygen in its molecular structure, leading to better combustion. Advanced injection and combustion when using biodiesel may also justify the CO_2 reduction with this fuel (West et al. 2005). It has also been reported that NO_x emissions are slightly increased with biodiesel and its blends with petro-diesel (Senthil et at., 2003; Kegl, 2008; Lapuerta et al.. 2008). This may be due to the higher temperature in the combustion chamber while using biodiesel. Impact of cetane number, flame temperature, oxygen availability and injection advance on NO_x levels in emissions using Biodiesel as fuel under varying load conditions is also reported (Lapuerta et al., 2008). The sensitivity of NO_x to changes in cetane number is higher at low load than at high load (Lapuerta et al., 2008). Exhaust gas recirculation can result in NO_x emissions reduction up to 50% and reduce smoke emissions by 15% (Greeves and Wang, 1981; Shahdat et al., 2006). The emission of aromatic and poly-aromatic compounds, as well as their toxic and mutagenic effect, has been generally reported to be less with biodiesel. No conclusive trend has been observed regarding the emissions of oxygenated compounds such as aldehydes and ketones (Lapuerta. et al., 2008). Experimental evidences suggest that overall toxicity of emissions in terms of metals reduces in biodiesel exhaust compared to diesel exhaust (Dwivedi et al., 2006).

2.5.2 Emissions from Complete Combustion

Emissions from complete combustion in compression ignition engine are those gases emitted through the exhaust to the atmosphere when there is perfect combustion of the fuel/air mixture in the combustion chamber. In addition, such combustion is without detonation and after burning in the exhaust manifold. The gases emitted include carbon dioxide ($C0_2$), Oxides of Nitrogen (NO_x). Nitrous Oxide (N_20), Oxides of Sulphur (SO_x), Hydrogen Chloride (HCL) and Heavy Metals (HM). The CO_2 neutrality of bio fuels has been explained in section 2.1, but besides CO_2 there are harmful emissions to take into consideration. Complete combustion of fuel nitrogen produces nitrous oxide. Emissions level of N_2O is very low for combustion of biomass. Other emissions from complete combustion like heavy metals and SO_x are very low compared to those of fossil diesel, which is self-evident, because bio fuels do not contain as much sulphur as fossil fuels and there is no heavy metal at all (Rabe, 2004). Hydrogen Chloride is produced if the biomass source contains chlorine. This is only the case for miscanthus, grass and straw; so, for biodiesel production this is not an important issue. Non-Methane Volatile organic compound (NMVOC) emission of biodiesel is generally below that of fossil diesel. Diesel engines have high emissions of fine particles. However, for particles of larger diameters, biodiesel engines emit fewer particles than fossil diesel (Rabe, 2004).

2.5.3 Emissions from Incomplete Combustion

Incomplete combustion occurs if the amount of oxygen is not in proportion to the amount of sprayed fuel. Low combustion temperature can also result in incomplete combustion. Emissions from incomplete combustion are carbon monoxide (CO), Methane (CH_4), Non-Methane Volatile organic compound (NMVOC), Particle Matter (PM), Polychlorinated Dioxins and Furans (PCDD/F), Ammonia (NH_3) and Ozone (O_3). On the average, the emissions of CO/PM are substantially lower when an engine is run on biodiesel (Rabe, 2004). Similar to ethanol, biodiesel have a great potential for reducing emissions due to the biodiesel oxygenated nature, especially particulate matter. It is further noted that diesel-biodiesel-ethanol blends can substantially reduce emissions of CO, total hydrocarbons (HC) and particulate matter (PM), (Shi et al., 2005).

2.6 EFFECT OF EMISSION ON THE ENVIRONMENT

All the exhaust emissions from a combustion process are harmful but mostly depend on their concentrations. Their effects on the environment and human health in Nigeria are not very much known and this is because industrial and transport emissions are neither monitored nor controlled.

The main greenhouse gas is evidently CO_2, followed by CH_4 and NO_x which also cause an increased greenhouse effect (Blasing and Smith, 2011). Emission from diesel engines could cause soil contamination as air pollutants form deposits, which end up in the ground water. The major contributors to this contamination are heavy metal and volatile organic compounds (VOC). Smog on the other hand, is of two types; photochemical smog and sulphurous smog. Photochemical smog results in a more brown instead of grey air. The production of photochemical smog is directly related to automobile use. Nitrogen oxide and organic compounds (HC) react under solar radiation via a complex reaction into photochemical smog (Botkin and Keller, 2000). Since compression ignition engine emits NO_x and running on diesel may increase the amount of emitted substance, this is a point of particular interest for the development of Jatropha oil. Sulphurous smog also called industrial smog, since primarily burning coal or oil at large quantity in large power plants produce it. Under certain conditions, the sulphur oxides that are produced at these power plants combine with particulate matter to form concentrated sulphurous smog. CO is an odourless, colourless and tasteless gas that can cause fatal poisoning. Exposure to low levels CO can produce symptoms like throbbing headache, dizziness, fatigue and shortness of breath. At higher levels, it can cause severe headache, weakness, dizziness and nausea, irregular heartbeat and unconsciousness. Very high levels of carbon monoxide can lead to seizures, coma, respiratory failure and death. Beside CO, SO_x, HM and PM can cause lungs problems. Acidification is caused by emission of NH_3, NO_x, SO_2, PM and NMVOC (Rabe, 2004). These gases could cause acid deposits, which can damage soil, vegetation, fresh water, buildings and ecosystems.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

The materials that were used to conduct the experiment for the determination of the effect of diesel-biodiesel fuel blends and engine loading on the emissions of a diesel engine include;

3.1.1 Biodiesel

The biodiesel (Jatropha biodiesel) was obtained from National Research Institute for Chemical Technology (NARICT), Zaria and the petrol diesel was also obtained from NNPC mega filling station, Zaria. The biodiesel/petrol diesel blends were prepared by mixing the fuels in volume ratio. Biodiesel/petrol diesel fuel blends of 12% biodiesel 88% petrol diesel, 15% biodiesel 85% petrol diesel and 17% biodiesel 83% petrol diesel simply represented as B_{12}, B_{15} and B_{17} respectively were prepared and used.

3.1.2 Experiment Set-Up for the Engine Emission Test

A Power Point, single cylinder diesel engine situated at a wielding workshop along BUK road, Kano was used as the test engine. It is an air-cooled direct injection, four-stroke, horizontal type engine. The engine specifications are as given in Table 3.1. The engine was mounted on a test bench and then connected to an alternator and control panel, which has accessories for monitoring torque, current, voltage and temperature. The fuel sample was fed from fuel tank mounted on the instrumentation unit and was being gravity fed to the engine, which was below the level of the tank. Plate 2 shows the engine set-up with the control panel.

Table 3.1: Test Engine Specifications.

S/No	Description	Specification
1.	Engine Model	Z165F
2.	Type	Horizontal Single Cylinder four stroke, air cooled
3.	Bore/Stroke	65/70 mm
4.	Compression Ratio	20.5–22
5.	Max. Torque	8.9 Nm
6.	Max. Brake Power	2.43 kW
7.	Rated Speed	2600 rpm
8.	Fuel Injection Pressure	14 MPa
9.	Injection opening angle	20°–24° before T.D.C

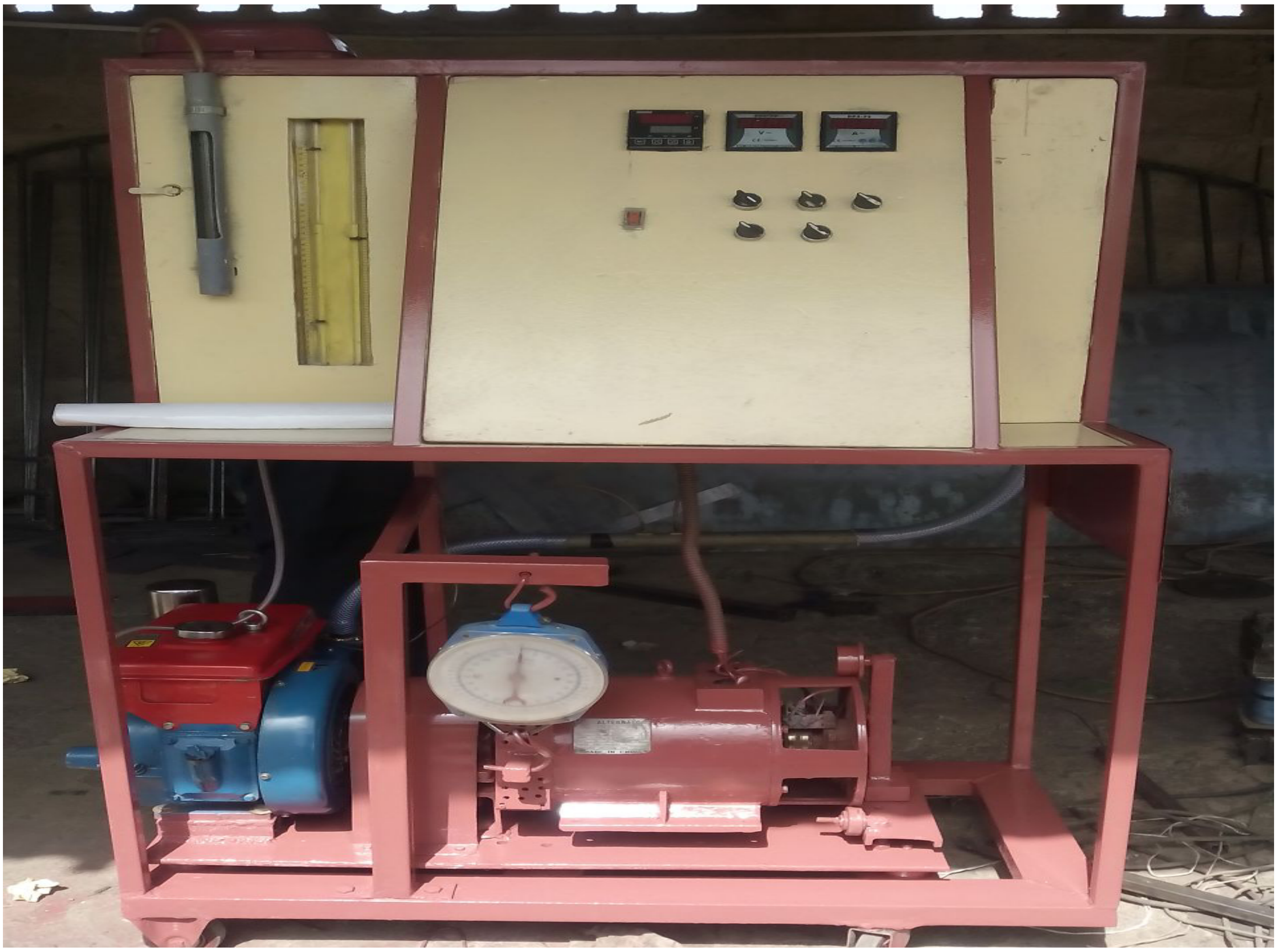
Plate 2: Engine Set-Up with Control panel.

3.1.3 The Gas Analyzers used for the Engine Emission Test

The compositions of the exhaust gases were measured using the Crowcon gas sensor obtained from the Pollution Control Laboratory, Ministry of Environment, Kano, Nigeria. Plate 3 shows the crowcon gas sensors for each of the three gases analysed, NO_2, CO, SO_2

Plate 3: Crowcon Gas Sensors

3.2 EMISSION PREDICTION PROCEDURE

The data obtained were analysed using the statistical method of regression analysis. Generally, multiple regressions is used to model problems that require analysis of two or more variables and determining how an aggregate result changes when one codependent variable is changed while the other(s) remained fixed. It is important to note that, the exhaust emission of NO_2, CO and SO_2 are functions of torque and blend ratio as shown in the equation 6.

$$\begin{cases} NO2 \\ CO \\ SO2 \end{cases} = F(T, R) \qquad (1)$$

Where T is the torque in Nm and R is the blend ratio.

Looking at the data obtained it is evident that there is no any particular pattern as regards to the way the values increase, therefore, for this study it is assumed that the relationship between the emissions and independent variables is linear and could be studied using linear regression techniques. Though, it should be noted that the word 'linear' in linear regression does not mean that the function is a straight line, but that the partial derivatives with respect to each coefficient are not function of other coefficients (Ken, 2012). Therefore equation 6 transforms to the following

$$\begin{cases} NO2 \\ CO \\ SO2 \end{cases} = A + BT + CR + DTR + ET^2R + FTR^2 + GT^2R^2$$

Where A, B, C, D, E, F and G are constant obtained from the regression analysis result.

Therefore, the emission of a particular gas may then be expressed in matrix form as:

$$[CO] = a + bT + cR + dTR + ET^2R + FTR^2 + GT^2R^2$$

$$[NO_2] = a + bT + cR + dTR + ET^2R + FTR^2 + GT^2R^2$$

$$[SO_2] = a + bT + cR + dTR + ET^2R + FTR^2 + GT^2R^2$$

The emission prediction was done using the embedded regression analysis software of Microsoft Excel Office 2007, the regression analysis tables are presented in section 4, tables 4.6, 4.7 and 4.8 for the CO, NO_2 and SO_2 respectively.

3.3 EXPERIMENT PROCEDURE FOR THE ENGINE EMISSION TEST

The diesel-biodiesel blend samples were mixed in volume ration, about 600ml of fuel blend of B_{17} was poured into the engine tank and the engine ignition was turned on. The engine was then started and left to run idle for 5 minutes for a stable operating condition to be achieved. The test started by loading a dry heater (soldering iron) of 400W and then using a stopwatch, the time taken to consume 5ml was recorded and the corresponding current (A), exhaust temperature (°C), Mass (kg) from the torque arm and the NO_2 emission (ppm); CO emission (ppm) and SO_2 emission (ppm) were also recorded. The procedure was repeated for the subsequent loading of 800W, 960W and 1120W. So also, the procedure was repeated for all the fuel samples. All readings were taken after stable operating condition is experimentally achieved.

3.4 ASSESSMENT OF ENGINE PERFORMANCE PARAMETERS

3.4.1. Power Output of the Engine

The power developed by an engine at the output shaft is known as the brake power (B.P.) and is given by

$B.P = \frac{2\pi NT}{60}$ ………………………………(2) (Theraja B.L. and Theraja A.K.

(2002))

Where N is the engine speed in rpm and T is the Torque in Nm and B.P is brake power in J

Considering the blend of B_{17} with torque of 5.35 Nm and also using equation (2) with a constant engine speed of 1600rpm, brake power B.P, was calculated. Using the same approach other values of the brake power (B.P) for different load conditions were determined and presented in Table 4.5 Chapter 4.

3.4.2. Specific Fuel Consumption

The specific fuel consumption rate Cs, is the fuel consumption rate per kW developed per hour

$Cs = C/_{B.P}$ ....(3) Rajput R.K. (2007)

Where, C is the fuel consumption rate in kg/s, and B.P is the brake power in kW

Considering the blend of B_{17} for the first loading that gave a torque of 5.35 Nm (see table 4.5) and also using equation (3) the specific fuel consumption was calculated

But $Q = \frac{Volume\ of\ fuel\ consumed}{time}$ ....(4) Rajput R.K. (2007)

Where, Q is the volume flow rate of the fuel in m^3/s.

Therefore, the fuel consumption rate C, from equation (3) will now be given as;

$$\therefore C = \rho \frac{Volume\ of\ fuel\ consumed}{time}$$ ....(5) Rajput R.K. (2007)

Where, ρ is the density of fuel in kg/m^3

Using the same approach other values of specific fuel consumption rate Cs for different load conditions and fuel blends were determined and presented in Table 4.5, chapter 4

3.4.3 Brake Thermal Efficiency

The brake thermal efficiency: This is defined as actual brake work per cycle divided by the amount of fuel chemical energy as indicated by lower heating value of fuel.

$$\eta_{b.th} = \frac{B.P}{H * C}$$ ....(6) Rajput R.K. (2007)

Where, H is the heating value of the fuel used in MJ/kg, C is the fuel consumption rate in kg/s

Using the same approach other values of Brake Thermal Efficiency for different load conditions and fuel blends were determined and presented in Table 4.5, chapter 4.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

An engine emission test was carried out using different diesel-biodiesel fuel blends prepared from Jatropha-based biodiesel. The parameters varied during the test are electrical load and composition of the fuel used. The properties of the biodiesel fuel blends used are given in Table 4.1 as obtained from the National Research Institute for Chemical Technology (NATRICT), Zaria.

Table 4.1: Presents the Properties of the Diesel-biodiesel fuel blends used

Property	**B_{12}**	**B_{15}**	**B_{17}**
Density at 15°C (kg/m^3)	853.8	855	855.4
Viscosity at 40°C (cSt)	2.64	2.78	2.87
Calorific Value (MJ/kg)	43.72	43.55	43.43
Cetane Number	50.51	50.64	50.72

4.1.2 Engine Emission Test

The engine emission test was carried out as explained in section 3.2.3. Table 4.2 presents the engine emissions at various load capacities, Torque and the corresponding exhaust temperature.

Table 4.2: Engine Emissions at Various Load Capacities (Fuel Sample B_{17})

S/No	LOAD CAPACITY (W)	TORQUE (Nm)	FUEL CONSUMPTION RATE(kg/s)	EXHAUST TEMP. (°C)	COMPOSITION OF EXHAUST GASES (ppm)		
					CO	NO_2	SO_2
1	400	5.35	0.000099	163	2	0.06	0.6
2	800	8.17	0.000157	228	1	0.05	0.6
3	960	8.71	0.000163	264	1	0.05	0.6
4	1120	8.84	0.000178	301	1	0.04	0.5

Table 4.3: Engine Emissions at Various Load Capacities (Fuel Sample B_{15})

S/No	LOAD CAPACITY (W)	TORQUE (Nm)	FUEL CONSUMPTION RATE(kg/s)	EXHAUST TEMP. (°C)	COMPOSITION OF EXHAUST GASES (ppm)		
					CO	NO_2	SO_2
1	400	5.08	0.000104	148	3	0.03	0.2
2	800	6.53	0.000144	196	3	0.02	0.2
3	960	7.80	0.000163	254	2	0.02	0.1
4	1120	8.80	0.000189	304	2	0.01	0.1

Table 4.4: Engine Emissions at Various Load Capacities (Fuel Sample B_{12})

S/No	LOAD CAPACITY (W)	TORQUE (Nm)	FUEL CONSUMPTION RATE(kg/s)	EXHAUST TEMP. (°C)	COMPOSITION OF EXHAUST GASES (ppm)		
					CO	NO_2	SO_2
1	400	5.81	0.000102	140	10	0.02	0.1
2	800	6.90	0.000137	202	8	0.01	0.1
3	960	7.80	0.000152	230	6	0.01	0.1
4	1120	8.71	0.000182	275	5	0.01	0.1

4.1.3 Emission Parameters:

4.1.3.1 Carbon Monoxide

Figure 4.1, 4.2 and 4.3 presents the variation of carbon monoxide, Nitrogen oxide and Sulphur dioxide with load for the three fuel blends.

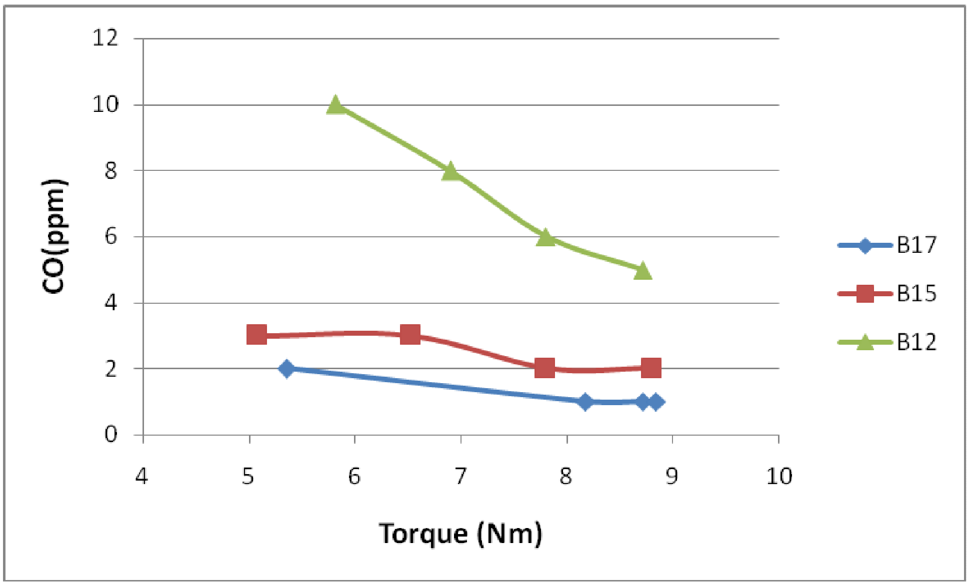

Figure 4.1: Load characteristics for CO

4.1.3.2 Oxide of Nitrogen

Figure 4.2 below shows the variation of Nitrogen dioxide with load for the three fuel blends.

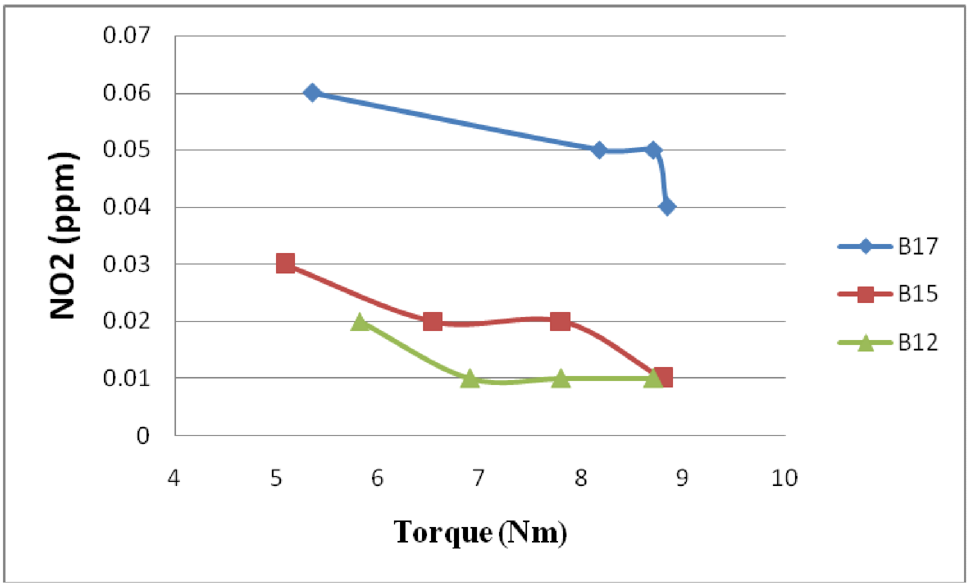

Figure 4.2: Load characteristics for NO_2

4.1.3.3 Oxide of Suphur

Figure 4.3 below shows the variation of sulphur dioxide with load for the three fuel blends.

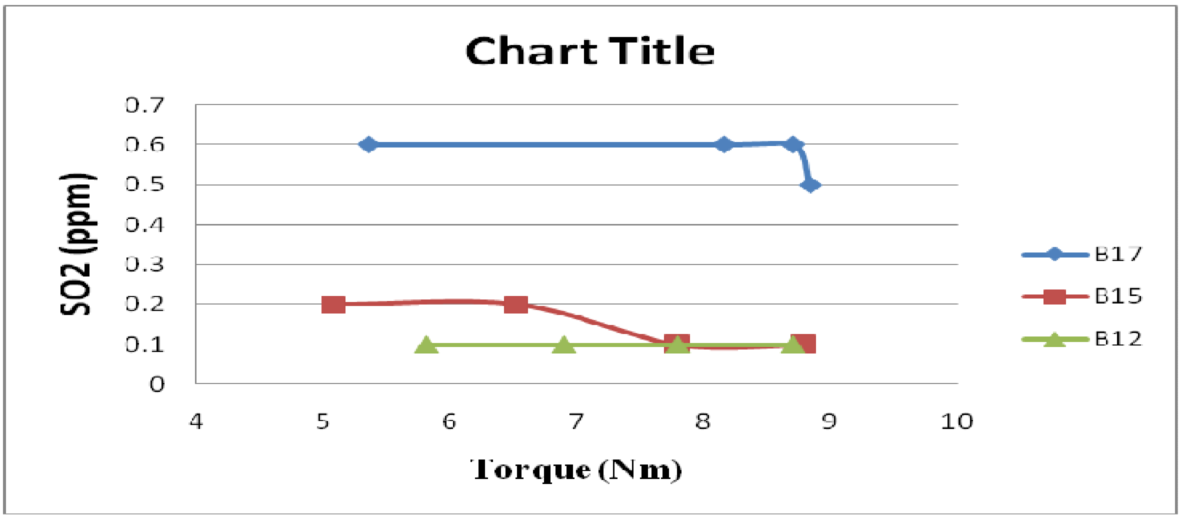

Figure 4.3: Load characteristics for SO_2

4.1.4 Engine Performance Assessment

The engine performance assessment was conducted as explained in section 3.3 and Table 4.5 presents the results.

Table 4.5: The Engine Assessment Calculated Values

LOADING CAPACITY (W)	SPECIFIC FUEL CONSUMPTION (kg/kWh)	BRAKE POWER (W)	Brake Thermal Efficiency (%)
B17			
400	0.398	896.40	20.81
800	0.413	1368.89	20.08
960	0.402	1459.37	20.62
1120	0.435	1474.45	19.07
B15			
400	0.440	851.60	18.79
800	0.474	1094.11	17.45
960	0.446	1306.90	18.52
1120	0.461	1474.45	17.91
B12			
400	0.377	973.47	21.83
800	0.427	1156.10	19.30
960	0.419	1306.90	19.67
1120	0.450	1459.40	18.34

4.2 DISCUSSION

The engine emission test was carried out as explained in section 3.2.3. Table 4.1 presents the properties of the diesel-biodiesel fuel blends used. Table

4.2, 4.3 and 4.4 present the engine emissions at various load capacities, torque and the corresponding exhaust temperature. From the result presented and the graphs plotted for the engine emissions at various load capacities, torque and the corresponding exhaust temperature for each load capacity, it was observed that the engine emits less CO with increase in the biodiesel ratio in the fuel blends. As the CO emitted when using B_{12} attained up to 10ppm, while when using B_{17} the highest CO emission recorded was found to be 2ppm. This could be attributed to the higher oxygen content in the biodiesel, which improved the combustion process and as such decreased the CO emission. The variation of CO emission with engine loading for all the three blends also followed a decreasing pattern as shown on the graphs (i.e Figures 4.1, 4.2 and 4.3). The graphs shows that when the load on the engine increases the CO emission decreases except at the blend ratios of B_{15} and B_{17} where it became constant even with the increase in load.

It was also observed from the graphs plotted, that due to the higher degree of un-saturation of the diesel-biodiesel blends, the NO_2 emission increases with the increase in biodiesel blend ratio across the three fuel samples, with B_{17} having 0.06ppm emission as the highest and B_{15} and B_{12} have 0.03ppm, and 0.02ppm respectively. The decrease of NO_2 though with increase in the exhaust temperature could be attributed to the higher cetane number and higher percentage of oxygen content of the fuel blends. Below a certain combustion temperature, NO_2 emission is controlled by air-fuel ratio and local oxygen concentration more than in-cylinder temperature.

Using the same approach it was observed that the SO_2 emission followed a decreasing trend for all the fuel blends used. The increase in SO_2 emission with increase in the biodiesel blend ratio could be attributed to the conversion of un-combusted biodiesel into particulate matter through condensation. The graphs also revealed a constant emission of SO_2 as the load increases. It showed that for B_{17} the SO_2 emission was at its highest point of 0.6ppm and decreases with increase in loading to 0.5ppm

Table 4.5 presents the performance assessment of the engine while using biodiesel/petrol-diesel fuel blends as explained in section 3.3. Table 4.5 present the specific fuel consumption rate at various load capacities, brake power developed and the brake thermal efficiency of the engine. Generally, the results showed that, the fuel consumption of the engine was less while using B_{17} fuel blend, then the consumption increases while using B_{15} fuel blend and then tended to decrease while using B_{12} fuel blend as shown in table 4.5 and increase slightly across the blend ratio with increase in loading. The consumption was found to be 0.435kg/kWh at a loading of 1.120kW for B_{17} while for the same load capacity the consumption was found to be 0.461kg/kWh and 0.450kg/kWh for B_{15} and B_{12} respectively. The brake thermal efficiency was relatively found to be higher while using B_{12} fuel blend as it was found to be 21.83% for a load capacity of 400W, while for an equal load capacity of 400W when using B_{15} and B_{17} fuel blend samples it was found to be 18.79% and 20.81% respectively.

4.2.1 Emission Prediction Result

The emission prediction was carried out as explained in section 3.4 and Tables 4.6, 4.7 and 4.8 shows the regression analysis result and variation of exhaust gas emissions for CO, NO_2 and SO_2 for the fuel blends used with respect to torque and blends ratio

TABLE 4.6: CO Emission With respect to Torque and Blend Ratio

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9904527
R Square	0.9809965
Adjusted R Square	0.9581923
Standard Error	0.6061365
Observations	12

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	6	94.82965955	15.80494	43.01819	0.00038
Residual	5	1.837007115	0.367401		
Total	11	96.66666667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	162.86844	59.07185144	2.757124	0.039971	11.0194	314.717464	11.01940748
b Variable 1	-12.467028	7.552894894	-1.650629	0.159726	-31.8824	6.94830654	-31.88236229
c Variable 2	-1051.4981	396.8846349	-2.64938	0.04546	-2071.72	-31.273687	-2071.722553
d Variable 3	-85.411069	36.42641229	-2.344757	0.065989	-179.048	8.22600469	-179.0481428
e Variable 4	15.300565	8.716365596	1.755384	0.139551	-7.10557	37.7066964	-7.105565759
f Variable 5	1117.8551	477.5756345	2.340687	0.066323	-109.792	2345.50237	-109.7921265
g Variable 6	-103.44679	57.23451784	-1.80742	0.130505	-250.573	43.6792241	-250.5727997

The equation is:

$$CO = 162.868 - 12.467(T) - 1051.498(R) - 85.411(TR) + 15.301(T^2R) + 1117.855(TR^2) - 103.447(T^2R^2)\ldots\ldots(9)$$

Similarly, table 4.7 shows the NO_2 emission with respect to Torque and the blends ratio.

TABLE 4.7: NO_2 Emission with respect to Torque and Blend Ratio

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.991237
R Square	0.982552
Adjusted R Square	0.961614
Standard Error	0.003557
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	0.00356175	0.000594	46.92662	0.000309
Residual	5	6.325E-05	1.27E-05		
Total	11	0.003625			

	Coefficients	*S E*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.557361	0.34662236	1.607979	0.168752	-0.33366	1.4483825	-0.3336598	1.44838247
b Variable 1	0.000813	0.04431895	0.018333	0.986082	-0.11311	0.114738	-0.113113	0.11473799
c Variable 2	-3.37828	2.32884338	-1.45063	0.206582	-9.36476	2.6082014	-9.3647636	2.60820136
d Variable 3	-1.39278	0.21374324	-6.51612	0.001272	-1.94222	-0.843332	-1.9422212	-0.8433322
e Variable 4	0.093974	0.05114597	1.837364	0.125573	-0.0375	0.2254487	-0.0375012	0.22544865
f Variable 5	9.067262	2.80232278	3.235624	0.023061	1.863662	16.270863	1.86366246	16.2708625
g Variable 6	-0.62806	0.33584124	-1.87012	0.120395	-1.49137	0.235245	-1.4913698	0.23524503

The equation is:

$NO_2 = 0.557 + 0.0008(T) - 3.378(R) - 1.392(TR) + 0.094(T^2R) + 9.067(TR^2) – 0.628(T^2R^2)$…………………………………..........(10)

TABLE 4.8: SO_2 Emission with respect to Torque and Blend Ratio

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99457
R Square	0.98917
Adjusted R Square	0.976175
Standard Error	0.034905
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	0.556408	0.092735	76.11547	9.46E-05
Residual	5	0.006092	0.001218		
Total	11	0.5625			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.854324	3.401691	0.545118	0.609097	-6.89	10.59865	-6.89	10.59865
b Variable 1	0.794077	0.434938	1.825722	0.127467	-0.32397	1.912121	-0.32397	1.912121
c Variable 2	-12.5707	22.85486	-0.55002	0.605971	-71.321	46.17962	-71.321	46.17962
d Variable 3	-17.1295	2.097639	-8.16608	0.000448	-22.5216	-11.7373	-22.5216	-11.7373
e Variable 4	0.423971	0.501938	0.844668	0.436835	-0.8663	1.714243	-0.8663	1.714243
f Variable 5	82.86114	27.5015	3.012968	0.029654	12.16627	153.556	12.16627	153.556
g Variable 6	-3.21087	3.295887	-0.97421	0.374697	-11.6832	5.261473	-11.6832	5.261473

The equation is:

$SO_2 = 1.854 + 0.794(T) - 12.571(R) – 17.130(TR) + 0.424(T^2R) + 82.861(TR^2) – 3.211(T^2R^2)$…………………………………..........(11)

The 0.9581923, 0.961614 and 0.976175 values of the adjusted R square from Table 4.6, 4.7 and 4.8 respectively indicate that there is a very good correlation between the data obtained and the regression analysis done, with CO emission of 95.8%; NO_2 emission of 96.2% and SO_2 emission of 97.6%. The equation under each table represents the model equation that can be used to predict the various emissions (CO, NO_2, and SO_2) of a biodiesel/petrol diesel fuel blend at any particular values of torque and blend ratio. It was observed that, the blend of B_{12} has the highest level of CO emission of 10ppm compared to the other blends of B_{15} and B_{17} which have 3ppm and 2ppm respectively and this is attributed to the carbon content in the blends ratio, which shows the higher the biodiesel in the blend ratio the lower the CO emission. However, with respect to NO_2 emission, the blend ratio of B_{17} has the highest emission of 0.06ppm; it shows a decrease pattern with decrease in the biodiesel blend ratio as indicated where B_{15} has 0.03ppm as the highest while B_{12} has 0.02ppm as its highest NO_2 emission. Similarly, it was observed that, the less the biodiesel blend ratio the less the SO_2 emission, as the biodiesel blend ratio of B_{12} is having 0.1ppm compared to B_{15} and B_{17} which are having 0.2 and 0.6 respectively.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The study has investigated the effects of biodiesel/petrol diesel blends and engine loading on the emissions of a diesel engine using Jatropha biodiesel fuel blends of B_{17}, B_{15} and B_{12} as fuel. The experiments were carried out on a power point air-cooled diesel engine while the compositions of the exhaust toxic gases were measured using a Crowcon Gas Sensor. Jatropha based biodiesel was used as the petrol diesel blending ratio. And the embedded regression analysis application of the Microsoft Excel Office 2007 was used for the emission prediction. The following conclusion can be drawn from this experimental study:

I. Based on the effect of torque on the exhaust emissions, all the fuel samples of B_{17}, B_{15} and B_{12} used, showed a decreasing trend of the CO, NO_2 and SO_2 emissions though with the increase in torque. As such, the fuel samples of B_{17}, B_{15} and B_{12} could a good alternative to petrol diesel, while B_{15} is the most optimal amongst the three fuel samples, which is in agreement with the work done by Kabiru (2014) and Faralu (2011).

II. The higher the blend ratio, the higher the oxygen content and the lower the CO emission. Generally, there was a decrease in the NO_2

and SO_2 with decrease in the biodiesel fuel content in the ratio. With B_{15} being the optimal alternative than the B_{17} and B_{12} samples in terms of biodiesel/petrol diesel exhaust emission of the three considered gases CO, NO_2 and SO_2.

III. The study also established that, the performance of the engine decreases with the increase in torque across each fuel blend but showed an unpredictable trend across the three fuel samples. The optimal alternative in terms of the increase in torque and engine performance is B_{17} because of the stable and higher efficiency trend even with increase in loading.

IV. The study has also established that B_{17} is the optimal fuel blend sample in terms of the engine performance and biodiesel/petrol diesel blend sample, with a stable and high efficiency of 20.81% and also less specific fuel consumption 0.398kg/kWhr at a load of 400W though B_{12} with a thermal efficiency of 21.83% and a specific fuel consumption of 0.377kg/kWhr, might seems better at the same load but it couldn't sustain the trend with increase in loading.

V. This study has successfully developed predictive model equations that show the relationship between the exhaust emissions of three gases (CO, NO_2 and SO_2) and the two parameters (blend ratio and load capacity) as shown below

$$CO = 162.868 - 12.467(T) - 1051.498(R) - 85.411(TR) + 15.301(T^2R) + 1117.855(TR^2) - 103.447(T^2R^2)$$

$$NO_2 = 0.557 + 0.0008(T) - 3.378(R) - 1.392(TR) + 0.094(T^2R) + 9.067(TR^2) - 0.628(T^2R^2)$$

$$SO_2 = 1.854 + 0.794(T) - 12.571(R) - 17.130(TR) + 0.424(T^2R) + 82.861(TR^2) - 3.211(T^2R^2)$$

5.2 RECOMMENDATIONS

It is recommended that;

i. Considering the results obtained for the exhaust emissions and engine performance, B_{17} Jatropha biodiesel fuel blend could be considered for electricity generation using diesel generators.

ii. Further research work should be conducted to further ascertain the trend of NO_2 and SO_2 emissions in low capacity stand-by generators for both low and higher loading.

iii. Other biodiesel/petrol diesel based blends should be used to find an optimum emission condition between this work and the others

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APPENDIX 1

Sample calculation;

1. **Power output of the Engine using B_{17} fuel sample;**

$$B.P = \frac{2\pi NT}{60} \quad \text{.................................(1)}$$

Where N is the engine speed in rpm, T is Torque in Nm and B.P is Brake Power in W.
T_1 for B_{17} = 5.35Nm,
N = 1600rpm.
Substituting the value of T and N into equation (1)

$$B.P = \frac{2\pi * 1600 * 5.35}{60} = 896.40W$$

Using the same approach other values of the brake power (B.P) for different load conditions were determined and presented in Table 4.5, Chapter 4.

2. **Specific Fuel Consumption using B_{17} fuel sample;**

$$Cs = \frac{C}{B.P} \quad \text{..................................(2)}$$

Where, C is the fuel consumption rate in kg/s, and B.P is the brake power in kW

C_1 for B_{17} = 0.0000992kg/s

$B.P_1$ for B_{17} = 896.40W

Substituting the value of C_1 and $B.P_1$ into equation (2)

$$Cs = 0.000099 * \frac{3{,}600}{896.40} = 0.398kg/kWhr$$

Using the same approach other values of specific fuel consumption rate Cs for different load conditions and fuel blends were determined and presented in Table 4.5, chapter 4

3. **Brake Thermal Efficiency using B_{17} fuel sample;**

$$\eta b.th = \frac{B.P}{H*C} \text{.................................}(3)$$

Where, H is the heating value of the fuel used in MJ/kg, C is the fuel consumption rate in kg/s

H for B_{17} = 43.43MJ/kg

C_1 for B_{17} = 0.000099kg/s

$B.P_1$ for B_{17} = 896.40

$$\eta b.th = \frac{896.40}{43.43 * 10^6 * 0.0000992} * 100\% = 20.81\%$$

Using the same approach other values of Brake Thermal Efficiency for different load conditions and fuel blends were determined and presented in Table 4.5, chapter 4.