MODELLING AND SIMULATION OF BIODIESEL BLENDS PERFORMANCE IN COMPRESSION IGNITION ENGINES

BY

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BY

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Declaration

I hereby declare that the work in this thesis entitled "Modelling and Simulation of Biodiesel Blends Performance in Compression Ignition Engines" has been carried out by me in the Department of Mechanical Engineering. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this work has been presented for another degree or diploma at this or any other institution.

Kaisan Muhammad USMAN _____ _____

Signature **Date**

Certification

This thesis entitled "MODELLING AND SIMULATION OF BIODIESEL BLENDS PERFORMANCE IN COMPRESSION IGNITION ENGINES" by Kaisan Muhammad USMAN meets the regulations governing the award of the degree of Doctor of Philosophy in Mechanical Engineering, of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dedication

This thesis is dedicated to the Almighty Allah alone, blessed is He in whose hands is the sovereignty and He is able to do all things; Who had created life and death that He might try us who amongst us is best in conduct. All praises, magnificence, benevolence, knowledge of the unknown and the remote control of the entire galaxies belong to Allah, the founder, the ruler, the provider and the controller of the universe. It is with His mercy that this thesis sees the light of the day; I hereby pray that the findings become beneficial to the humanity till the end of times.

Abstract

This research was conducted to investigate the suitability of using a renewable, sustainable and environmentally friendly biodiesel as part or full substitute of the petroleum diesel. Biodiesel from Cotton, Jatropha and Neem seeds, were produced and their compositions were analysed using Gas Chromatography-Mass Spectroscopy. The biodiesels were then blended with petro-diesel, thereby forming binary blends and multi-blends in different percentages and the physico-chemical properties for all the blends were determined and analysed. The physico-chemical properties of different biodiesel feedstocks from past literature were reviewed and their mean values computed. The performance of the biodiesel and the blends in a stationary multi cylinder Compression Ignition engine at full load with variable speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm were investigated and the composition of their exhaust gas emissions were recorded and analysed. A model was developed for the compression ignition engine with the test rig's specifications using the GT-Power modelling software. The primary data obtained were used to validate the modelled engine during simulation, while the performance of biodiesels from the secondary data sources were further simulated under similar conditions**.** The results revealed that, the Cotton, Jatropha and Neem seed oils are reliable sources of biodiesel which are renewable and have the potential to replenish the partial energy demands in an eco-friendly way. The physico-chemical properties of most the fuels and blends conform to the ASTM standards, which suggests that they are suitable for use in CI engines operations. The quality of atomisation, combustion, fuel droplets and air-fuel mixing can be improved in CI engines by using these blends. The best performances in terms of brake power were recorded by using B10J, B20C B20J, and B30C blends. In terms of brake specific fuel consumption, the least value was generated by B10C, the Jatropha blend B25J is the overall best blend at most speeds. B30J has very low brake mean effective pressure at all speeds, while at maximum speed the highest value of brake mean effective pressure was generated by B30C. The highest values of brake thermal efficiency were recorded with B20J and B15N blends. Pure biodiesel samples and the B15C, B15J, B20C and B20J gave the lowest NOx and CO_2 emissions. The values of SO_2 emissions were null for most of the fuels except B20C at all speeds and B15C at 2500rpm in both cases which have a negligible SO_2 value of not more than 0.12 % in all cases. The engine performance simulation in GT-power confirms that the software is valid to be used in compression ignition engine simulation with biodiesel from any feedstock and at all speeds because both experimented and simulated results are very close with identical curves. The simulation of the secondary fuel data revealed that, highest brake specific fuel consumption was depicted by castor followed by coconut and then tallow, the highest brake mean effective pressure was observed during the simulation of the compression ignition engine performance with sun flower, tallow, waste cooking oil and soy biodiesels correspondingly. The highest brake thermal efficiency values were depicted by soy, sunflower, palm and safflower in descending order during the Cussons stationary 4 cylinder CI engine simulations with GT Power software.

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Abbreviations and Symbols

Symbol	Meaning
$\dot{m}_f$	Fuel Consumption Rate (kg/s)
P_{im}	Indicated Mean Effective Pressure (kPa)
Q_{LHV}	Lower Heating Value (MJ/kg)
η_{bth}	Brake Thermal Efficiency
ρ_f	Density of Fuel (kg/m^3)
ρ_w	Density of Water (kg/m^3)
A	Area (m^2)
B	Bore (m)
h	Hour
K	Number of cylinders
kW	Kilo Watt
L	Stroke (m)
N	Speed (rpm)
t	Time (s)
T	Torque (Nm)
v	Volume (m^3)
W	Watt
BP	Brake Power (kW)
SFC	Specific Fuel Consumption (kg/kW-h)
kg	Kilo Gramm
π	Pi = 3.142

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy supply to a nation must be made in a responsible and sustainable deportment, which is an approach that not only convenes the needs of the present generation but also guarantees the future generations to meet their demands (Sambo, 2011). Unfortunately, one of the challenges facing the actualisation of meeting the future generations' developmental needs is the unsympathetic effects of climate change because of the disconcert of natural balance of greenhouse gases (GHG) in the atmosphere, predominantly, carbon dioxide. Several researches were carried out and many others are still ongoing in search for solutions to the environmental menace and socioeconomic sustainability. One of the cleanest ways of burning fossil fuels is by blending them with biofuels (Akindale, 2011). The use of vegetable oil and animal fats to obtain biodiesel is theoretically attractive due to their compatibility with the current automobiles and diesel supply chains. However, the profitability of biodiesels depends heavily on the economics of the byproducts like glycerol. For sometimes, glycerol has been a valuable byproduct of the biodiesel industry. Nigeria has joined the league of countries seeking for alternatives to fossil fuels. Biofuels have emerged as a credible alternative to blend stock for the environmentally polluting petroleum resources (Izah and Ohimain, 2012).

Over the decades, fossil fuels and other carbonising energy sources have been used to generate power for sustainable industrial growth; for transportation, lighting, powering of heating and cooling devices and for prime moving in machining and production processes.

The effects of fossil fuels to our environment particularly, in climate change which is principally due to the discharge of greenhouse gases during the combustion of fossil fuels

cannot be overemphasised. However, research has justified the use of biodiesel and bio ethanol in diesel and petrol fuels respectively to produce efficiently combustible fuels which burn in internal combustion engines with reduced carbon dioxide emissions and similar power outputs as conventional diesel (Kaisan, 2014).

According to the National Energy Policy, NEP (2014), Nigeria shall:

i- Vigorously pursue the development of an optimal energy mix for the transport sector,

ii- Ensure regular and adequate availability of all fuel types for the transport sector,

iii- Ensure the use of efficient and environmentally friendly technologies in the transport sector.

As part of the strategies enlisted in the NEP (2014), there is need for "*Encouraging the use of the diesel for commercial and mass transit transportation*". Therefore, it has become absolutely necessary for the Nigeria to optimise its energy mix through the use of more environmentally friendly diesels (biodiesels) in the transportation sector.

Furthermore, biodiesel resources are abundant in Nigeria; so many crops and other resources which have high potentials of producing biodiesel in large quantities are either cultivated on Nigerian soil or are abundantly found in natural habitats. These include *Jatropha curcas*, palm oil, flax, field pennycress, mustard, sunflower (Ma *et al.*, 1998), wild grape seeds or *Lannea microcarpa (*Nafiu *et al.*, 2011; Kaisan *et al.*, 2013), virgin oil and fat feed stocks (Adams *et al.*, 1983) and used cooking oil (Stevenson, 2003).

Microalgae has also received much attention recently because it has high lipid contents, fast growth rates and potentials to mitigate the competition for land-use and food-for-fuel conflicts (Hu *et al., 2*008). They are also able to reduce the GHG effects via CO_2 sequestration (BP, 2012).

Therefore, since Nigeria has a very good reserve of some of the feedstock, it is appropriate to work on the integration of these feed stocks into the Compression ignition engines' fuel supply so as to optimise the nation's energy mix principally in the transport sector, and broadly in industrial, residential and commercial sectors.

1.2 Statement of Research Problem

Many problems are associated with the Nigerian oil and gas sector, and there is an urgent need to arrest the situation. First of all, Nigeria still depends on foreign nations for the supply of refined fuel products, most of the existing refineries in the country are not working to their full installed capacities, and there has not been expansion in the sector for some decades now while the countries energy demand increases rapidly due to the fast growing population of over 160 million people (Izah and Ohimain, 2012; Kannahi and Arulmozhi, 2013).

Secondly, there is price hike in petroleum products in Nigeria. This affects the costs of raw materials, processed goods and services as a result of cost incurred by the farmers, traders and manufacturers while powering plants and machineries, during transportation, lighting and conditioning residential and commercial buildings (Izah and Ohimain, 2012; Kannahi and Arulmozhi, 2013)

Thirdly, greenhouse gas (GHG) emissions; climate change is given serious global attention because of its adverse effects on the environment. The effects include but not limited to flooding, acid rain, rise in sea pH which claim aquatic lives, oil spillage and dessert encroachment among others.

It has been established in the literature that, burning pure petro-diesel contributes to the GHG emissions (Izah and Ohimain, 2012; Kannahi and Arulmozhi, 2013; EIA, 2013). Gas flaring is also one of the problems of petroleum exploration in Nigeria. The rate of flaring is high and as such, Nigeria was tagged the most enormous gas flaring country in Africa in particular, and the world at large (Kaisan *et al.,* 2010; EIA, 2013).

Fuel subsidies saga is also a great issue globally (EIA, 2013). In Nigeria for instance, on the 1st of January, 2012, the divergence over the removal of fuel subsidy has led to nationwide strikes (Onyishi *et al.,* 2012). It is an apparent bit of evidence that, the consequential strike has caused a brutal financial loss to Nigeria. Fuel subsidy in Nigeria is a policy of the federal government meant to assist the people of Nigeria to cushion the effects of their economic hardship. Subsidies were introduced in the Nigerian energy sector in the mid 1980's (Onyishi *et al.,* 2012). Something of a creeping phenomenon, the value of the subsidies has gone from 1 billion USD in the 1980s to an expected 6 billion Dollars in 2011 (Onyishi *et al.,* 2012). In this period, the specific products targeted for subsidy have changed. Diesel oil has had its associated subsidy removed while petrol and kerosene continue to enjoy a 54.4 % subsidy over the international spot market price at the Nigerian pump until the year 2016.

Ultimately, security risks are also associated with petroleum exploration in Nigeria (EIA, 2013). Sometimes the experts are being kidnapped, oil rigs and pipelines vandalised by militants, and tankers been attacked by armed robbers leading to serious energy crises.

Fourthly, there are problems associated with non simulation of biodiesel feedstock into diesel engines. There are only a few researches that consider the simulation of binary biodiesel blends only, but no attention was given to biodiesel from pure feedstock and multi-blends.

1.3 The Present Research

The present research focused on finding renewable and sustainable alternative fuels for use in the compression ignition engines from a range of biodiesel feedstocks. Thus, this thesis investigated the chemical composition of biodiesel samples, forms various binary and fractional blends between the biodiesels and diesel, and tested the physico-chemical properties, performance and exhaust emission characteristics of these blends in a stationary four-cylinder compression ignition engine.

Same engine was modelled and simulated using the GT-Power software and the primary data was used to validate the model. Secondary data was obtained for properties of so many other biodiesel feedstock; the mean of the data was computed, GT Power software was used to model some compression ignition engines, the primary and secondary data were used to feed the model. The engines performance and exhaust emissions were optimised using the GT simulations. The results were presented, analysed and discussed to make constructive inferences.

1.4 Aim and Objectives of the Research

The aim of this research is to model and simulate biodiesel blends performance in a compression ignition engine using GT Power software for environmental sanity and energy sustainability.

The specific objectives of this research are to:

i. produce biodiesel from Cotton, Jatropha, Neem oils and to analyse the composition using Gas Chromatography/Mass Spectroscopy (GC-MS) analyses;

ii. blend the biodiesels produced from Cotton, Jatropha and Neem seed oil with petro-diesel, thereby forming binary blends and multi-blends of each biodiesel with petroleum diesel in different percentages and to examine the physico-chemical properties like specific gravity, viscosity, flash point, calorific value, sulphur content,

cetane number, acid value, copper strip corrosion, iodine value, and colour for each of these blends;

iii. review the physico-chemical properties of different biodiesel feedstocks from literature and compute the mean of the physico-chemical properties of the biodiesels data sourced from the literature;

iv. investigate the performance of the biodiesel and the blends in a stationary four-cylinder Compression Ignition engine at full load with variable speedsand to investigate exhaust gas emissions during the combustion of these blends in the CI engine, and

v. develop compression ignition engine model with the test rig's specifications using GT Power software, use the primary data obtained to validate the modelled engine, and simulate the engines performances of the biodiesel multi-blends and biodiesels from the literature sources under full loading condition at variable speeds.

1.5 Justification

It is important for Nigeria to explore other potential economic means in order to improve her already pulverised economy (Izah and Ohimain, 2012) through renewable and alternative fuel sources; hence, the issue of biodiesel is of paramount significance in tackling this problem. Moreover, there is availability of biodiesel feedstock in Nigeria most of which are non-edible crops (Idusayi *et al.*, 2014). Since there are so many non-edible feedstock that decay naturally into the earth crust without been properly harnessed, it has only become necessary for those feedstock to be utilised in biodiesel production so that they could add value instead of them to be left as a constituent of environmental pollutions. Hence, there are economic benefits of converting from waste to wealth.

Global warming (Idusayi *et al.*, 2014) has claimed so many lives in Nigeria due to flooding, desertification, increased in ocean pH which claims aquatic lives, and acid rain

which was proved to be carcinogenic. One of the major causes of global warming is the burning of petro-diesel in power generation and hence we have to reduce these to its barest minimum. It was confirmed by prior researches that biodiesel blending has serious impact in reducing global warming; as such this research is vital and timely. Also, this is in line with the Kyoto protocol of 1997 which Nigeria is a signatory and which has the main mandate of reducing global emissions of flue gases from CI engines, gas flaring as well as coal fired power plants (Idusayi *et al.*, 2014.

Additionally, there is a potential market of biodiesel in Nigeria (Idusayi *et al.*, 2014). Production, procurement and blending of biodiesel for use in conventional CI engines in Nigeria will lead to increased job creation, reduction in rural-urban migration and increase in agricultural participation.

One of the most popular softwares used in internal combustion engines and engine components design, modelling, optimisation, simulation and analyses is GT-power which is an integral component of the GT-Suite developed by Gamma technology Inc. The software is deficient of biodiesel data in its library (Rahim *et al.*, 2012a), as such, there is need to simulate a CI engine with biodiesel data obtained from the literature in the GT-Power interface. Therefore, this research work is justifiable by all the aforementioned assertions.

This thesis has established how binary and multi-blends of biodiesel can be used effectively in CI engines to curtail the environmental menace caused by burning petroleum diesel in the engines. The thesis has suggested the tendency of controlling climate change by blending biodiesel with diesel, this leads to further reduction in the propensities of having acid rain, desert encroachment, and flood as well as the continuous lost in aquatic lives. It would also help in reducing the problems of over dependency on foreign nations, price hike of petroleum products, job creation, reduced rural-urban

migration and wipe out the pain of fuel subsidy saga. Hence, the findings will help in achieving environmental sanity, energy sustainability and renewable energy integration into the nations' economy.

1.6 Scope

The scope of this research includes the production of biodiesel samples from Cotton, Jatropha, Neem seed oil, carrying out gas chromatography-mass spectroscopy (GC-MS) analyses and moisture content test to determine the percentage of methyl esters present in the samples. In addition, to mix the biodiesel with diesel, forming various binary blends with the diesel as well as multi-blends.

In addition, there was experimental testing of the physico-chemical properties of the blends, and to determine the engine performance parameters as well as the exhaust emissions in a stationary four-cylinder diesel engine. In addition, secondary data was obtained for the Physico chemical properties of other biodiesels from the literature and the data was computed. The scope further includes the development of the test rig model in the GT Power software and using the primary data to validate the model. Besides, the secondary data was used to feed the model. GT Power was also used to simulate the modelled engine performances as carried out by Kofar bai and Zeng (2014).

CHAPTER TWO

LITERATURE REVIEW

2.1 Relevant Literatures

2.1.1 Diesel fuel

Diesel fuel is a petroleum-based fuel for compression ignition engines. It is a viscous oily fuel that is obtained from the fractional distillation of crude petroleum oil. Diesel fuel has an ignition temperature of about 540^0C and it is ignited by the heat of compression in compression ignition engines (EIA, 2013).

2.1.2 Nigerian diesel

Nigeria produces mainly sweet (Low sulphur) crude oil of which the cosmic mainstream is exported to the global market (EIA, 2013). Nigeria is the principal oil producer in Africa and was the world's 4^{th} foremost exporter of liquefied natural gas (LNG) in 2012. The International Monetary Fund (IMF) reckons that oil and natural gas proceeds accounted for 96 % of entire export returns in 2012. It was estimated that in 2011, total principal energy utilization was about 4.3 quadrillion British Thermal Unit (EIA, 2016). According to EIA (2016), the Organization of Petroleum Exporting Countries (OPEC) unforeseen crude oil supply interruptions is approximately 2.3 million barrel per day (b/d) in June, 2016. The supply decreased with 0.3 million barrel per day (b/d) less in May, 2016 as a result of lower production from Nigeria, Libya, and Iraq. While Nigeria's outcomes decreased in June 2016 (EIA, 2016). More decreases in Nigeria's interruptions occurred in July 2016, as Royal Dutch Shell lifted a force majeure on exports of Bonny Light in early July, 2016, subsequent to the reinstatement of production into Bonny Terminal (EIA, 2016).

Nevertheless, Forcados and Brass River, Niger-Delta, which together account for roughly 0.3 million b/d of the disrupted volume, remain under force majeure. While some

reinstatement of production is anticipated in the impending months, attacks on oil facilities remain, plus attacks aiming at wells, oil pipelines and three of Chevron's manifolds in early July, 2016, (EIA, 2016).

2.1.3 Biodiesel

Biodiesel is presently the most promising source of renewable fuel with high potentials to replace petroleum derived diesel fuel, owing to similarities in physico-chemical properties between the diesel fuels and the biodiesel (Ghorbani *et al.*, 2011). Bio-diesel can be defined as simple alkyl esters of fatty acids produced from vegetable oils and animal fats. Nigeria is blessed with many of such plants (Nafiu *et al,* 2011). According to Nigeria National Petroleum Corporation (NNPC) approved ethanol policy, bio-diesel shall represent fatty acid methyl ester or mono-alkyl esters originated from vegetable oil or animal fats for use in diesel engines, in line with quality specifications predetermined by the Standards Organization of Nigeria (SON), Department of Petroleum Resources (DPR) and any other dexterous governmental institute (Nigerian Bio-Fuel Policy and Incentives, 2011). One predilection is to develop biodiesel fuel and this has drawn more and more recognition (Haresh, 2008). In the United States, to a large degree, the impetus for the extension of biodiesel had come from soybean farmers who perceived it as a potential pioneering advert for soybean oil (EIA, 2013).

2.1.4 Advantages of biodiesel

Biodiesel fuels have so many advantages over petroleum diesel as readily established in the existing literature. The main advantages of biodiesel over regular diesel are: biodegradability, liquid nature, portability, low toxicity, availability, lower NOx except in leguminous feedstocks, emissions, environmentally friendly, better lubricating properties, higher flash point (safer to handle and store), can be used alone or blended with diesel, its blends extends the life span of CI engines, job creation, providing green

cover to waste land, reduce dependency on imported refine oil, lower aromatic content, reduced urban migration, energy security, rural market expansion, higher cetane number improves ignition quality, reduced crime activities associated with petroleum exploration, calorific value is 9 % lower than petrol diesel, gives more complete combustion, thus, increasing the engine energy output, has no sulphur content, less flammable than petrol-diesel and burn at 50 ^{0}C, loose viscosity- (gel) at lower temperatures (Biswan *et al.*, 2006; Akande and Olorunfemi, 2009; Belewu, 2011; Madarasz and Kumar, 2011; Izah and Ohimain, 2012; Simonyan and Fasina, 2013; Bugaje, 2014).

2.1.5 Disadvantages of biodiesel

The disadvantages of biodiesel include but not limited to: high production cost, reduced cold flow properties, detergent characteristics in fuel tank, higher viscosity, lower volatility and reactivity, higher flash point and fire point (producing carbon deposits), corrosive to rubber and liner materials, not storable in concrete lined tanks, the modification of fuel intake orifices to create higher cylinder pressure (Ghorbani *et al.*, *2*011; Izah and Ohimain, 2012; Idusayi *et al.*, *2*013).

The following challenges have been identified with biodiesel in the established literature: Competitions with food security and pharmaceutical demands on the feedstock, feedstock supply shortage, poor quality of the feedstock, processing challenges, technological challenges and poor policy framework (Izah and Ohimain, 2012).

2.1.6 Feedstocks used for biodiesel production

The potential economic and social benefits of modern biomass energy arise from the fact that, agriculture could face enormous demand for the feedstock. The feedstock will need to be produced, harvested, transported, converted into biodiesel, blended, stored and distributed for final utilisation (Akande and Olorunfemi, 2009). In India, only about 12

out of almost 100 varieties of feedstocks are tapped so far, with mahua, jatropha, neem and karanja on the lead (Madarasz and Kumar, 2011).

The following are some of the feedstocks used for biodiesel production according to Madarasz and Kumar (2011); Izah and Ohimain (2012); Kannahi and Arulmozhi (2013), majority of these seeds are found in Nigeria: Soybean oil, Palm oil, Castro oil, *Parkia biglobossa*, Jatropha curcas, Sunflower oil, Coconut oil, Rapeseed oil, Groundnut oil, Neem seed oil, Peanut oil, Cotton seed oil, Tobbaco, Dessert date, Caston hola, Rubber tree, Tung, Abyssinian mustard, False flax or gold of pleasure, Polanga, Cardoon, Sesame, Marula, Pumpkin, Jogoba, Gingelly oil.

The non-edible biodiesel feedstocks according to Madarasz and Kumar (2011); Kannahi and Arulmozhi (2013), are as follows: Almond oil, Karanja oil, Caster bean, Hemp, Pongame seed, *Jatropha curcas*, Ratanjyot, *Pongamia pinnata* or Karanja seed, *Callophylum inophyllum* or Nagchampa, *Hevea brasilinsis* or Rubber seeds, *Calotropis gigantia* or Ark, *Euphorbiatirucalli* or Sher, *Boswellia ovalifolotata*, Neem seed and *Madhuca indica*.

Other biodiesel feedstocks include Myco Biodiesel / Fungal Biodiesel Feedstock. Fungus- *Rhizopus oryzae* and *Aspergillus niger (*Kannahi and Arulmozhi, 2013); these organisms were recently discovered in Nothern Patogoria, India, and have the unique capability of converting cellulose into medium term hydrocarbons typically found in diesel. *Aspergillus niger* is also available in Nigeria (Adejuwon and Olorunfemi, 2010), hence Nigeria can also utilise this opportunity of harnessing Myco/Fungal biodiesel feedstock.

2.1.7 Biodiesel production and purification

Oil processing- The various existing methods of oil extraction and processing are as follows:

i. Extraction: This canbe done according to Breerens and Eijck (2009) in any of the following ways:

a- Mechanical extraction using engine driven oil expellers

b- Soxhlet-chemical extraction method

ii. Purification of the oil for biodiesel production: The various methods of purification of oil are given by Biswas *et al. (*2006) as follows:

a- Sedimentation

b- Boiling with water

c- Filtration

iii. Processing: This can be done in accordance with Biswas *et al. (*2006) through any of the following methods:

a- Pyrolysis: Pyrolysis refers to a chemical change caused by application of thermal energy in the absence of fresh air or nitrogen

b- Micro-emulsion: micro emulsion method is one of the versatile preparation technique which enables control of particle properties such as size, geometry, morphology, homogeneity and surface area (Hu *et al.,* 2008). Micro-emulsion is a crystal clear or virtually transparent, quasi-homogeneous, thermodynamically steady blend of two immiscible liquids stabilised by surfactant (or mixture of surfactants). Frequently average chain alcohols are used as co-surfactants.

c- Trans-esterification: This is the process of using alcohol (Methanol, ethanol or propanol) in the presence of catalyst such as Sodiumhydroxide or Potassiumhydroxide (NaOH or KOH) to break the molecule of the raw renewable oil chemically into methyl ester or ethyl ester of the raw renewable oil with glycerol as a bye product.

2.1.8 Biodiesel blending

Blending simply means mixing of biodiesel with petroleum diesel, for example, 5 % of biodiesel can be blended with 95 % diesel and the mixture is named B5. Similarly, B10 refers to a mixture of 10 % biodiesel with 90 % diesel. There are higher ratios like B15, B20, B30, B50 etc. B100 refers to a pure biodiesel. Nigeria is committed to blending biodiesel up to 20 % by volume (Izah and Ohimain, 2012).

According to Stark *et al. (*2010), blending biodiesel with hydrocarbon blend stock can be done in any of the following ways:

a- In line blending - Here two tanks are involved, one containing biodiesel and the other containing refined petro-diesel both passing through a pipe and hose, mixed in a particular ratio and collected in another third tank. A temperature above 6^0C above cloud point is required to avoid the risk of shock crystallisation (Stark *et al.,* 2010).

b- Splash Blending - This is done by pumping biodiesel at a temperature of 18^0C - 20^0C into tank already containing diesel at about 8^0C. This method is associated with quality rejection risk and as such is rarely practiced (Stark *et al.,* 2010).

c- Injection Mixing - This is the blending of fuels in tanks at the manufacturing points before delivery to the tanker trucks. Valve controls are used to ensure that a particular quantity of biodiesel components is injected alongside the petro-diesel (Stark *et al.,* 2010).

2.1.9 Physico-chemical properties of biodiesel

The Physico-chemical properties of fuel are the fuels specifications that define and set the quality standards. For biodiesel, Physico-chemical properties are a set of property specifications measured by specific American Society for Testing and Material (ASTM) test methods such as ASTM 6751 – 02. These specifications must be met for a fatty acid

ester product to carry the designation “biodiesel fuel” or “B100” or for use in blends with any petroleum-derived diesel fuel (Garpen *et al.*, 2004). Therefore, these properties are termed physico-chemical properties which include but not limited to: specific gravity, viscosity, flash point, calorific value, cetane number, acid value, volatility, and saponification value.

2.1.10 Use of biodiesel in compression ignition engines

Biodiesel has attracted considerable interest as an alternative fuel for combustion in CI engines (Izah and Ohimain, 2012). According to the inventor of diesel engines *Rudolph Diesel (*1912) “The use of *Vegetable Oils* for *Engine Fuels* may seem insignificant today, but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time”, (Akindale, 2011).

2.2 Theoretical Background

2.2.1 Engine performance parameters

Engine performance parameters are exceptionally critical in design and development of an IC engine. Engine performance is a gesticulation of the level of accomplishment of the engine to execute its assigned job, the conversion of the chemical energy contained in the fuel into the valuable mechanical work. The engine performance conditions include: brake power, torque, brake mean effective pressure, specific fuel consumption, brake thermal efficiency, etc.

i. Brake Power: This is the functional power output of an engine; it does not consist of the power required to fuel, lubricate, or warm up the engine, circulate coolant to the engine, or drive after-treatment devices. It is the power developed by the engine at the output shaft. The brake power is given by the equation 2.1 (Stevenson et al., 2005).

$$BP = {}^{2\pi NT}/_{60000} \qquad (2.1)$$

Where:

BP = *Brake Power (kW)*

$N = Angular\ Speed\ (rpm)$

$T = Torque\ in\ (Nm)\ developed\ by\ the\ shaft$

ii. Engine Torque: Energy is the engine's capability to do work, while power is the rate of this work done. The power, *P*, conveyed by an engine and absorbed by a dynamometer is the product of the torque and angular speed (Kaisan and Pam, 2013).

The force ***F*** applied at a distance ***b*** from the centre of the rotor, the torque applied by the engine on the dynamometer is ***T***:

$$T = Fb \qquad (2.2)$$

Where:

$F = the\ applied\ force$

$b = perpendicular\ distance\ from\ the\ point\ of action\ of\ the\ force$

iii. Brake Mean Effective Pressure: Mean Effective Pressure (P_m): is that theoretical steady pressure which is supposed to be acting on the piston throughout its expansion stroke generating the same work output as that from the actual cycle. The Brake Mean Effective Pressure (BMEP) of an engine is the average (mean) pressure which, if imposed on the pistons equally from the top to the bottom of each power stroke, would produce the measured (brake) power output for four stroke engine given by Erol (2005); Kaisan and Pam (2013):

$$P_{im} = \frac{2\ BP}{LANK} \qquad (2.3)$$

Where:

$P_{im} = Brake\ mean\ effective\ pressure$ (N/m^2)

$L = Length\ of\ the\ stroke\ (m)$;

$A = Area\ of\ the\ piston\ (m^2)$;

$N = Speed\ in\ rpm;\ and$

$K = Number\ of\ cylinders$

iv. Fuel Consumption, which is in two stages:

a- Consumption Rate (Mass Flow Rate of Fuel into the Engine, $\dot{m}_f$)

The consumption rate of the fuel is the product of volume flow rate of the fuel and the density of the fuel. Mathematically,

$$\dot{m}_f = \frac{v}{t}.\rho_f \quad (2.4)$$

Where:

$v = volume\ of\ fuel\ consume;$

$t = time\ taken\ to\ consume\ the\ fuel,$

$\rho_f = densityoffuelused$

Similarly,

$$\rho_f = specific\ gravity\ of\ Fuel\ X\ densityofwater \quad (2.5)$$

The density of water is taken as 1000kg/m^3

b- Specific fuel consumption: This is defined as the ratio of mass flow rate of fuel into the engine to engine brake power. Mathematically;

$$SFC = {\dot{m}_f}/{BP} \quad (2.6)$$

$Where$:

$\dot{m}_f$ = rate of fuel flow into the engine

BP = Brake Power (kW)

v. Brake Thermal Efficiency: Brake thermal efficiency is the ratio of brake power to the fuel energy input. It is noticed that the use of oxygen-rich biodiesel fuels promotes a better mixture formation and combustion, thus, improving the thermal efficiency (Perihan and Zeki, 2011; Kaisan and Pam, 2013). The improvement in brake thermal efficiency are related to the enhanced oxygen content, which improves combustion especially during the phase of diffusion combustion, and to the higher lubricity of biodiesel, which reduces the friction loss (Perihan and Zeki, 2011).

vi. Brake thermal efficiency is given by Erol (2005); Kaisan and Pam (2013):

$$\eta_{bth} = \frac{BP}{\dot{m}_f . Q_{LHV}} \tag{2.7}$$

$Where$:

$\eta_{bth} = Brake\ thermal\ efficiency$;

$BP = Brake\ power$

$\dot{m}_f = rate\ of\ fuel\ flow\ into\ the\ engine$

$Q_{LHV} = lower\ heating\ value\ of\ fuel$

2.2.2 Modelling

A model is a structure that has been purposely built to exhibit features and characteristics of some other objects only. Some of these features and characteristics are generally retained in the model (Williams, 2008). Models are central to scientific thinking and essential to many kinds of practical problem solving (Bello, 2014). A model can be any of the two:

- Concrete model: For example, a model aircraft used for wind tunnel experiment
- Abstract model: Mathematical models used in operations research.

The types of models include mathematical programming models; simulation models; network planning models; economic models; time series models etc.

Mathematical programming models are programming in the sense of planning and they all involve optimisation and are different from computer programming. Optimisation means to maximise or minimise a quantity (Objective function). According to Williams (2008), the principles of building mathematical programming models are divided into the following approaches:

a- Linear Programming models (LP): In this model, whatever decision variables appear in the objective function and in the constraints of an optimisation model,

the decision variables are always multiplied by constants and added together (Williams, 2008).

b- Integer Programming models (IP): If one of the decision variables must be an integer, then the optimisation model is an integer model. On the contrary, if all the decision variables are free to assume fractional values, then the optimisation model is a non-integer model (Williams, 2008).

c- Deterministic Programming models (DEP): Supposed that for any value of the decision variables, the value of the objective function and whether or not the constraint are satisfied is known with certainty, then the optimisation model is deterministic (Williams, 2008).

d- Stochastic Programming models (STP): Supposed that for any value of the decision variables, the value of objective function and whether or not the constraint are satisfied is NOT known (Not certain), then the optimisation model is stochastic (Williams, 2008).

e- Static Programming Models (STP): This is a model in which the decision variables do not involve sequence of decisions over a multiple period (Williams, 2008).

f- Dynamic Programming Model (DYP): This is a model in which the decision variables involve a string of decision over multiple periods (Williams, 2008).

g- There are many other Programming models (Williams, 2008).

2.2.3 Simulation

Simulation is the imitation of the operation of a real-world process or system over time (Banks *et al., 2*001). The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviours/functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Often, computer experiments are used to study simulation models. Simulation is also used with scientific modelling of natural systems or human systems to gain insight into their functioning. Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist (Sokolowski and Banks, 2009).

2.2.4 GT Power

This is the industry standard engine simulation tool used by all leading engine makers and vehicle manufacturers and their suppliers. It is also used in ship and power generating engines, small 2 and 4 stroke engines and racing engines (GTI Soft, 2014). GT Power has the following features:

a- Models boosting systems, exhaust gas reticulation (EGR) concepts, variable valve timing (VVT), variable geometry systems, and after treatment systems;

b- Includes built –in 3D computer aided design (CAD), diffractive optical element (DOE), optimization and neural network training tools and

c- Coupled to MATLAB and Simulink technical computing software for control systems analysis.

The GT-Suite simulation consists of a set of simulation modelling libraries- tools for analyzing engine breathing, combustion and acoustics, vehicle power trains, engine cooling systems, engine fuel injection systems, valve trains, crankshafts, and lubrication systems (GTI Soft, 2014).

The code can be used to investigate a wide range of issues such as component designs, vehicle emissions and system interaction. Each of the GT-SUITE application areas can be linked with simulink to provide a flexible environment for investigating and developing control strategies. Engine and vehicle quantities such as pressure, flow rate and speed can be sensed from the GT-SUITE model and passed to simulink. The simulink model can then use these values in its own calculations. GT-SUITE can also receive actuated quantities, such as throttle angle, orifice diameter accelerator position, from Simulink and use these values in its calculations. The simulink model can consist of control systems or any physical system that interacts with the GT-SUITE model. GT-SUITE and Simulink together represent entire engine or vehicle and control system package.

The following are some of the applications of GT Power (GTI Soft, 2014):

1. Torque curve and fuel consumption
2. Manifold design and tuning
3. Transient performance and response
4. Valve profile and timing optimisation
5. Combustion and emissions
6. Turbocharger response and matching
7. EGR system design

8. Acoustic analysis (intake/ exhaust noise)
9. Full vehicle performance
10. Thermal analysis of cylinder components
11. Exhaust system warm-up
12. Control system analysis
13. Real-time engine modelling
14. Design analysis with dynamic optimization of exhaust (DOE)
15. Coupled (1 dimentional or 3 dimentional (1D/3D) simulations

2.3 Review of Related Past Works

2.3.1. Biodiesel properties, engine performance and emissions

There are substantive works on trans-esterification of biodiesel from various feedstocks Chhetri*et al.* (2008); Caprita and Caprita, (2005) investigated the use of waste cooking oil as an alternative feedstock for biodiesel production.

Izah and Ohimian (2012) investigated the challenges of biodiesel production from oil palm feedstock in Nigeria. Mansourpoor and Shariati (2012) worked on optimisation of biodiesel production from sunflower oil using response surface methodology. Moser (2009) reviewed biodiesel production properties and feedstocks.

Topare *et al. (*2011) produced biodiesel from micro algae. Chalatlon *et al. (*2011) produced biodiesel from Jatropha oil and investigated its use in direct injection diesel engines (Kaisan *et al.*, 2015).

Other methods of biodiesel production for instance, using superficial methanol technology was recorded by Saka *et al.* (2006). In this work, biodiesel production was done using the alkali trans-esterification method.

Significant efforts were made in the engine performance, emissions and combustion characteristics of different biodiesel fuels blended with diesel fuels. Ong *et al.* (2014a)

investigated the engine performance and emissions of Jatropha, Ceiba pentandra, and Callophyllum innophylum in a stationary diesel engine and established that, the biodiesel blends show significant reduction in the emissions of carbonmonoxide and carbondioxide (CO and CO_2), although with little increase in nitrogen oxides (NOx) emissions. The best performance in terms of engine parameter like torque, specific fuel consumption and brake thermal efficiency as reported by the findings of Ong *et al. (*2014b) was observed during the combustion of 10 % biodiesel blends.

Similarly, another research established that, 5 % and 10 % biodiesel blends produced lower exhaust emissions in compression ignition engines with a record of low specific fuel consumption shown by the 5 % blend with diesel. This was obtained during the comparative evaluation of performance and emissions characteristics of moving Oleifera and Palm based biodiesel in CI engines carried out by Mofijur *et al.* (2014).

In another development, Amin *et al.* (2016) showed that 20 % blend of castor biodiesel can be used in CI engine without modification. Makareviciene *et al.* (2015) found out that rapeseed methyl ester can be successfully replaced with rapeseed butyl ester. Further studies have compared the fuel properties of Jatropha, Sterculier foetida and *Ceiba pentandra* as potential biodiesel feedstock (Ong *et al.*, 2013).

It was established that, the feedstocks are suitable non-edible biodiesel materials and conformed with ASTM 6751 and EN 14214 standards. Kasiraman *et al. (*2016) blended cashew nut shell oil with oxygenates (diethyl ether and dimethyl carbonate), alcohol (Methanol, ethanol and butanol) and vegetable oils (Camphor oil, orange peel oil, cotton oil and palm oil) and experimented their performances in CI engines. It was established that, amongst the oxygenate blends, diethyl ether gave the best brake thermal efficiency, 30 % camphor blend was the best amongst vegetable oils so also 30 % butanol amongst alcohols.

Furthermore, Lei *et al.* (2016) investigated the performance and emissions characteristics of a diesel engine running on optimised ethyl levulinate-biodiesel-diesel blends, it was observed that, HC, CO and smoke emissions decreased while NOx and engine parameters like brake specific fuel consumption and brake specific energy consumption increased with the blends.

Similarly, Monirul *et al.* (2016) investigated the performance and emissions characteristics of a diesel engine running on the blends of Palm, Jatropha, and *Callophyllum innophyllum* with diesel. The study revealed that, 20 % Palm gave lower emissions and higher engine performance than diesel, 10 % Jatropha blend produced lower smoke and 20 % Jatropha blend produced lower CO and HC emissions than pure diesel.

Woo *et al.* (2015) investigated the dependency of the engine combustion on blending ratio variation of lipase-catalysed Coconut oil biodiesel with diesel. The authors established that, over 70 % smoke and NOx reduction was achieved although with slight increase in brake specific fuel consumption of the engine. Roy *et al.* (2014) established that, 5 % biodiesel blend with additive outperformed diesel in hydrocarbon (HC) emissions and cold flow properties during the investigation of performance and emissions of a diesel engine fuelled by biodiesel-diesel, biodiesel-diesel-additive and kerosene-biodiesel blends. The authors also established that NOx was reduced by kerosene blends.

Finally, Palash *et al.* (2014) worked on Impacts of NOx in reducing antioxidant additive on performance and emissions of multi-cylinder diesel engine fuelled with Jatropha biodiesel blends. The authors found that, the antioxidant additive reduced NOx, CO and HC emissions but slightly reduced engine performance.

Research Gap1: However, to the best of our knowledge, despite all the optimistic results above-mentioned, the fuel properties, engine performance and emissions characteristics of multi-blends of biodiesel from various feedstocks with diesel have not been investigated. In particular, the performance of biodiesel blends made up of different percentages of biodiesel from Cotton, Jatropha and Neem with diesel or any other similar combination has rarely been investigated and therefore, forms a research gap in this field of studies. In this thesis however, the physico-chemical properties of biodiesel from Jatropha, Neem and Cotton oil together with their binary and multi-blends with diesel were examined. Although the research trend has been mostly on the properties of biodiesel alone, this thesis went further to investigate properties of different mixtures of biodiesels with diesel. Furtherance to that, in this thesis, the engine performance and emission of binary and multi-blends of biodiesel from cotton, Neem and Jatropha with diesel were investigated in a 4-cylinder CI engine.

2.3.2. Direct injection CI engines modelling and simulations using GT-Suite

Kolade *et al.* (2014) studied the coupled 1D/3D analyses of fuel injection of diesel engine combustion. It was established that, the injection largely controls the combustion process, and there are a wide range of related issues, such as fuel efficiency, emissions, startability, load acceptance (acceleration) and combustion noise.

Bhave *et al. (*2004) worked on modelling a dual fuelled multi-cylinder hot charged compression ignition (HCCI) engine using a probability density function (PDF) based engine cycle simulator. The effect of octane number and combustion emissions and engine performance in a 6-cylinder truck engine fuelled with n-heptane, iso-heptane and iso-octane and running in homogenous charged compression ignition engine were investigated. The authors observed a good agreement between the predicted values and measurement for in cylinder pressure, auto-ignition and carbonmonoxide (CO),

hydrocarbon (HC) as well as nitrogen oxides (NOx) emissions. The integrated model provides reliable predictions for in-cylinder temperature, CO, HC, as well as NOx emissions over a wide range of octane numbers studied.

Rahim *et al. (*2012a) studied the influence of fuel temperature on a diesel engine performance operating with biodiesel blended. They have measured typical physical properties of the fuel before it could be installed into GT Power data base. The diesel engine was simulated to study engine performance characteristics operating with 5 % biodiesel blend as an alternative fuel. It was established that the standard fuel data base of GT Power does not contain any biodiesel property.

Rahim *et al. (*2012b) made a comparative study of biofuel and biodiesel blends with mineral diesel using one dimensional simulation. The testing of biofuels properties conducted according to ASTM standards. The fuels used are straight vegetable oil (SVO), biodiesel 20 % blend and biodiesel 5 % blend (B20 and B5) respectively. The properties data were used in the simulation of GT Power software to obtain comparative measures of engine parameters. There was no significant difference in the engine performance when fuelled with B5 and Pure diesel.

Kakee and Pishgoogie (2011) determined the optimal valve timing for internal combustion engines using parameter simulation methods. A four-stroke spark ignition engine including its different systems was modelled using GT Power software and the model is coupled to the MATLAB/Simulink to control input and output parameters. The optimised model was used for sensitivity analysis and minimising the engine specific fuel consumption. It was established that, there was enhancement in engine performance, the torque diagram in the variable valve timing (VVT) become smoother and the torque increased with speeds at low engine speeds.

Kyrtatos *et al. (*2010) worked on the predictive simulation and experimental validation of phenomenological combustion and pollutant models for medium speed common rail diesel engines at varying inlet conditions. The paper portrayed the ability of the model to predict diesel combustion and emission during the significantly varying inlet charge and injection conditions in common rail medium speed diesel engines.

Hossenzadeh *et al. (*2012) conducted an experimental and numerical study of impact of air filter holes masking on altitude at heavy duty diesel engine (HDDE). Pressure drops against 0 %, 26 %, 52 %, 66 % and 74 % of air filter holes masking for different mass flow rates have been studied by computational fluid dynamics. The analyses output mass flow rate pressure diagram for the air filter was used as input in the GT Power software and the effects of masking on altitude and performance at different revolutions per minute of the engine was investigated.

Sinnamon (2007) worked on co-simulation analyses of transient response and control for engine with variable valve trains. The research described a system model using GT Power to model the engine, AMESim model to model cam phases and the engine lubrication system, and MATLAB/Simulink to model engine controllers and the vehicle. It was instituted that simple, conservative phase control strategy such as position command using steady-state-based tables and phrase-rate-limiting cannot present satisfactorily precise delusion control.

Mohiuddin *et al. (*2007) studied optimal design of automobile exhaust system using GT Power. Exhaust (Manifold) system was designed using GT Power software and its performance was compared with an existing system. It was established that, the newly designed exhaust manifold showed lower back pressure which ultimately resulted in better performance of the engine.

Liu *et al. (*2010) worked on combustion emissions modelling and testing of conventional diesel fuel. GT Power was used to perform engine combustion simulations. The simulation approach was a predictive combustion simulation, direct injection jet modelling which was primarily used to predict the burn rate and the NO_x emissions. It was established that the B100 biodiesel fuel reduced NOx emissions by 10 %.

Research Gap 2: Despite the beautiful findings by the above mentioned scholars on engine simulations, research on the simulation of multi-blends of biodiesel in CI engines has left a vacuum in this broad area, hence, one unique feature addressed by this thesis is the simulation of biodiesel multi-blends into compression ignition engines.

Research Gap 3: Furthermore, the literature review has identified a gap in the area of simulation of biodiesel from different feedstocks in CI engines. Therefore, this thesis has investigated the performance of biodiesel from various feedstocks in a 4-cylinder diesel engine modelled in GT Suite.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials and Equipment

3.1.1 Raw materials

The raw materials used for the purpose of this research are as follows:

1- Diesel fuel sourced from NNPC Mega Station, Katampe, Abuja

2- Reagents: Methanol, Sodium hydroxide, sulphuric acid, phenolphthalein, distilled water

a. Vegetable oil samples comprising 5 litres each of Cotton seed oil and Jatropha seeds oil, they were sourced (From an extect made in the Lab) from Chemical Engineering Department, Ahmadu Bello University, Zaria, 5 litres of Neem seeds oil was sourced from Golden Star Mills, Kano, Nigeria.

3.1.2 Equipment

The following sets of equipment were used during the blending and experimentations/ testing of properties:

i- Measuring cylinder, 1litre maximum calibration produced by Goel Scientific Glass Works

ii- Beakers: 1litre, 3litre and 5litre produced by Goel Scientific Glass Works

iii- 50 ml burette, produced by Heta Glass Industries

iv- Retort Stand Produced by Garg Process Glass India Private Limited

v- 250 ml conical flask, produced by Heta Glass Industries

vi- Stirrer

vii- Stopped clock from i-phone 4 phone, Produced by Apple Inc.

viii- 160 L Hair Thermocool double door Refrigerator

ix- 9 ml, 15 ml and 20 ml test tubes and cork produced by Katyal Scientific Glass Works, Ambala Cantt, India

x- 0 to 110 ^{0}C thermometer, manufactured by Walnut. 110Ln. North Augusta, SC 29860

xi- Gas chromatography mass spectroscopy (GC-MS) machine, GCMS-QP2010 PLUS, Shimadzu, Japan, available in National Research Institute of Chemical Technology (NARICT), Zaria, Nigeria

xii- Viscometer: Product-Koehler; Number 4 Viscometers; Size 150 (Equal Size); S/numbers: 1st-1372; 2nd-1379; 3rd-1187 and 4th-1189, available in Fuel Testing Laboratory, Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xiii- Bomb calorimeter, available in Fuel Testing Laboratory, Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xiv- Monochromatic Wavelength-Dispersive X-ray Fluorescence (MWDXRF) Spectrometry, available in Fuel Testing Laboratory, Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xv- Fisher Brand Hydrometer (Size 0.795-0.910; Accuracy- 0.001), available in Kaduna Refining and Petrochemical Company, Fuel Testing Laboratory, KRPC, NNPC, Kaduna, Nigeria

xvi- Portable Cetane/Octane metre, available at the Fuel Testing Laboratory., in Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xvii- Pensky Martens Closed Cup, Stanhope-Seta Product, available at the Fuel Testing Laboratory., in Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xviii- Copper Strip Corrosion Tester, available at the Fuel Testing Laboratory., in Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xix- Colour Tester: ASTM D1500-1P 196 Colour Tester, available at the Fuel Testing Laboratory., in Kaduna Refining and Petrochemical Company, KRPC, NNPC, Kaduna, Nigeria

xx- A PC system installed with GT-Suit package version 7.4,

xxi- The engine test bed used is a P8616 1600 CC 4-cylinder water cooled compression ignition engine manufactured by Cussons Technology, Manchester, and Year 2011 model. The Engine specifications are presented in Table 3.1. Available in the Department of Mechanical Engineering, Bayero University, Kano, Nigeria.

Table 3.1: Specifications of the Engine Fleet, Manufactured by Cussons Technology, Manchester, UK, 2010

Engine Type	**4 cylinder in-line DOHC Duel Mass Flywheel**
Number of Valves	16
Block	Aluminium
Head	Aluminium
Horse Power	81 kW(11OPS) at 4000 rpm
Torque	240-260 NM at 1750 rpm with transient over boost
Displacement	1560 CC
Bore	75mm
Stroke	88.3mm
Compression Ratio	18:1
Alignment	Transverse
Weight	107 kg
Dimensions HXLXW	600X500X580mm

Source: Cusson's Manual (2010)

xxii- The IMR 1400 combustion gas analyser, 2014 model, manufactured by Environmental Equipment Incorporation, Central Avenue, St. Petersburg, Florida, USA available in the Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria.

xxiii- Separating Funnel

xxiv- Vacuum Filtration Funnel

xxv- Heating mantle

3.2 Methodology

3.2.1 Sample preparation

The samples preparation was carried out in the Petro-Chemical section of NARICT, Zaria, the stages of the preparations involved are explained in the following sections:

3.2.1.1 Biodiesel production

The oil samples from cotton seed, Neem seed and Jatropha seed were procured; biodiesel were produced from each sample through alkali transesterification reaction. A given mass (0.40g) of sodium hydroxide (NaOH) was added to 40cm^3 of methanol and stirred until it was completely dissolved. 100 g of cotton seed oil was placed in a flask and the methanolic sodium hydroxide solution was added to it. The mixture was stirred for 20 minutes and then poured into a separating funnel (Kaisan *et al.*, 2013). After about an hour, when no separation occurred in the products, the mixture was left to stand in the separating funnel for 24 hours, three layers were formed: water, glycerol and biodiesel. The water was at the bottom, the middle layer is glycerol and the top layer was the biodiesel. The glycerol and water were collected leaving the biodiesel behind.

The methyl ester was heated on the heating mantle at low temperature and then washed by adding silica gel, stirring the mixture for 20 minutes and then filtered. Sodium sulphate crystals were added to a vacuum filtration funnel and the methyl ester was filtered to remove any trace of water. The dried methyl ester was then bottled and kept for further analysis as recommended by Kaisan *et al. (*2013). This procedure was repeated several times in order to produce up to 3 litres of biodiesel. A similar procedure was followed for Jatropha and Neem seeds oils.

3.2.1.2 Blending

The blending was done for each biodiesel type with the petroleum diesel alone, and that of a mixed biodiesel samples (Fractional Blends or Multi Blends) with pure petroleum

diesel. Each biodiesel sample was blended with fossil diesel in a ratio of 5:95, 10:90, 15:85, 20:80, 25:75, 30:70 by volume and a pure sample of each biodiesel as well as a pure diesel sample was kept for control purpose. The blends were denoted as B5, B10, B15, B20, B25, B30 and B100 for the biodiesel blends and B0 for the pure petroleum diesel respectively (Kaisan *et al.*, 2013).

Furthermore, a mixed samples of all biodiesel with the fossil diesel was made to form fractional/multi blends with B(2:2:2), B(3:3:3), B(4:4:4) B(5:5:5) and B(10:10:10) meaning 2 % of each of the 3 samples in 94 % diesel, 3 % of each of the 3 samples in 91 % diesel, 4 % of each of the 3 samples in 88 % diesel, 5 % of each of the 3 samples in 85 % diesel and10 % of each of the 3 samples in 70 % diesel mixed together respectively.

Finally, the samples of the pure petro diesel, 100 % biodiesels from Cotton, Jatropha and Neem seed were kept as control samples labelled as B0, B100c, B100j and B100n respectively. The binary blends of Cotton Seed alone with diesel were labelled B5c, B10c, B15c, B20c, B25c and B30c. The binary blends of Jatropha alone were labelled B5j, B10j, B15j, B20j, B25j and B30j. The binary blends of Neem seed and petro-diesel alone was labelled B5n, B10n, B15n, B20n, B25n and B30n correspondingly. Ultimately, the multi-blends of Cotton, Jatropha and Neem seed biodiesel with petro-diesel was labelled B2:2:2, B3:3:3, B4:4:4, B5:5:5 and B10:10:10 in that order. The samples were kept for further analyses.

3.2.2 GC-MS Analyses

The Gas Chromatography-Mass Spectroscopy (GC-MS) was carried out to determine the percentage of methyl ester (Biodiesel) present in B100C, B100J and B100N. The fatty acid methyl esters (FAMEs) entrails of Jatropha, Neem and Cotton biodiesels were instituted using gas chromatography and mass spectroscopy. Separation was achieved via capillary column DB-5MS (30 m×0.32 mm, 0.25 μm of film skinniness). The haulier gas

was helium with flow rate of 1.5 ml/min. The column temperature was programmed from 120 to 300 °C at the rate of 10 °C/min as established by Tariq *et al. (*2011). The temperature of both injector and detector was set at 200 °C. A sample volume of 0.1 µL of each methyl ester was injected using a rip mode, with the split ratio of 1:10. The mass spectrometer was set to scan in the range of m/z 50–550 with electron impact (EI) mode of ionisation (Tariq *et al.*, 2011). GC-MS analysis was used to study the chemical composition of the synthesised biodiesel. The major peaks were observed in the total ion chromatogram. Each peak corresponds to a fatty acid methyl ester content of each of the biodiesels and was identified from the library match software (NO. NIST, 02). The identified FAMEs were verified by running the standards under identical experimental conditions and comparing the respective retention time data which were confirmed by mass spectrometric analysis and the results were kept for further analyses (Tariq et al., 2011). The conditions adopted for the analyses are Column Oven Temperature, Injection Temperature and Injection Pressure were 200 ^{0}C, 60 ^{0}C and 112.8kPa respectively.

3.2.3 Determination of physico-chemical properties

The physico-chemical properties of the biodiesels were determined. These include parameters such as specific gravity, flash point, calorific value, cetane number, copper strip corrosion, viscosity, total sulphur, aniline value, cloud point, pour point and acid value for all the samples.

3.2.3.1 Measurement of the specific gravity

The specific gravity of the samples was measured at room temperature using a Fisher brand hydrometer (size 0.795-0.910, accuracy 0.001) as shown in Plate 3.1. The measurement was performed according to the method adopted from Coronado *et al*. (2009).



Plate 3.1: Fisher Brand Hydrometer

3.2.3.2 Measurement of viscosity

The viscosity of oils as well as derived bio diesel were measured with the viscometer as shown in Plate 3.2 at 313K. According to Adebayo *et al*. (2011) the viscosity at 40^0C (313K) is measured following the ASTM D445 method using a calibrated viscometer with a calibration constant of 0.1057. In this research, determination of viscosity was done following the Institute of Petroleum (IP) method. This involves measuring the time of flow of the sample between two marked points on the Ostwald viscometer. (Nafi'u *et al*, 2012).

$$\eta_{sp} = \frac{t - t_0}{t_0} \tag{3.1}$$

Where:

$\eta_{sp} = Specific\ Viscosity$

$t_0 = efflux\ time\ of\ solvent$

$t = efflux\ time\ of\ solution$



Plate 3.2: Viscosity Bath

3.2.3.3 Flash point

The flash point of the biodiesel/diesel blends was determined by the method of ASTM D93 using the Pensky-Martens closed cup tester. The determination of the flash point of biodiesel was done in the temperature range of 60 to 190 °C by an automated Pensky-Martens closed cup apparatus according to the standard method of testing flash point. The flash point determination was carried out by heating a sample of the fuel in a stirred container and passing a flame over the surface of the liquid. If the temperature is at or above the flash point the vapour will ignite and an easily detectable flash can be observed. The fire point will produce sufficient vapour to maintain a continuous flame (Nafiu *et al,* 2012).

3.2.3.4 Cetane number

The cetane number was determined using a ortable Cetane/Octane metre. The cetane index of the biodiesel-diesel blend was determined by ASTM D.976 method as done by Kywe and Oo (2009).

3.2.3.5 Cloud point

The cloud point was determined by visually inspecting for a haze to become visible as the fuel is cooled in a cloud points and pour points tester as shown in plate 3.3. This is so far the generally acceptable method of testing cloud point as reported by Kywe and Oo (2009).

3.2.3.6 Pour point

The pour point was determined by ASTM D.97 method (Kywe and Oo 2009). 3.00 g of the sample (oil or biodiesel) was placed into a test tube in which a thermometer was inserted through a cork which was used to cover the mouth of the test tube. The test tube was then placed in a Cloud and Pour Point Tester shown in Plate 3.3 and observed at 10 minutes' interval for a period of two hours. The test tube was removed and tilted to ascertain if the oil will flow or move, until it showed no movement when the test tube is held horizontally for seconds; it is solidified. The pour point was then taken at the temperature 5 ^{0}C above the solid point.



Plate 3.3: Cloud Points and Pour points Tester

3.2.3.7 Calorific value

The calorific value of the biodiesel/diesel samples were measured using a bomb calorimeter. A known amount of fuel was placed in the crucible. The crucible was then placed over a ring and a fine Magnesium wire touching the fuel sample was stretched across the electrodes. The lid was tightly screwed and the bomb was filled with oxygen up to 25 atmosphere pressure. The initial temperature was recorded. The electrodes were then connected to a 6 volts battery and the circuit was switched on. The fuel in the crucible burn with the evolution of heat. Heat liberated by burning of the fuel increase the temperature of water and the maximum temperature attained was recorded. The concept of change in temperature and specific heat were then used to compute the calorific values.

3.2.3.8 Total sulphur content

The total sulphur content was determined using X-ray analyses of the fuel samples as indicated in Plate 3.4. This test method covers the determination of total sulphur by monochromatic, wavelength-dispersive X-ray fluorescence (MWDXRF) spectrometry in single-phase biodiesel, diesel fuels. The precision of this test method was determined by an inter laboratory study using representative samples of the fuels (Kaisan *et al,* 2013).



Plate 3.4: X-ray fluorescence (MWDXRF) spectrometer

3.2.3.9 Copper strip corrosion

ASTM D130 is used to measure the level of copper corrosion that would occur if biodiesel were used in any application where metals such as copper are present as reported by Fernando *et al. (*2007). This test monitors the presence of acids in the fuel. The test was accomplished by using a copper strip tarnish test. A three (3) inch copper strip was prepared by cleaning and polishing all sides so that no discolouration or blemishes were visible. The strip was then placed in the test samples and held for 3 hours at 100 °C as the typical starting point. A polished copper strip was immersed in a sample of biodiesel and heated for a specified length of time at a specified temperature. The copper strip was removed, washed, and was then compared to the ASTM certified Corrosion Standard. The maximum corrosion allowed was that corresponding to a No. 3 Copper Strip Corrosion Standard. The data associated with corrosion of the biodiesel samples are reported.

At the end of the exposure period, the strip was removed, wiped cleaned and matched with coloured reproduction strips characteristic of the descriptions.

3.2.3 Engine test procedure

The engine test was performed to measure some parameters using compression ignition engine. The parameters include specific fuel consumption, brake power, brake mean effective pressure and brake thermal efficiency. This study was conducted to investigate the performance and emission characteristics of a stationary four (4) cylinder diesel engine run on different bio-diesel/ petro diesel blends and also on diesel fuel alone. The engine was coupled to an eddy current dynamo-metre. Before initiating the tests, the engine shall be started and allowed to warm up for 15 minutes. The engine was operated first on diesel fuel alone, followed by the different blends. In order to evaluate the performance of oil blends and pure diesel fuel, the Brake mean effective pressure, specific fuel consumption (SFC), and brake thermal efficiency (BTE) were recorded.

The engine was tested under full loading conditions at varying speeds conditions of 1000 rpm, 1500 rpm, 2000 rpm, 2500 rpm and 3000 rpm for each of the blends. Thereafter, time taken for a given fuel to be consumed was noted at each speed.

Engine torque was measured with the aid of a dynamometer. The engine was secured to a test bench where its output shaft was coupled to the dynamometer rotor. The rotor was broken by hydraulic and mechanical friction. The energy supplied by the engine was converted to heat and therefore the dynamometer was adequately cooled. The opposing torque exerted on the stator was measured by electronic means. Plates 3.5 to 3.6 displayed the experimental set up.

Finally, the remaining engine performance parameters were calculated using the engine torque values and equations (2.4), (2.5) and (2.6) for brake mean effective pressure, specific fuel consumption and brake thermal efficiency correspondingly.

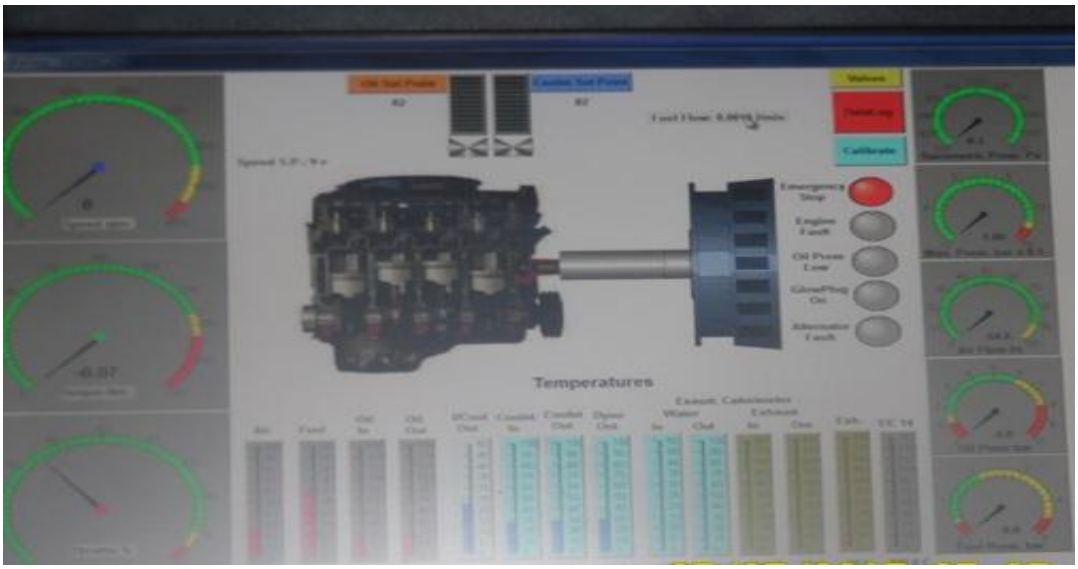


Plate 3.5: PC Monitor Display of the Engine Test Bed

3.2.4 Exhaust gas analyses

The combustion gases were analysed using the IMR 1400 combustion gas analyser, 2014 model. The exhaust gas analyser has a built-in sampling pump which drew the gas-sampling probe from the engine exhaust into the sunction pipe of the analyser. The gases flew through the gas sampling probe to the condensation trap. The gases then passed through the particle filter and the gas particles were removed. Finally, the gas entered the sensor chamber of the analyser. The result was displayed on the display screen and the values of flue gas temperature, excess air; combustion efficiency, heat losses, carbon dioxide, carbon monoxide, sulphur dioxide, and nitrogen oxide were recorded for each sample and kept for further analyses. This study was conducted to investigate the emission characteristics of a stationary four-cylinder diesel engine run on different bio-diesel/ petro diesel blends and also on diesel fuel alone. The engine was tested under full loading conditions at varying speeds conditions of 1500 rpm, 2000 rpm and 2500 rpm for each of the blends, the set up is shown in plates 3.6.



Plate 3.6: Exhaust Gas Analyser

3.2.5. Secondary Biodiesel Data Sourcing and Analyses

The secondary data of the physico-chemical properties of biodiesel made up of different feedstock such as yellow grease, palm, rapeseed, soy, canola, sunflower, tallow, corn, algae, coconut, camelina, safflower, waste cooking oil, castor, and others were obtained through an extensive literature review. Data from literature sources were obtained for most of the renowned biodiesel feedstock. For each physico chemical property per feedstock, the mean of the data, the mean deviation and the standard deviation was computed. Graphs were plotted for each property against the ASTM and or EN Standards, the results were presented and discussed accordingly. The statistical results were kept for further analyses.

3.2.6 Modelling and simulation of engine performance

The one dimensional numerical analyses of GT-Power software was used to simulate the diesel engine. Using the modelling tool of GT-Power, engine cycle simulation for biodiesel/ diesel fuels and the engine specifications for the test rig used in section 3.2.4

above, a compression ignition engine was modelled (Built) into the GT Power software to reflect the used test rig. The primary data which was obtained from the tests of the physico chemical properties were used to validate the model.

Therefore, biodiesel properties needed to be measured before they can be installed in the simulation software, hence, both the primary and secondary data obtained from the tests and the review respectively was used to feed the model. According to reference in GT-power gas properties also known as reference objects are carbon, hydrogen, oxygen and nitrogen commonly described as C:H:O:N composition, calorific value, critical temperature, critical pressure, enthalpy and transport properties which includes dynamic viscosity and thermal conductivity. Equally important liquids information on density, enthalpy and transport properties are incorporated so that the properties of the liquid will be known if the fluid evaporates (Kofar bai and Zheng, 2012).

The modelled engine was simulated using the GT Power software to study engine performance characteristics. These studies were made when the simulated engines were operating on petro-diesel alone, when the engines were running on biodiesels alone, as well as when they were running on various biodiesel blends with petro diesel. Plate 3.7 portrayed the GT Power interface.

Figure 3.1 shows a simple flow chart for the execution of GT Power program and GT Post result. The flowchart of the simulation is presented in figure 3.1. the flow chart depicts a step by step recipe for the execution of the programme. The GT Power software was launched, a 4-cylinder engine model was developed in the software interface and the model was saved as “4cyl-kaisan.gtm” in the home directory.

GT-ISE was opened on the PC, the following path was followed: Start→ Programs→ GTI Applications Group→ GTise v6.1.0, the saved 4-cylinder model “4cyl-kaisan.gtm” was opened by clicking on File-Open. From the “Run” menu in GT-Power, the “Case

Setup" was entered; the engine speed of 1000 rpm value was set as Case 1 in the model. Same path was followed to create another cases with 1500 rpm, 2000 rpm and 2500 rpm, hence to accomplish this, the "Append Case". Was clicked on.

Then in Case 2, the value of rpm was changed to 1500. The same process was repeated to create case 3 with 2000 rpm and case 4 with 2500 rpm. The parameter "CASE" was clicked on, and in the description of Case 1, Case 2, Case 3 and Case 4, the speed values "1000rpm" ''1500rpm'', ''2000rpm'' and ''2500rpm'' respectively were typed and the ''OK'' button was clicked.

The blue icon was clicked to Run the Simulation Preprocessor, when there were ''no errors'' the yellow icon was clicked to run the Simulation. The model has run successfully, from the Run menu "Open GT-POST" was selected and the results was viewed with GT-POST.

To view all the available plots, menu was opened, then "View" and "View All Checked" as sellected. (Alternately, this was also done by clicking on the icon that shows two lines intersecting). The plot navigation arrows towards the end of the icon bar was used to view all the pages. To view only the plots related to engine cylinder, the "EngCylinder: Cylinder01" was right clicked on, in the ". gx" File Pane and view was selected. Also, the Case selector just above the ".gx" File `Pane was used to view other cases.

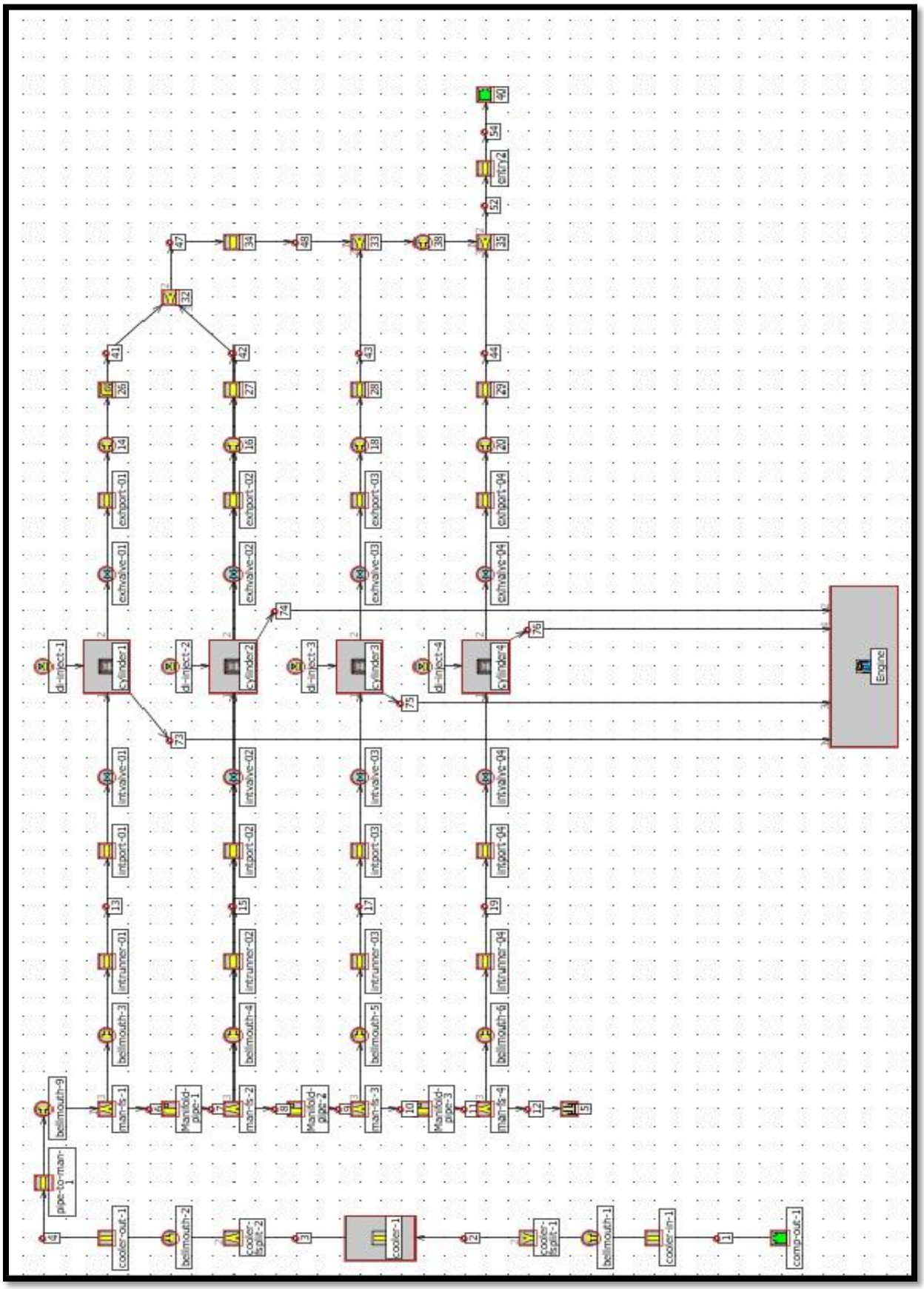


Plate 3.7: Engine Model from GT-Power Software

Additionally, the simulation was conducted under full loading conditions and at varying engine speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm. The Engine parameters like brake mean effective pressure; brake specific fuel consumption and brake thermal efficiency were recorded for each engine simulation. After completing the simulation, the results were recorded and tabulated for comparison with those obtained from the engine test rig. After the software validation, the same engine fleet was simulated using different fuel properties of biodiesels obtained from the secondary data. The list of biodiesel fuels used include: yellow grease, palm, rapeseed, soy, canola, sunflower, tallow, corn, algae, coconut, camelina, safflower, waste cooking oil, castor, and others (Peanut, karanja, rice bran, sorghum, lard, poultry fat, mustard, peanut, babarsu, fish oil, kusum, beheda and groundnut). Conclusively, the results obtained were presented, analysed, discussed and concluded accordingly.

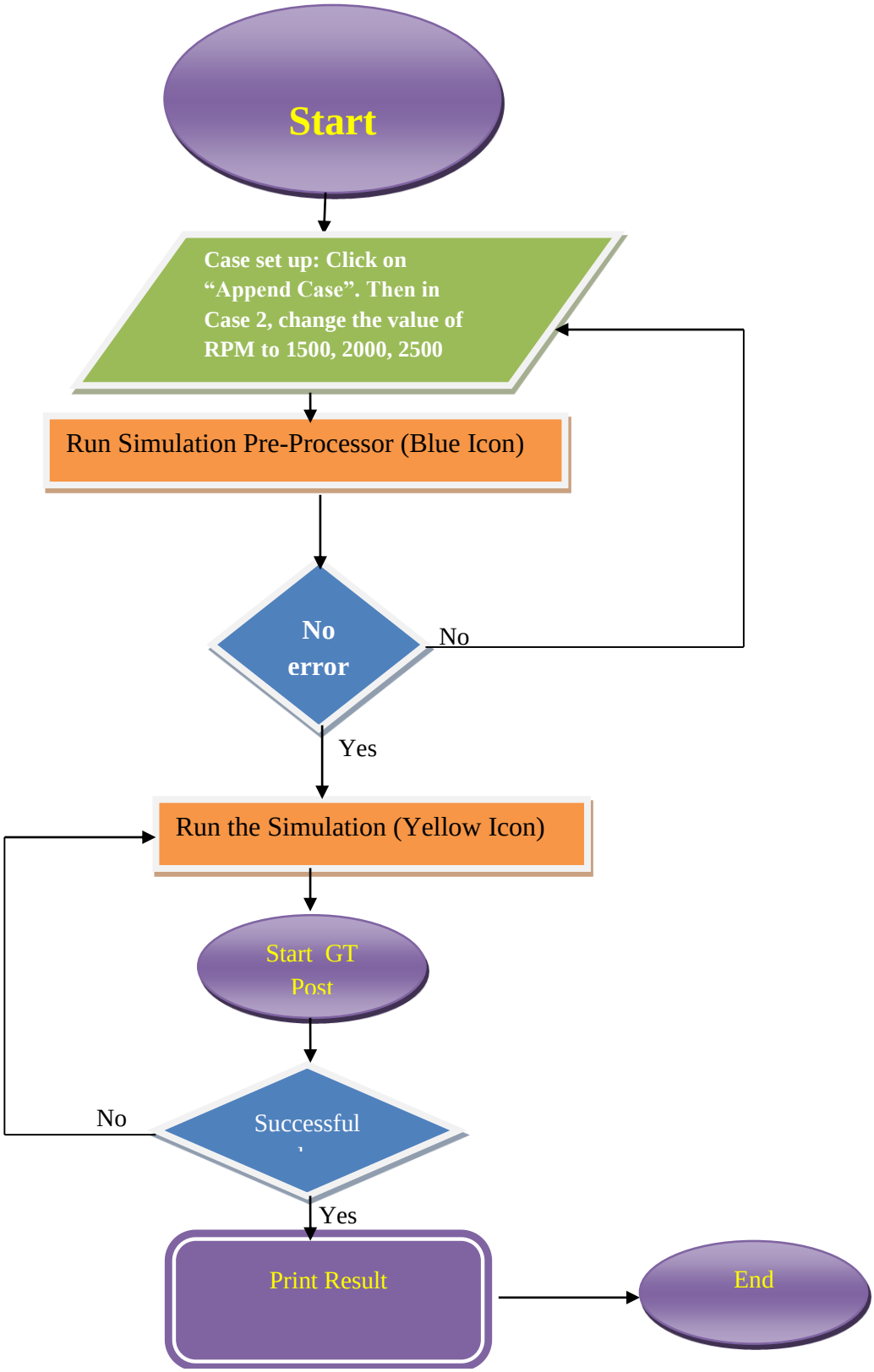


Figure 3.1: Flowchart for the Execution of GT Power Program

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 GC-MS Results

The results of methyl esters percentage contents of the biodiesel products were analysed by the Gas Chromatography - Mass Spectroscopy of the biodiesel; produced from Cotton, Jatropha and Neem oil are presented in Plates 4.1, 4.2 and 4.3 respectively and the interpretation of the peaks of the chromatogram was given after each figure, paying more attention to the methyl esters present in each chromatogram only.

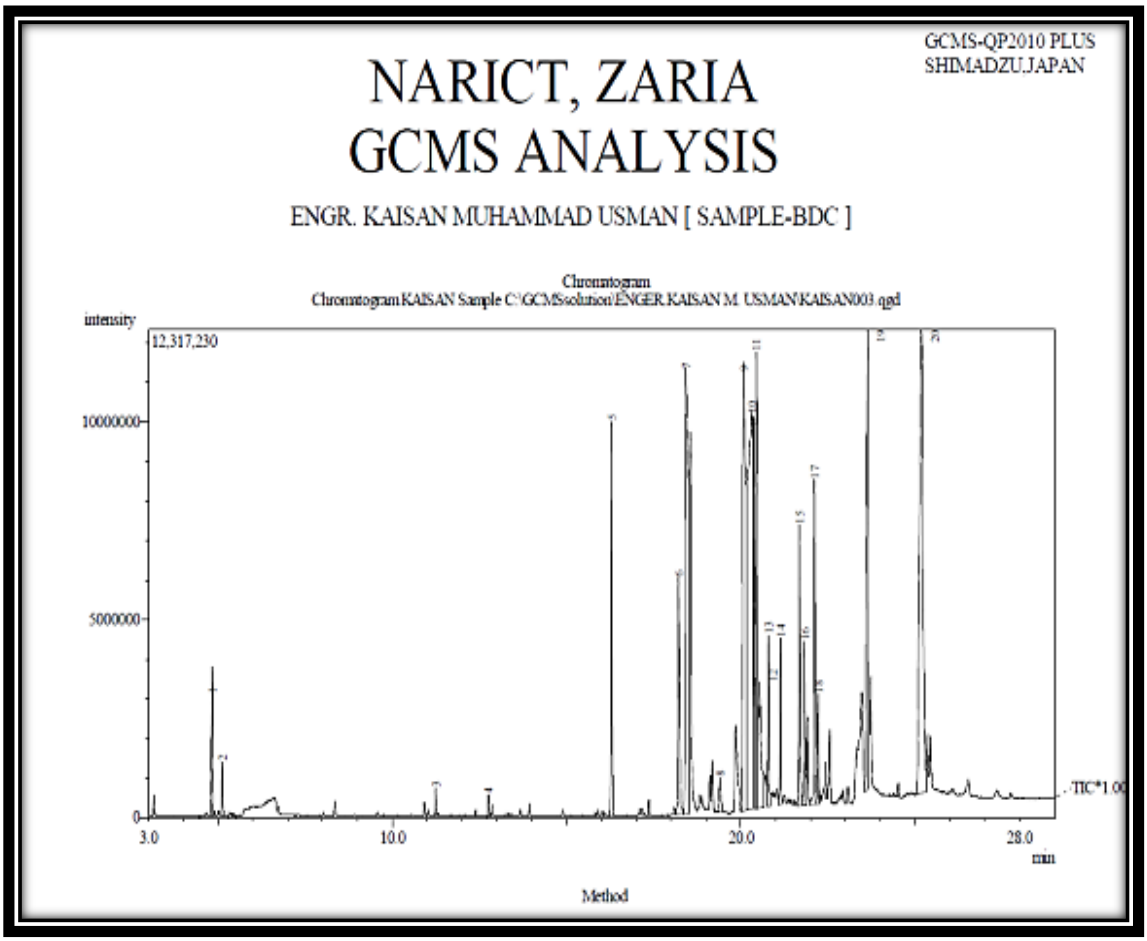


Plate 4. 1: GC-MS Chromatogram of Cotton Seed Biodiesel

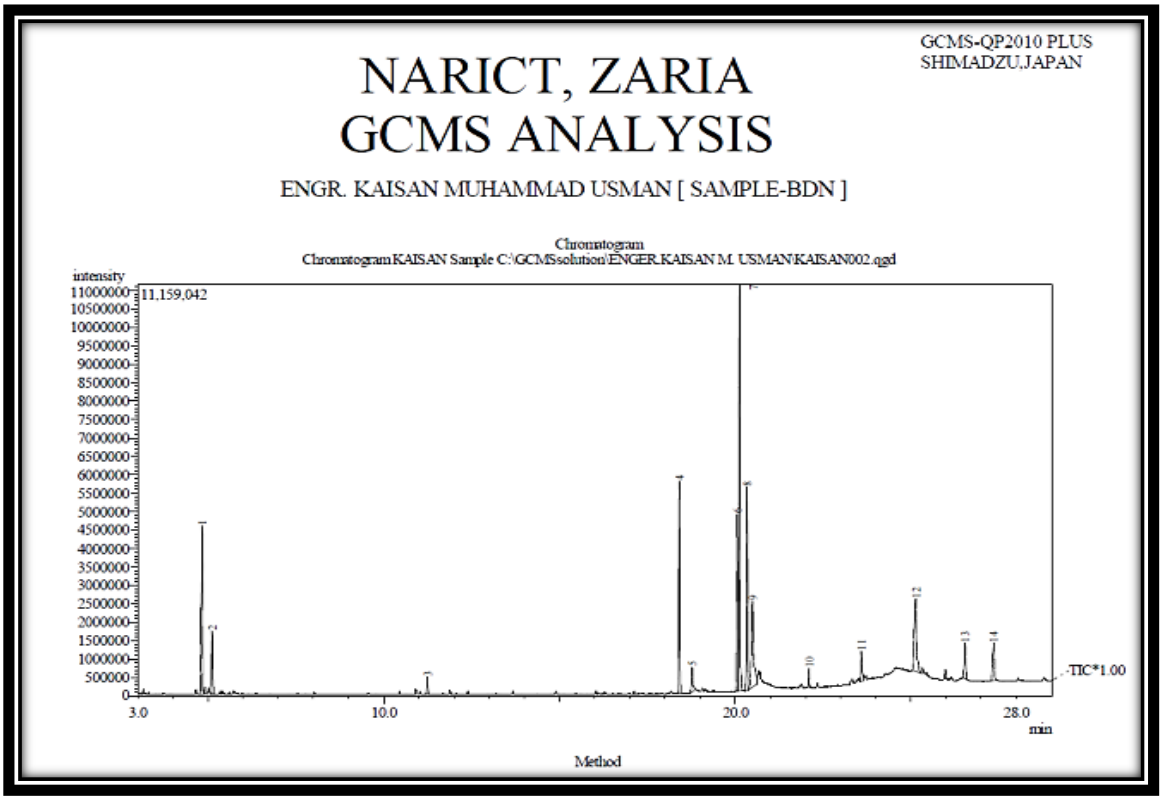


Plate 4. 2: GC-MS Chromatogram of Neem Seed Biodiesel

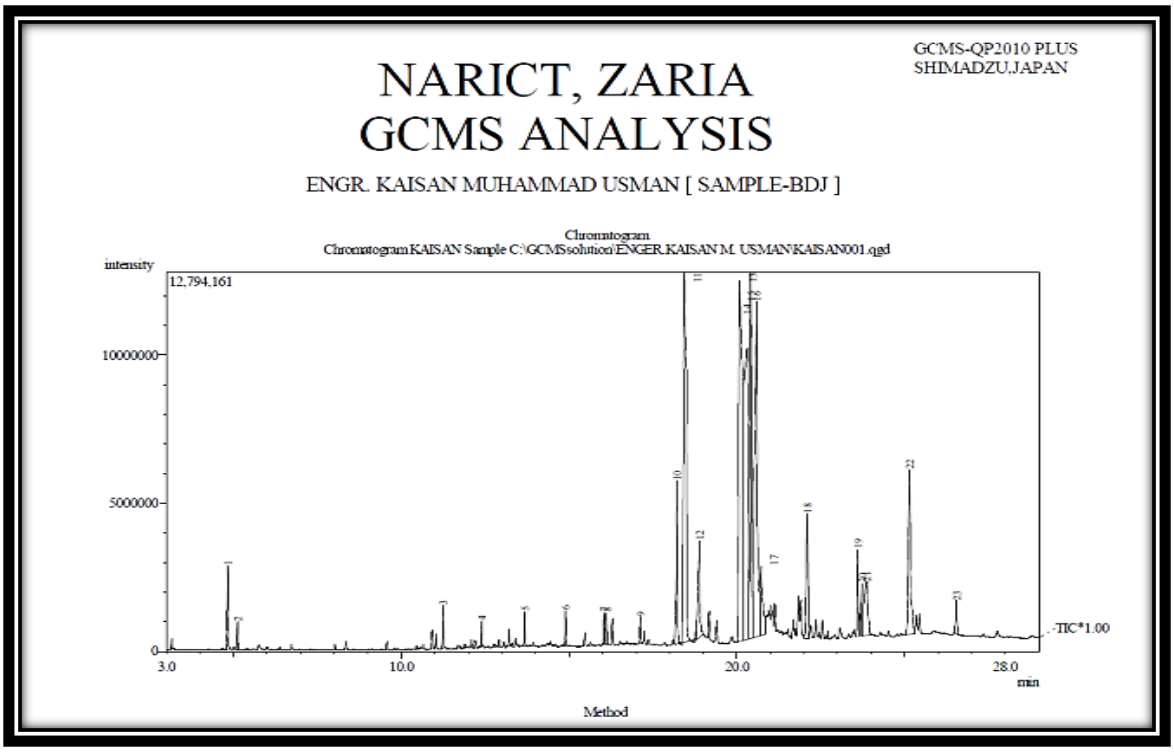


Plate 4. 3: GC-MS Chromatogram of Jatropha Seed Biodiesel

4.1.1 Cotton oil methyl ester

From Plate 4.1, the main methyl esters present in the biodiesel produced from cotton oil are methyl nonanoate ($C_9H_{18}O_2$), methyl hexadecanoate ($C_{17}H_{34}O_2$) and methyl octadecenoate ($C_{19}H_{36}O_2$). Their respective percentages by composition were 0.20, 11.53 and 17.72 %. Other esters found in the biodiesel were methyl eicosanoate ($C_{21}H_{42}O_2$), methyl pentanoate ($C1_7H_{34}O_2$) and Methyl octadecenoate ($C_{19}H_{38}O_2$); having respective percentages of 3.47, 11.53 and 7.32 %. The profile revealed that, the methyl octadecenoate ($C_{19}H_{36}O_2$) is the predominant compound in the mixture having the highest percentage of 17.72 %. The fatty acid methyl ester profile is one of the key factors that determine the suitability or otherwise of any feedstock for use in biodiesel fuel production (Sokoto *et al.,* 2011). The results in Plate 4.1 indicate that, the most abundant ester in the cotton diesel is mono saturated methyl octadecanoate. It is a very good compound that has the tendency of assigning stability to the biodiesel, this is because, higher degree of unsaturation in the fatty acid methyl esters limits its suitability for use as a fuel due to high polymerisation tendency, which is caused by peroxidation (Bamgboye and Hensen, 2008; Sokoto *et al.,* 2011).

4.1.2 Jatropha oil methyl ester

The methyl ester content in the Jatropha biodiesel as portrayed by the GC-MS analyses are depicted by Plate 4.2. The main methyl esters are: methyl octadecanoate ($C_{19}H_{36}O_2$), methyl hexadecanoate ($C_{17}H_{34}O_2$) and methyl penta decanoate ($C_{16}H_{30}O_2$). Their respective percentages are 53.44 %, 17.77 % and 14.25 % correspondingly. Other esters found in the biodiesel are Eicosonoic acid methyl ester ($C_{21}H_{42}O_2$) 3.11 % and Docosanoic acid methyl ester ($C_{23}H_{46}O_2$)1.05 %. The profile revealed that, octa decanoic acid methyl ester ($C_{19}H_{36}O_2$) is the dominant compound in the mixture with 53.44 %. The fatty acid methyl ester profile is the main factors that decide the aptness or otherwise of

any feedstock for use in biodiesel fuel production (Sokoto *et al.,* 2011). The results in Plate 4.2 point out that, the bulk profuse ester in the Jatropha biodiesel is mono saturated methyl octadecanoate. It is a very good compound that has the tendency of assigning stability to the biodiesel, this is because, higher degree of unsaturation in the fatty acid methyl esters limits its suitability for use as a fuel due to high polymerisation tendency which is caused by peroxidation (Bamgboye and Hensen, 2008; Sokoto *et al.,* 2011).

4.1.3 Neem oil methyl ester

The methyl ester content in the Neem biodiesel as portrayed by the GC-MS analyses are depicted in Plate 4.3. The main methyl esters are methyl octadecanoate ($C_{19}H_{36}O_2$), methyl hexadecanoate ($C_{17}H_{34}O_2$) and methyl penta decanoate ($C_{16}H_{32}O_2$). Their respective percentages are 54.69 %, 3.88 % and 10.64 % correspondingly. Other esters found in the biodiesel are Eicosonoic acid methyl ester ($C_{21}H_{42}O_2$) 0.99 %. The profile revealed that, octa decanoic acid methyl ester ($C_{19}H_{36}O_2$) is the dominant compound in the mixture with 54.69 %.

The fatty acid methyl ester profile is the main factors that decide the aptness or otherwise of any feedstock for use in biodiesel fuel production (Sokoto *et al.,* 2011). The results in Plate 4.2 point out that, the bulk profuse ester in the Jatropha diesel is monounsaturated methyl octadecanoate. It is a very good compound that has the tendency of assigning stability to the biodiesel, this is because, higher degree of unsaturation in the fatty acid methyl esters limits its suitability for use as a fuel due to high polymerisation tendency which is caused by peroxidation (Bamgboye and Hensen, 2008; Sokoto *et al.,* 2011).

From the Plates and details of the result obtained from the GC-MS machine, the percentage of methyl-esters present in the compounds of Neem, Jatropha and Cotton are respectively 70.2 %, 91.97 % and 89.75 %, which has been clearly depicted in the results.

The GC-MS analyses confirmed that most of the products are methyl-ester compounds with a very big percentage each of the biodiesel components present in the compounds. At high temperatures, the peroxidation can be accelerated and engine can quickly become gummed with polymerised fatty methyl esters, this is commonly experienced in compression ignition engines (Gopinath *et al., 2*010). Hence, feedstocks with high percentage of poly unsaturated acid is not suitable for usage as biodiesel. Since the dominant fatty acid methyl esters for Cotton, Jatropha and Neem biodiesel are methyl octadecanoate, methyl hexadecanoate and methyl pentadecanoate are monounsaturated they might not have much affinity to oxygen that will lead to quick peroxidation. These dominant esters are similar to the major fatty acid methyl esters in *Jatropha curcus* is consistent with the findings of Carraretto, *et al. (*2004) whose results gave 51.7 % and 14.3 % respectively (Carraretto, *et al.*, 2004). Palm and olive oil methyl esters have been reported to be good feedstocks for biodiesel production (Carraretto, *et al.,* 2004). Their dominant esters are methyl octadecanoate and methyl hexadecanoate similar to those present in the Cotton, Jatropha and Neem biodiesel. Similarly, methyl octadecanoate and methyl hexadecanoate were the dominant esters in rapeseed methyl esters with percentage composition of 77.9 and 3.86, (Carraretto, *et al.,* 2004). Equally, in *Rhus Succelanea Linn and Annona Reticulate*as reported by Demirabas (2005); Demirabas (2008a) respectively, hence, it could be inferred that, Cotton, Jatropha and Neem biodiesels are sustainable, renewable, reliable, combustible and suitable for use in compression ignition engines.

4.2 Physico-Chemical Properties of Biodiesel from Cotton, Neem and Jatropha Seeds

Results of Physico-Chemical Properties of Cotton, Jatropha and Neem Biodiesel are presented in figures 4.1 to 4.12 respectively for specific gravity, acid number, sulphur content, colour and copper strip corrosion of Jatropha, Neem, and Cotton biodiesel with their binary and mixed blends.

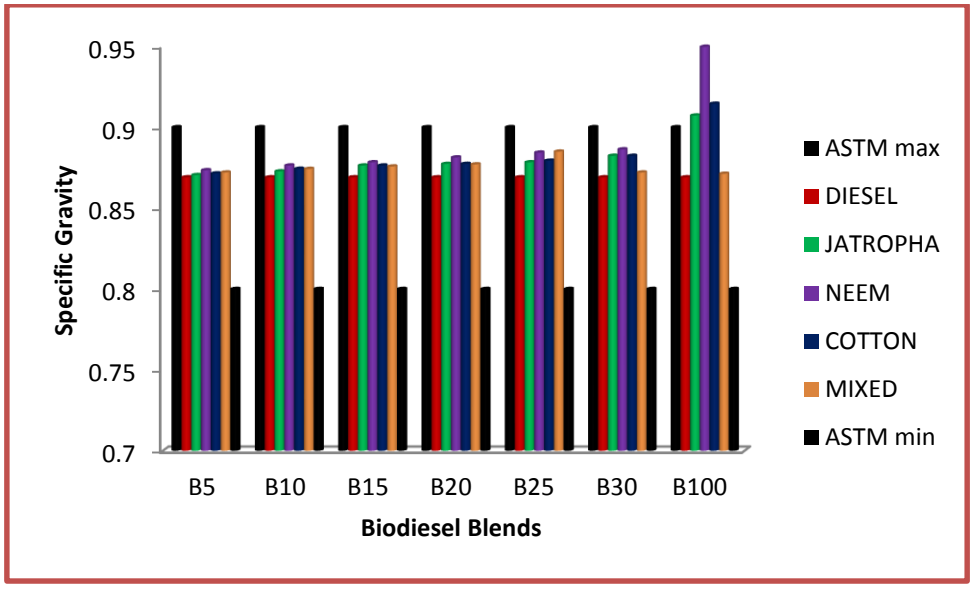


Figure 4. 1: Specific Gravity of biodiesel and blends with diesel

In figure 4.1, the result of specific gravity of Jatropha biodiesel and its binary blends were presented for the pure biodiesel of Neem and its binary blends, pure biodiesel from cotton and its binary blends and the multi-blends of cotton, Neem and Jatropha biodiesels. The charts of specific gravity against the blends were depicted, in each case, the values of pure diesel and the ASTM standards maximum and minimum values were captured. The specific gravity of Jatropha increase with increase in the percentage of biodiesel in the blends of Jatropha as it is seen in figure 4.1 from B5 up to B100.

All the specific gravity values conform to the ASTM standard values except for B100 which is above the ASTM maximum point. All the values are slightly above the pure diesel value of the specific gravity. Binary blends of biodiesel from Neem and cotton also

show an identical trend with Jatropha. This implies that, Neem and cotton biodiesel blends conform to the ASTM standard values of specific gravity. Although the pure biodiesel from Neem and cotton are above the maximum standard values, but the differentials are significant. For the multi-blends, however, from B5 to B20 the slope shows a linear increase, it increases further to B25 and descended down at B30. From B30-B000 the graph shows that these blends are within the ASTM standard values.

From the results presented so far, the values of specific gravity are slightly above that of diesel fuel. This is consistent with work of Hellier *et al. (*2015); Enwerenmadu *et al. (*2014); Belewu *et al. (*2010); Kalbande (2009); Reyadth (2009) and ASTM standard values. Hence, the quality of atomisation, combustion and the fuel droplets as well as air fuel mixing would be satisfactory while burning these binary and multi-blends of Cotton, Jatropha and Neem biodiesel.

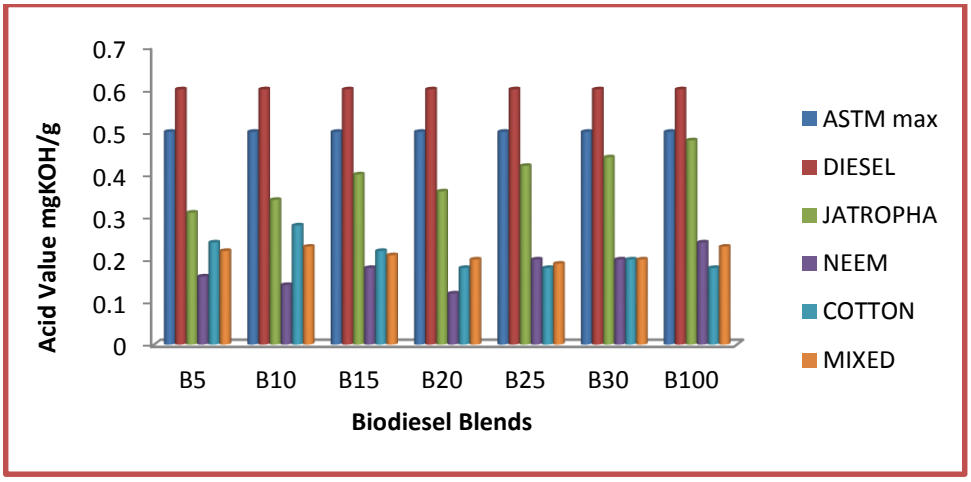


Figure 4. 2: Acid values of Jatropha, Neem and Cotton Biodiesel Multi-Blends

The acid values of binary and multi-blends of biodiesel from Jatropha, Neem and cotton oil with fossil diesel were depicted in figure 4.2. According to Boz *et al. (*2009), the acid value measures the amount of unreacted acid in the finished fuel, and is always an indication of oxidized fuel. A high acid value damages fuel pumps and fuel filters. The acid value gives an indicator of the quality of fatty acids in oil/diesel (Belewu *et al.*, 2010).

From figure 4.2, the acid value of all the blends (both binary and multi-blends) is very low including those for pure biodiesel samples and fossil diesel. In fact the acid values are even lower than the ASTM maximum standard which is 0.5. This implies that the fuels are good to be used in compression ignition engines without any fear of damages on fuel Pumps and filters.

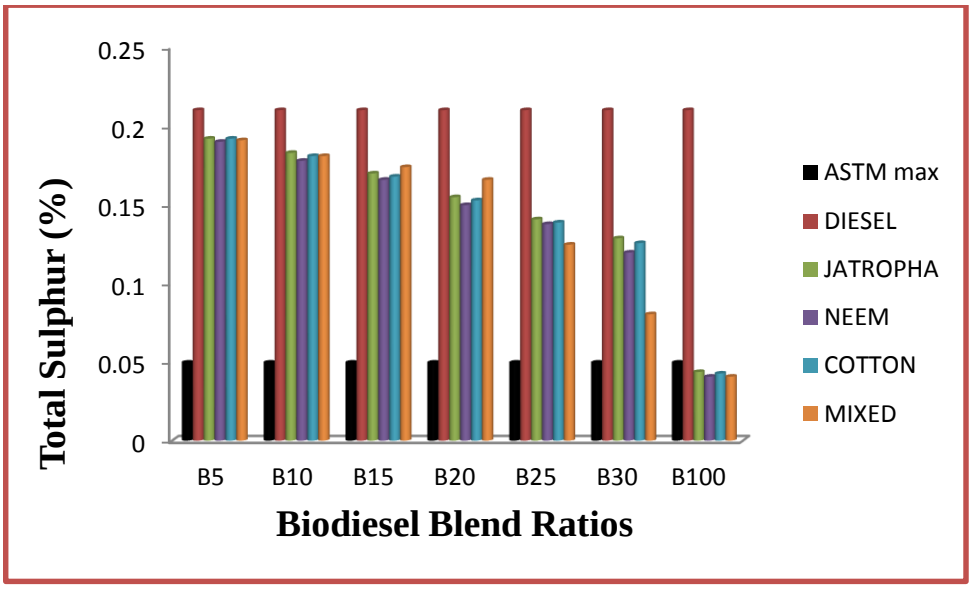


Figure 4.3: Sulphur Content of Jatropha, Neem and Cotton Biodiesel Multi-Blends

The total sulphur present in the fuel samples were plotted against the blends. The ASTM maximum values were also inclusive as depicted in figures 4.3. The reduction in sulphur content of the fuel reduces the tendency of emitting sulphur (IV) oxide to the atmosphere during the combustion of the biodiesel fuel. This leads to the reduction of the formation of acid rain, which occurs when the rain water dissolves SO_2 to form sulphuric acid. The acid rain is one of the major causes distruption of the ecosystem, damage of plants and rapid deterioration of buildings. These results are consistent with the findings of Kaisan *et al. (*2013) on sulphur content of wild grape seeds biodiesel.

Table 4. 1: Copper Strip Corrosion of Binary and Mixed-Blends of Jatropha, Neem & Cotton Biodiesel

	Copper Strip						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	1	1	1	1	1	1	1
NEEM	1	1	1	1	1	1	1
COTTON	1	1	1	1	1	1	1
MIXED	1	1	1	1	1	1	1
ASTM min	1	1	1	1	1	1	1
ASTM max	3	3	3	3	3	3	3
DIESEL	1	1	1	1	1	1	1

The minimum value for copper strip corrosion based on ASTM standards is Table 4.1 and the maximum is 3. From table 4.1 all the samples have the best copper strip value of 1 each. This is consistent with the work of Kaisan *et al. (*2013) on copper strip corrosion of wild grape seeds biodiesel. This shows that all the fuel samples are not liable to cause corrosion in compression ignition engines. The samples are hereby suitable for CI engines operations.

Table 4. 2: Colour Index of Binary and Multi-Blends of Jatropha, Neem and Cotton Biodiesel

	B5	B10	B15	B20	B25	B30	B100
JATROPHA	2.0	2.0	<2.5	2.5	2.5	2.5	2.0
NEEM	2.0	2.0	<2.5	2.5	2.5	<3.0	<4.0
COTTON	2.5	2.5	<3.0	2.0	2.0	3.0	<3.0
MIXED	2.5	2.5	<3.0	2.5	2.5	2.5	2.5
ASTM min	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ASTM max	3.5	3.5	3.5	3.5	3.5	3.5	3.5
DIESEL	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Table 4.2 shows the colour indices for all the biodiesels from Jatropha, Neem, cotton and the pure diesel with their respective binary and mixed blends. The minimum ASTM

colour code is 1.0 and the maximum is 3.5. From Table 4.2, all the fuel samples under study except the 100 % Neem biodiesel have consistent colour indices. B100N has a colour index <4.0 which is not a suitable colour for biodiesel, although this does not affect any of the performances of the biodiesel in diesel engine. This result is contrary to the findings of Kaisan *et al. (*2013) where all the colour indices are beyond the standard values prescribed by ASTM. This is because, the wild grape seed oil has dark brown color, that is to say, the colour indices are very high because the products have dark brown colours, while in the later, the colours are clean. Hence these fuels are very good to operate any compression ignition engine.

Furthermore, results of the viscosity of Cotton, Jatropha and Neem Biodiesel with their respective binary and Multi-blends are presented in figures 4.4

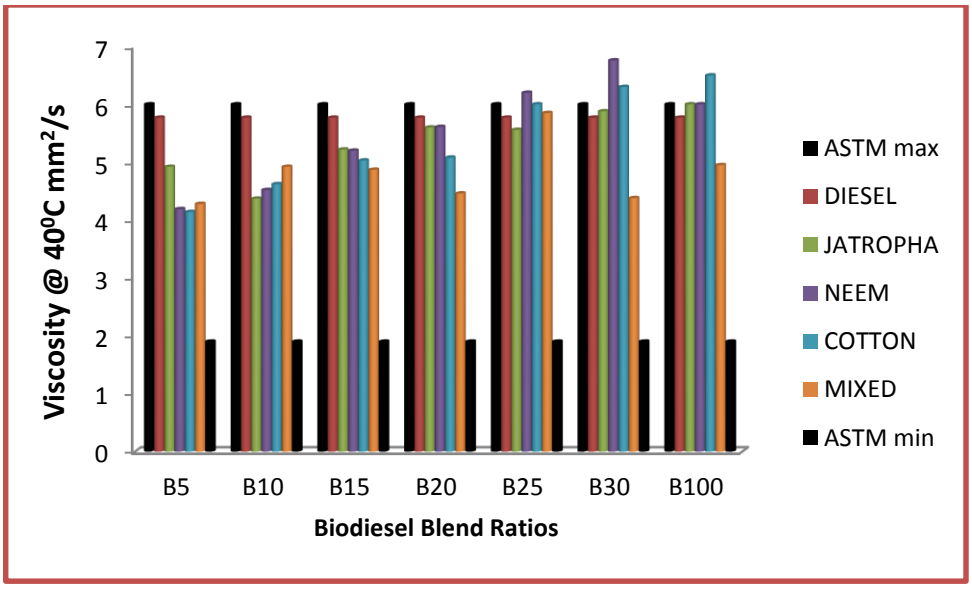


Figure 4.4: Viscosity of Mixed Biodiesel Blends

The kinematic viscosity of a biodiesel influences the ease of starting an engine, the spray quality, the particle size, and the quality of air-fuel mixing and the penetration of the injected jet (Boz *et al.*, 2009; Enwerenmadu *et al.*, 2014). Too low viscosity gives low spray but leads to poor penetration, while a too high viscosity causes operational problems at high temperature. Once the viscosity is decreased to the lower value than the prescribed

standard, there would be reduction in the peak heat release rate, it leads to a degree of fuel impingement on the piston bowl and cylinder walls which reduces air-fuel mixing rate (Hellier *et al.,* 2015). Biodiesel has much less viscosity than the oil from which it is produced.

From figure 4.4, the kinematic viscosity values of the binary and multi-blends of biodiesel from Cotton, Jatropha and Neem with diesel were presented with the ASTM standard values. For Jatropha biodiesel, from B5-B10, the kinematic viscosity decreases, however, it kept increasing from B10-B20; it then increased to B25 and increase to B100. Most of the viscosity values are consistent with the ASTM maximum and minimum standard values. The biodiesel blends except B25N, B30N and B100C are lower than pure diesel in viscosity. This shows that there is high tendency of producing a very good air –fuel mixing, spray quality and combustion quality with B5-B25 binary blends than pure diesel based on the findings of Boz *et al.* (2009) and Enwerenmadu *et al. (*2014). This behaviour is similar to that of multi-blend shown on figure 4.4. All the values are lower than that of diesel except for B25, B30 and B100. Meaning that, all the rest would perform better in diesel engine than the pure diesel as confirmed by the results of Boz *et al. (*2009) and Enwerenmadu *et al.* (2014). Conversely, B25N, B30C and B100C fall above the ASTM maximum values. This is also consistent with the B100 of cotton biodiesel. In all cases, B5-B20 conforms to ASTM standards, have lower viscosity than diesel and will improve CI engine performance undoubtedly as supported by the conclusions of Boz *et al.* (2009) and Enwerenmadu *et al.* (2014).

Furthermore, as the viscosity is a measure of internal fluid resistance (friction) of the biodiesel flow, this tends to oppose dynamic change in fluid motion (Sivarimakrishnan and Ravikumar, 2012). Kinematic viscosity is an important property of biodiesel since it affects the operation of fuel injection equipment (Atabani and cesar, 2014). This means

that, the biodiesel blends especialy B5 to B20 have very good fluidity at all temperatures, and this will promote favourable pumping leading to efficient fuel-air mixing (Izah and Ohimain, 2012). Kinematic viscosity is the primary reason why biodiesel is used in CI engine (Moser, 2009). This justifies why this research is vital and timely, this is also consistent with the work of Chalatlon *et al. (*2011) and Isioma *et al. (*2013). The acceptable viscosity ranges for biodiesel according to ASTM D6751 which fall between 1.9 to 6.0 mm^2/s (Chalatlon *et al., 2*011), when the viscosity is too low between 1.9 mm^2/s, the out flow will correspond to a power loss in the engine, and if it is high, above 6.0mm^2/s, the injection pump will be unable to supply enough fuel to fill the pumping chamber, again it will result to power loss.

Furthermore, the results of cold flow properties of different fuel samples from diesel, Jatropha, cotton and Neem biodiesel as well as binary and mixed-blends of the four fuels are presented in figure 4.5.

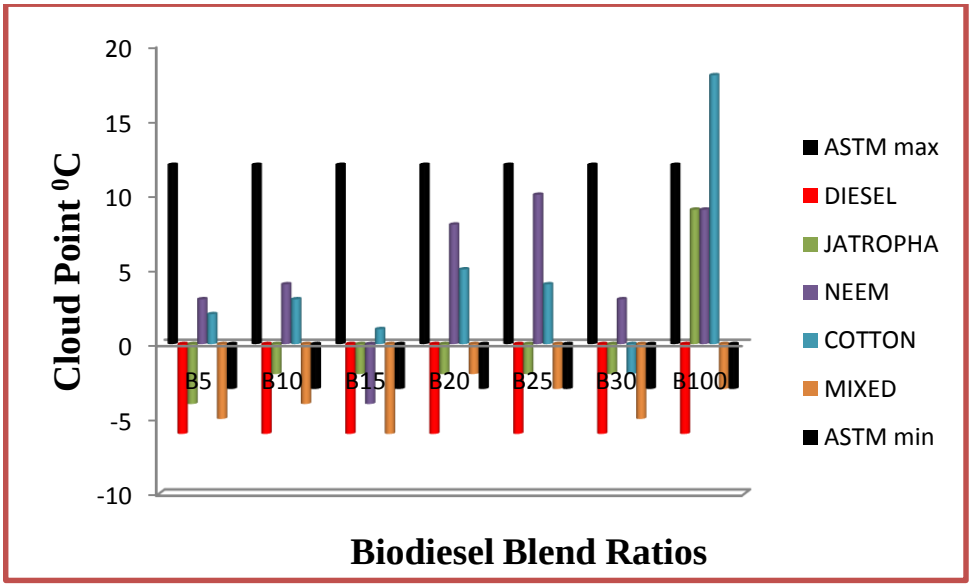


Figure 4.5: Cloud Point of Mixed Biodiesel Blends

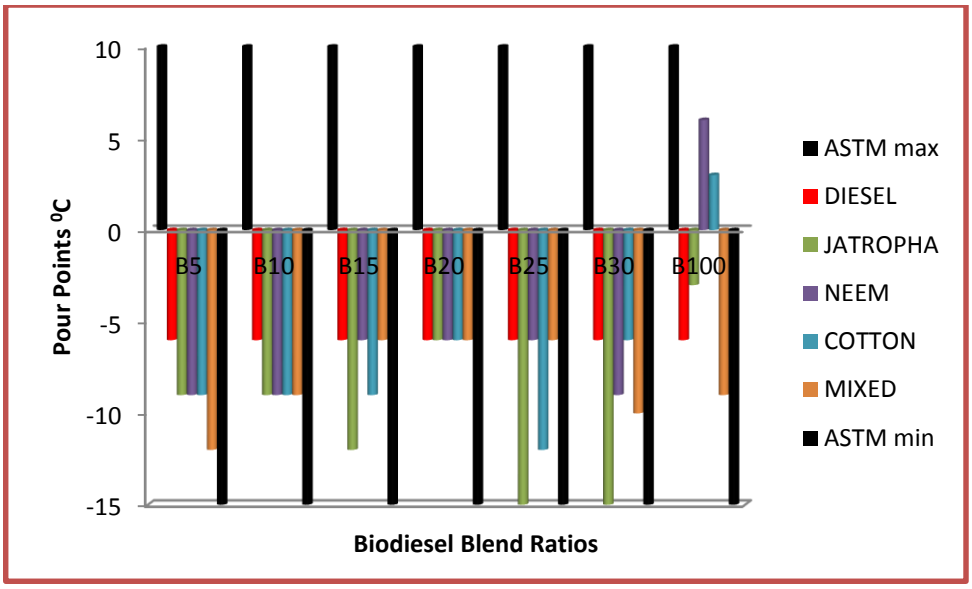


Figure 4.6: Pour Point of Mixed Biodiesel Blends

The cold flow properties are pour point, cloud point and cold filter flogging point of the fuels. In this research, only the first two was considered. The results are shown in figures 4.5 and 4.6 for the pour point and for the cloud points of the biodiesel from Jatropha, Neem and cotton with diesel binary and multi-blends, respectively. The cold flow properties are properties that describe the fluidity of biodiesel in low temperature (Isioma *et al.*, 2013).

Pour points define the lowest temperature at which the fuel can still be moved before it has gelled (Boz *et al.*, 2009). The pour points and freezing points of fuel affect the utility of fuel. From figure 4.6, the pour points of all the fuel samples conform to the ASTM standards. Pure bio diesel samples have relatively higher pour point than the pure diesel. This means that the whole 28 fuel samples under investigation have a very good fluidity, cannot easily turn to gel and can be used at lowest ASTM temperature of -15 ^{o}C without any trouble. These results are consistent with the findings of Boz *et al. (*2009).

The cloud points of biodiesel are the temperature at which wax crystals first become visible when cooled (Atabani and Cesar, 2014). From figure 4.5, for Jatropha blends, all the samples except B5J conform to the ASTM standard values of cloud points. B5J and

pure diesel have cloud points below the standard. Similarly, the cloud point of Neem blends with diesel except B15N and pure diesel which are not within, all the blends fall within the ASTM limits. This is dissimilar to the cotton blend where B100C and pure diesel fall outside the standard limits and the result are consistent. Although in the latter case, B100 has cloud point far above the maximum limit. Conversely, for the mixed blends, only B20 is consistent with the ASTM limit as shown in figure 4.5. The rest are far below the minimum limit. Conclusively, all those who fall outside the standard limit except the B100C are far below the minimum, so there is no much adverse effect and the fuels can be used in CI engines without any vacillation.

Furtherance to the above discussions, accordingly, the results of the calorific value, flash point and cetane number of binary and mixed blends of Cotton, Jatropha and Neem Biodiesel with diesel are presented in Figure 4.7.

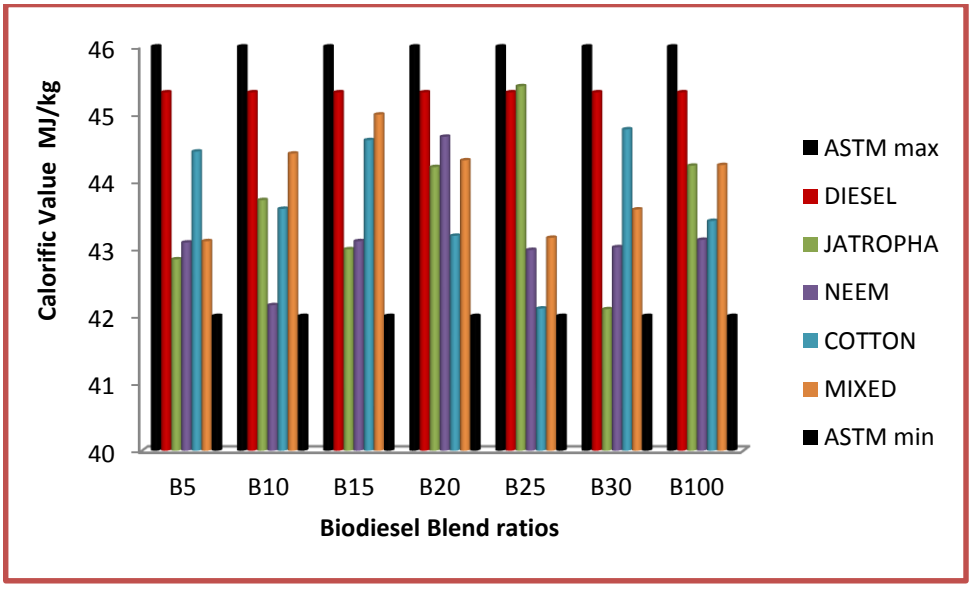


Figure 4.7: Calorific Values of Binary and Mixed Biodiesel and Blends

The Calorific value is an important parameter in the selection of a fuel. The calorific value of biodiesel is usually lower than that of diesel due to its higher oxygen content (Atabani and cesar, 2014). Figure 4.7 depicts the calorific values of Jatropha, Neem and cotton binary blends and the mixed blends respectively. The heating values are consistent with

the ASTM values for Jatropha, Cotton and Neem binary and multi-blends but slightly lower than that of pure diesel at B100. All the calorific values for all the blends are above the ASTM minimum standard value but in some cases close to the diesel values. These are consistent with the work of Atabani and Cesar (2014). Calorific value of a fuel is the thermal energy release per unit quantity of fuel when burnt completely and the products of combustion are cooled back to the temperature of the combustible mixture (Sivarimakrishshnan and Ravikumar, 2012). More biodiesel need to be pumped in order to achieve the same energy or higher energy than the pure diesel (Enwerenmadu *et al.,* 2014), but in the case of this research, most of the blends have close heating values when compared with that of diesel. This makes them suitable for use in CI engine operations. The calorific values herein obtained are consistent with Belewu *et al. (*2011); Nevase *et al. (*2008); and Divani *et al. (*2009).

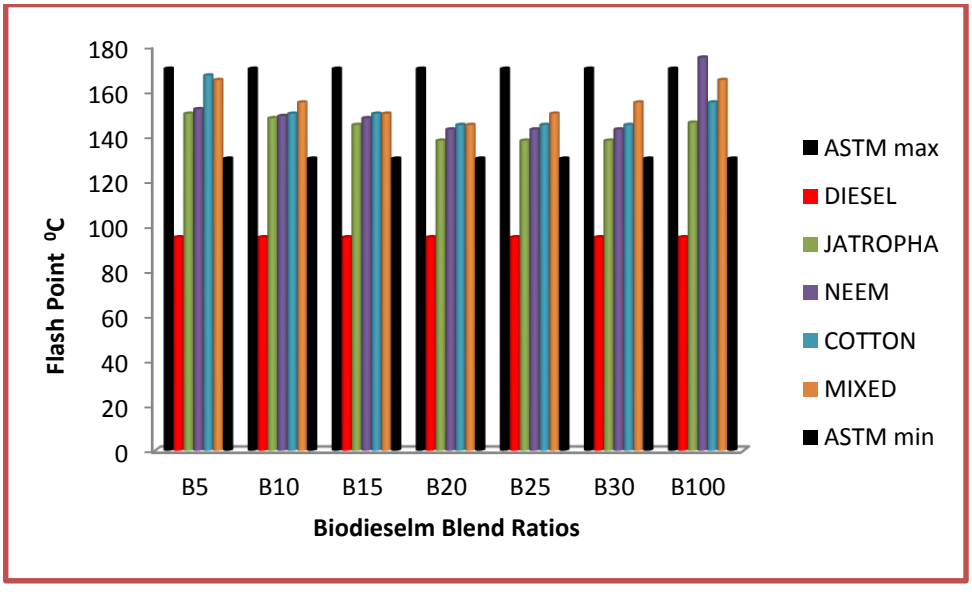


Figure 4.8: Flash Points of biodiesel binary and Mixed Blends

The flash point is related to the safety requirement in handling and storage of fuel (Belewu *et al.,* 2010). The flash point of a fuel is the minimum temperature at which the fuels will flash upon ignition (Boz *et al.*, 2009). In another words, flash point is a measure of the temperature to which a fuel must be heated such that the mixture of air and vapour above

the fuel can be ignited (Sivarimakrishnan and Ravikumar, 2012). Figure 4.8 presents the flash points of binary and multi-blends of biodiesel from Jatropha, Neem and Cotton with pure fossil diesel. It is clear that, amongst all the samples considered, 28 of them fall within ASTM standard values for flash points of biodiesels. Only B100N has a value slightly above the maximum standard. However, the difference is very negligible between the B100N (100 % Neem biodiesel) and the ASTM maximum.

The implication here is that; all the fuel samples are safe to handle. This is consistent with the works of Ewerenmadu *et al.* (2014); Boz *et al. (*2009). Similarly, high flash point leads to the formation of carbon deposits and inferior cooking (Izah and Ohimain, 2012). These biodiesel blends herein investigated are therefore good to use on CI engine and devoid of carbon deposits and inferior cooking. These fuels cannot easily flash when exposed to flame or spark. The results are consistent with Atabani and Cesar (2014). The temperature at which the fuel gives off inflammable vapour (flash point) and the lowest temperature at which the fuel will sustain burning for 5 seconds (fire point) have great important while determining the fire hazard. Conclusively, these fuel samples under investigation have passed the safety test in relation to the flash point.

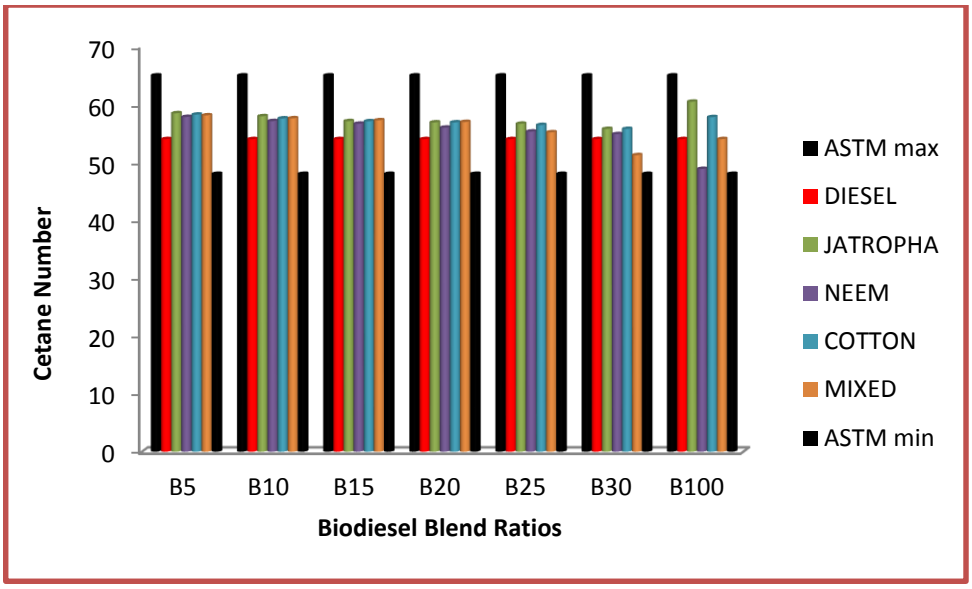


Figure 4.9: Cetane Number of Mixed Biodiesel and Blends

The cetane number is the measure of ignition quality of a fuel and influences white smoke and combustion roughness (Boz *et al.*, 2009). The cetane number of a fuel is one such important property responsible for the delay period. A fuel of higher cetane number gives lower delay period and improves engine performance (Sivarimakrishnan and Ravikumar, 2012). Figure 4.9 depicts the cetane number of binary and multi-blends of Jatropha, Neem and cotton biodiesels with diesel. All the fuel samples are consistent with the ASTM standards for cetane number. Generally, shorter ignition delay results in higher cetane number and vice versa based on the findings of Boz *et al. (*2009) and Enwerenmadu *et al. (*2014). It is related to the ignition delay time a fuel experience once it has been injected into a diesel engines combustion chamber (Moser, 2009). This implies that the diesel fuels and the respective blends herein examined would have the no ignition delay when burn in a CI engine. Hence, all the fuel samples are recommended blends for CI engine operations.

4.3 Results of Physico-Chemical Properties from Secondary Data Analyses

The results of the Physico-chemical properties of the secondary data obtained are presented in figures 4.10 to 4.18.

4.3.1 Kinematic viscosity

Kinematic viscosity is a measure of fluids resistance to flow over time (Isioma *et al.*, 2015). Figure 4.10 presents the kinematic viscosity of all the biodiesels under consideration. The kinematic viscosity of all the biodiesel reviewed fall within the ASTM standards except that of castor oil.

The castor oil biodiesel has a very high viscosity and as such, its the fluidity will be affected it will have lower volatility; this will lead to poorer atomisation of the fuel spray during its combustion in CI engines. The operation of the fuel injection of castor biodiesel will be less accurate (Kaisan, 2014, Sivarimakrishnan and Ravi kumar 2011). This will further lead to incomplete combustion and carbon deposits on the injection nozzles.

To lessen this problem castor biodiesel most be blended with diesel for smooth operations in CI engines (Tesfa *et al.*, 2013).

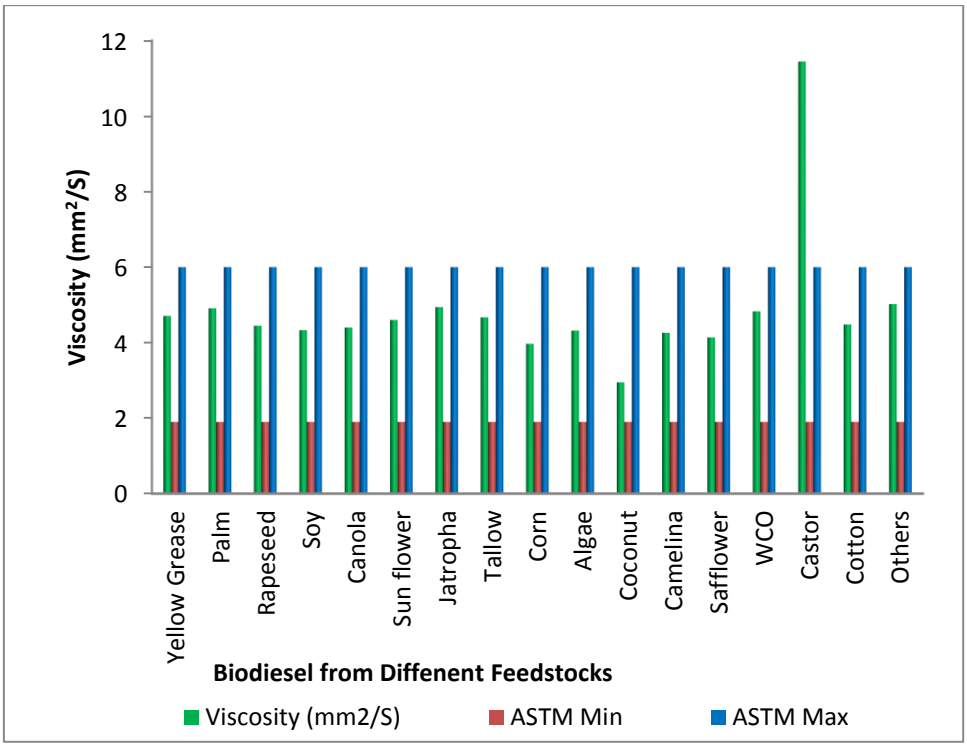


Figure 4.10: Kinematic Viscosities of Different Biodiesel Feedstock

4.3.2 Density

The densities of all biodiesels are depicted in figure 4.11 the densities of all biodiesel from all feedstocks except the algae conform to the EN standard. The density of algae was relatively high almost 0.95g/cm^3 which is5.6 % above the EN standard.

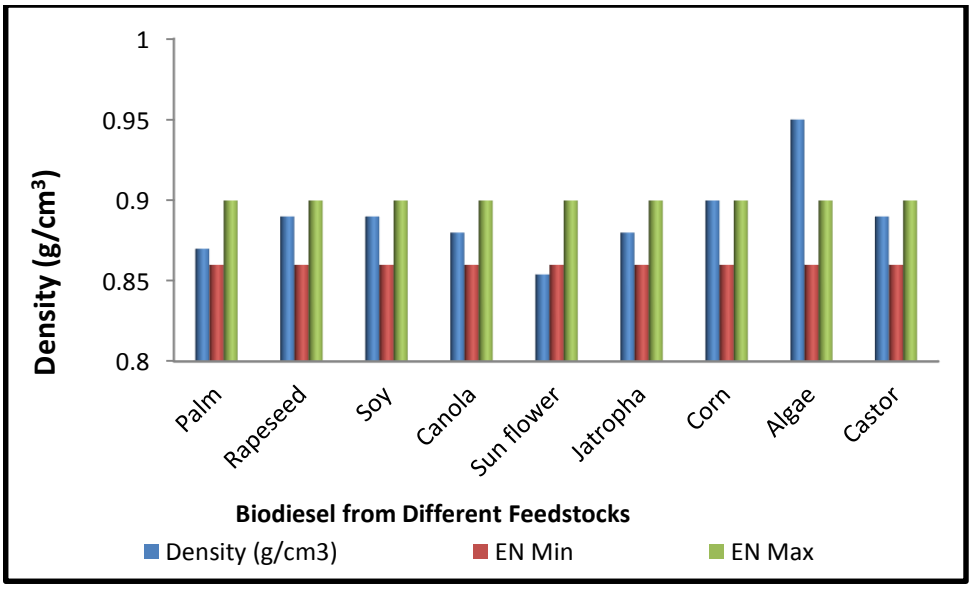


Figure 4.11: Density of Different Biodiesel Feedstock

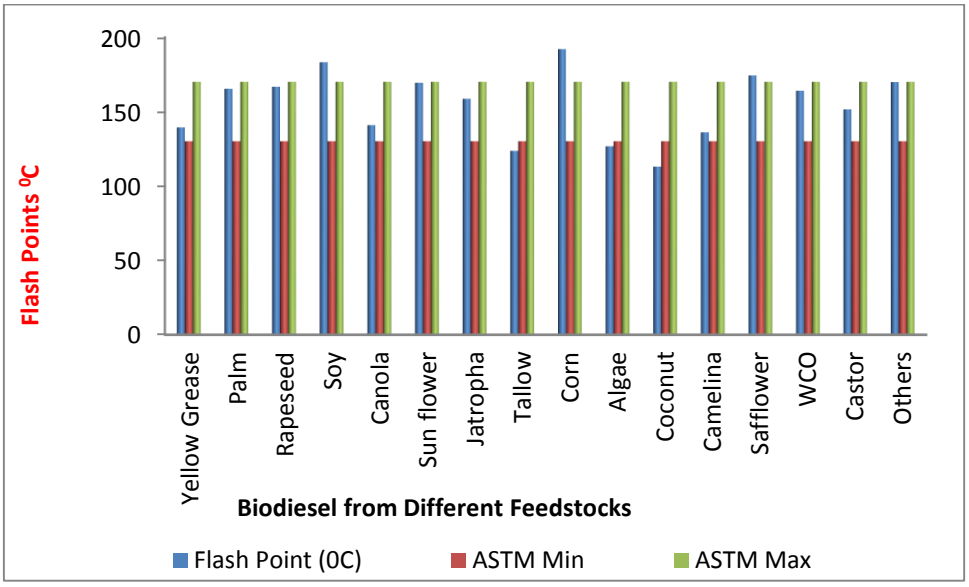


Figure 4.12: Flash Points of Different Biodiesel from different Feedstocks

4.3.3 Flash point

Figure 4.12 presents the flashpoint values of the biodiesel fuels. The flash points of most biodiesel from various feedstocks fall within ASTM limits. The flash points of soy and corn and safflower are slightly higher, while that of coconut algae and tallow is slightly lower than the ASTM min. The flash point is the temperature above the liquid fuel at which combustible mixture can be formed. i.e. the mixture that can be easily ignited by a

spark/flame (Kaisan and Pam, 2013). Therefore, soy and corn and safflower biodiesel have little tendency of producing carbon deposits on CI engine unless blended with diesel.

4.3.4 Heating value

The heating values of all biodiesel are presented in figure 4.13. All the values except that of the castor biodiesel conform with the EN minimum standards. Castor biodiesel has a heating value less than the EN minimum which makes it to be characterised with lower thermal energy (Kaisan *et al.*, 2015).

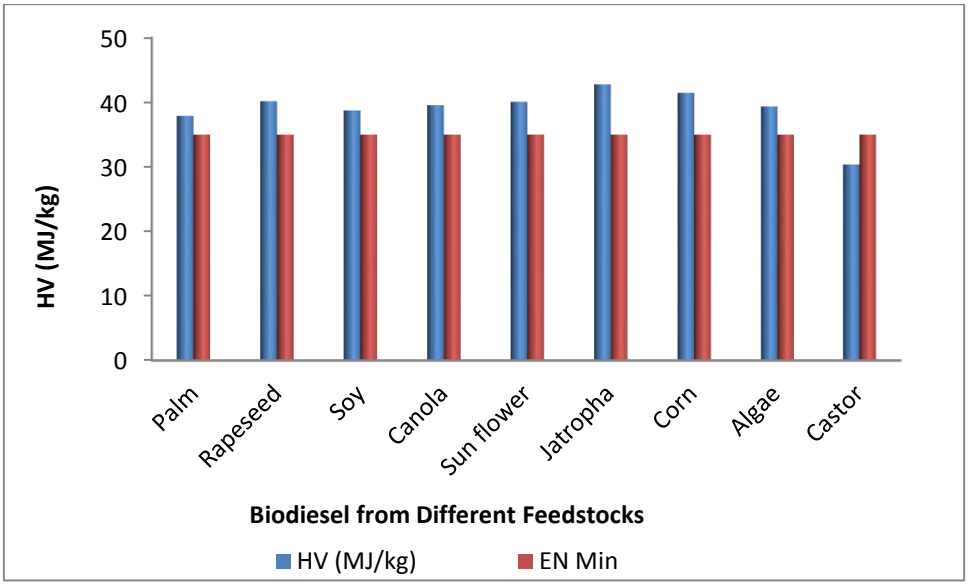


Figure 4.13: Heating Values of Different Biodiesel Feedstock

4.3.5 Specific gravity

The specific gravity of different biodiesel feedstocks are depicted in figure 4.14. All the specific gravity values except the algae conform to ASTM minimum and maximum standards level as depicted in the figure. Algae biodiesel has an average specific gravity of 0.91 which is far above the ASTM range of 0.85-0.88. Specific gravity is a function of fuel density. Fuel density directly affects the performance of a fuel, some fuel properties, such as cetane number, heating value and viscosity are strongly related to fuel density

(Enwerenmadu *et al.*, 2014). The specific gravity of the fuel also affects the atomisation and combustion. Therefore, there is high tendency that algae biodiesel may have low quality of atomisation and fuel droplet size as well as air fuel mixing in an IC engine due to its higher mass to volume ratio.

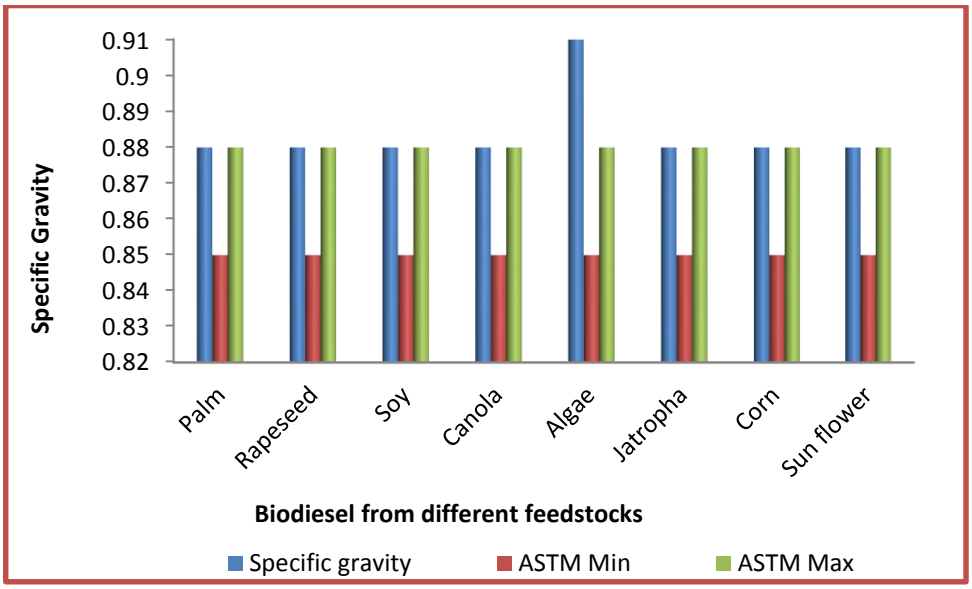


Figure 4.14: Specific Gravity of Different Biodiesel Feedstock

4.3.6 Pour point

Pour point values are presented in figure 4.15. The pour point of a biodiesel is the lowest temperature at which the fuel will still pour from its container. From the figure, most of the biodiesel values of pour point fall within ASTM limits except the Palm and Tallow biodiesel, with high positive values of 12.90 ℃ and 10.86 ℃ respectively. All the remaining have pour points between –0.5℃ to -13℃, which makes the very good in terms of cold flow characteristics. The pour point is a temperature at which the fuel contains so many agglomerated crystals to form a gel and will no longer flow (Enwerenmadu, 2014). Whereas the tendency of forming a gel is only ascribed to the palm and tallow at a temperature above the ice point of water (0℃), while others have super-efficient pour points of negative temperatures. In Nigeria, the average room temperature (ambient

temperature) is above 20℃ whence, all the biodiesel feedstock considered in this research can pour well in Nigerian weather.

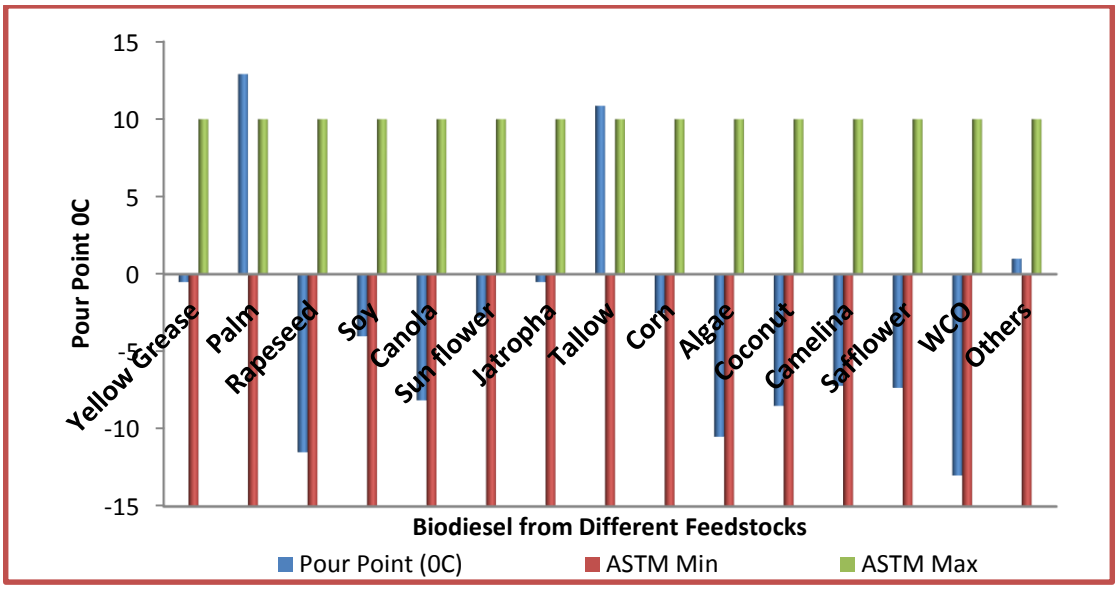


Figure 4.15: Pour Point Values of Different Biodiesel Feedstock

4.3.7 Cloud points

The cloud points for the biodiesel produced from different feedstocks are shown in figure 4.16. The cloud point is the temperature at which wax crystals first start to form in a fuel. From the figure, all the biofuels except that of palm have relatively very low cloud point of below 0 ℃.

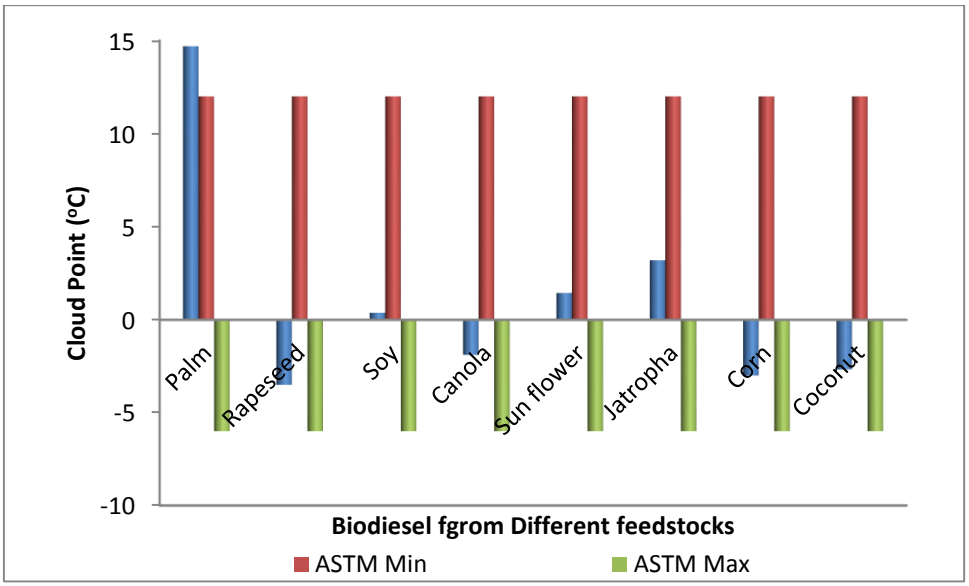


Figure 4.16: Cloud Point Values of Different Biodiesel Feedstock

4.3.8 Cold filter floggingpoints

The cold filter flogging points of the biodiesel are presented in the figure 4.17. Cold flow properties of a biodiesel describe the fluidity of biodiesel at low temperatures (Isioma *et al.,* 2013). Palm, yellow greese and tallow biodiesel have positive values, while the rest have negative values. This is supported by Isioma *et al. (*2013). The remaining biodiesel from vegetable oils with lower temperatures have better fluidity.

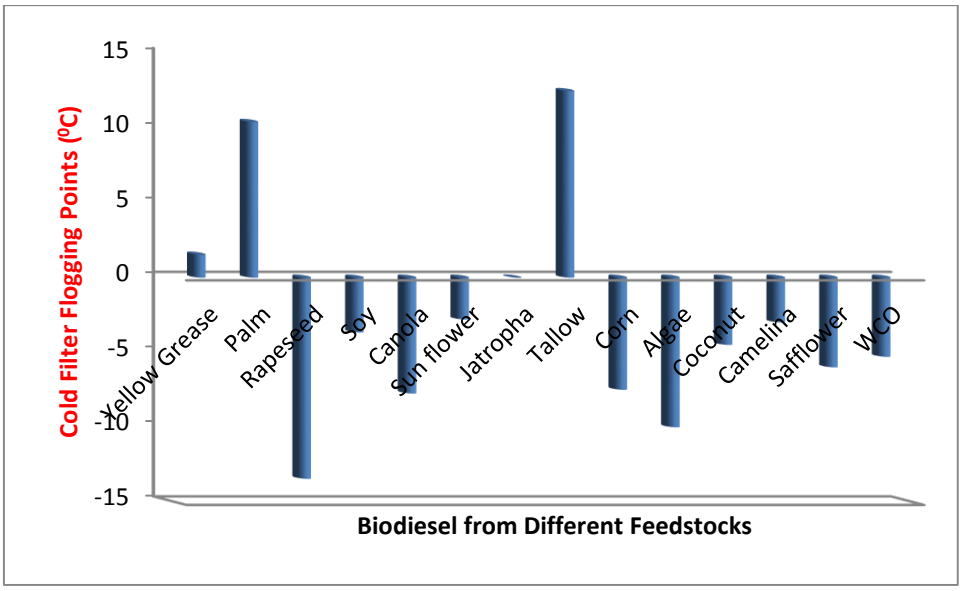


Figure 4.17: Cold Filter Flogging Point of Different Biodiesel Feedstock

4.3.9 Cetane number

The cetane numbers of different biodiesel feedstocks were presented in the figure 4.18. All the average cetane values under consideration conform to the ASTM standards. Cetane number is a primary indicator of fuel quality as it describes the ease of self-ignition. Low cetane numbers lead to long ignition delay and make starting the engine difficult (Enwerenmadu, 2014). Higher cetane number promotes faster auto ignition of the fuel. Cetane numbers affects specific fuel consumption of the engine. Whence, all the biodiesel under consideration here are safe, qualitative and have appreciable specific fuel consumption.

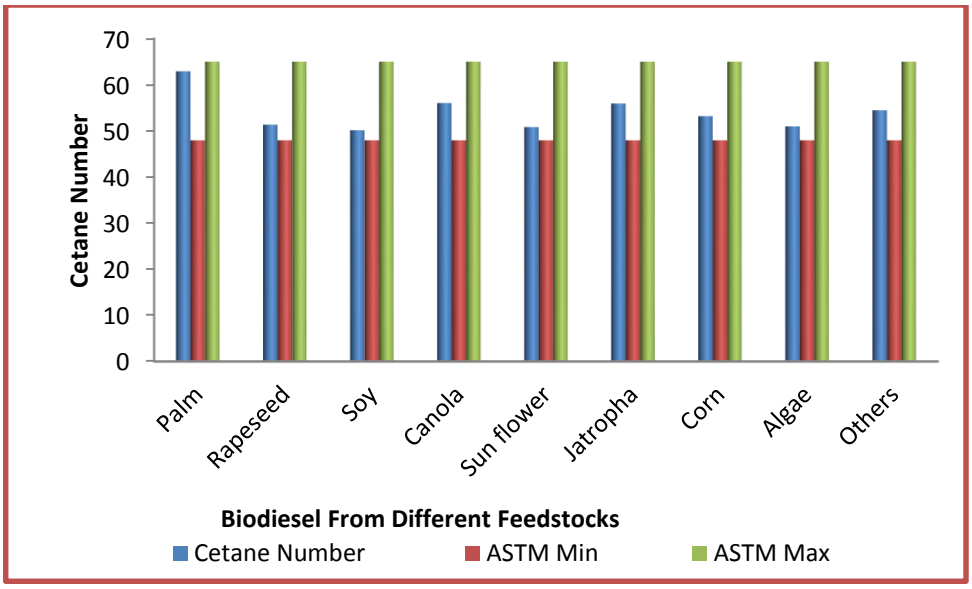


Figure 4.18: Cetane Number of Different Biodiesel Feedstock

4.4 Engine Performance Results Using Cotton, Jatropha and Neem Biodiesel

4.4.1 Exhaust gas temperature

According to Suarez-Bertoa *et al.* (2015), vehicular emissions significantly influence the composition of greenhouse gas and adversely impact on climate change. Figures 4.19, 4.20, 4.21 and 4.22 present the exhaust gas temperatures of the combustion of various biodiesel binary and mixed-blends in the stationary 4-cylinder diesel engine at variable speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm congruently. From figure 4.19 at the speed of 1000 rpm, B25J has the lowest exhaust temperature. That is the binary blend of 25 % Jatropha and 75 % diesel. While the highest exhaust temperature at that speed is given by B100J for 100 % pure Jatropha biodiesel fuel. Besides the B100J, all the Jatropha blends have the lowest exhaust temperatures at 5 %, 10 %, 15 %, 20 %, 25 % and 30% as compared to the blends of Cotton, Neem and the mixed blends.

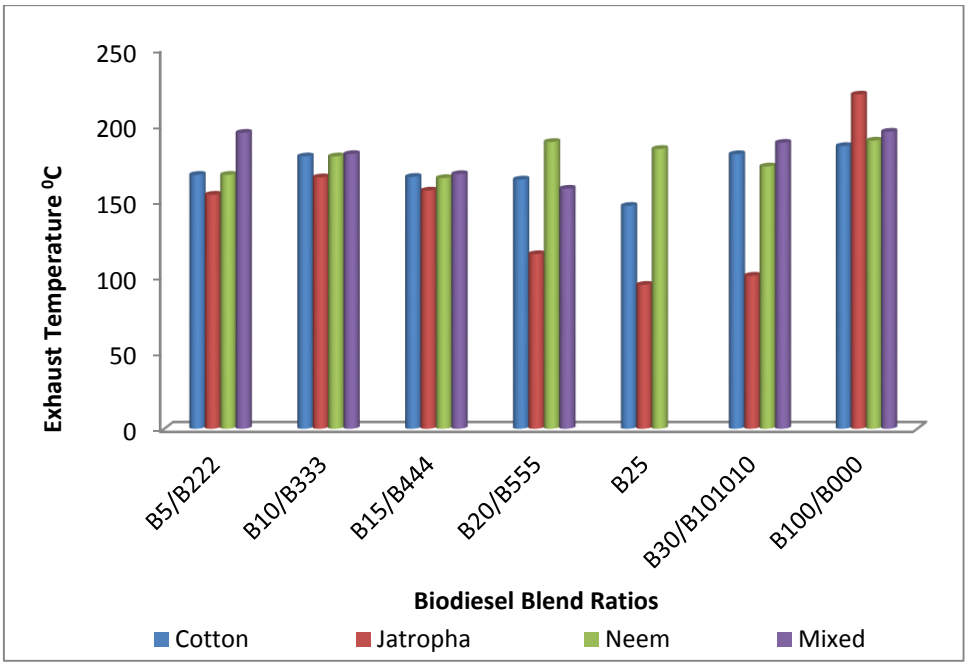


Figure 4.19: Exhaust Gas Temperature at 1000 rpm

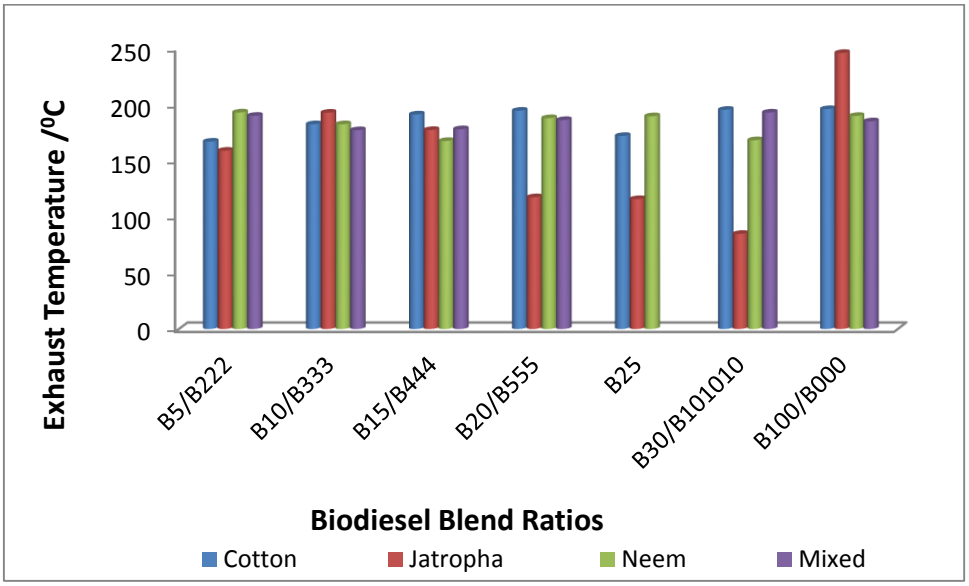


Figure 4.20: Exhaust Gas Temperature at 1500 rpm

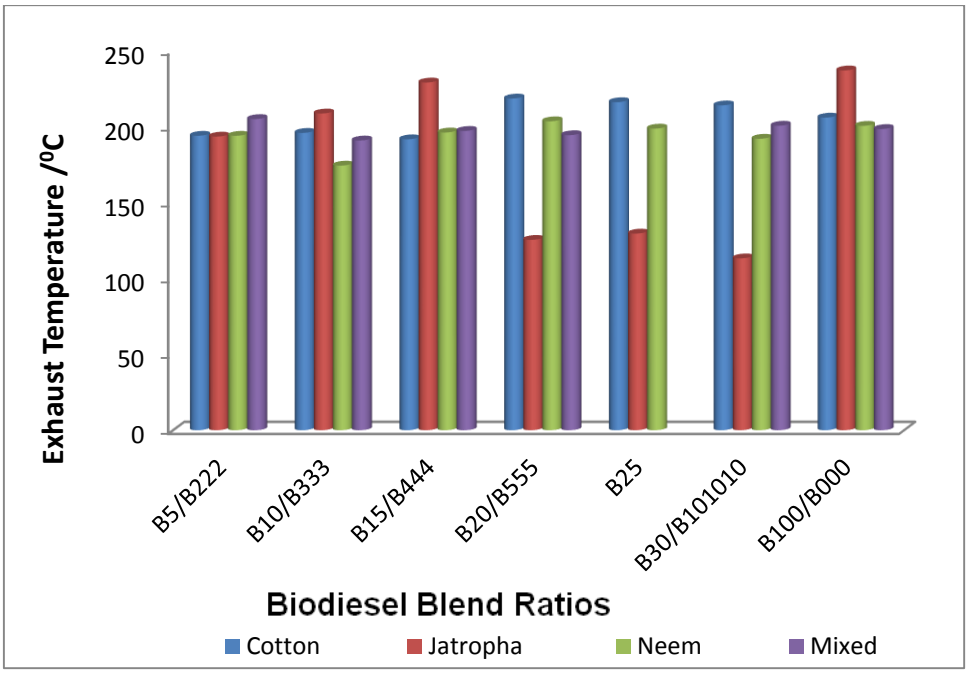


Figure 4.21: Exhaust Gas Temperature at 2000 rpm

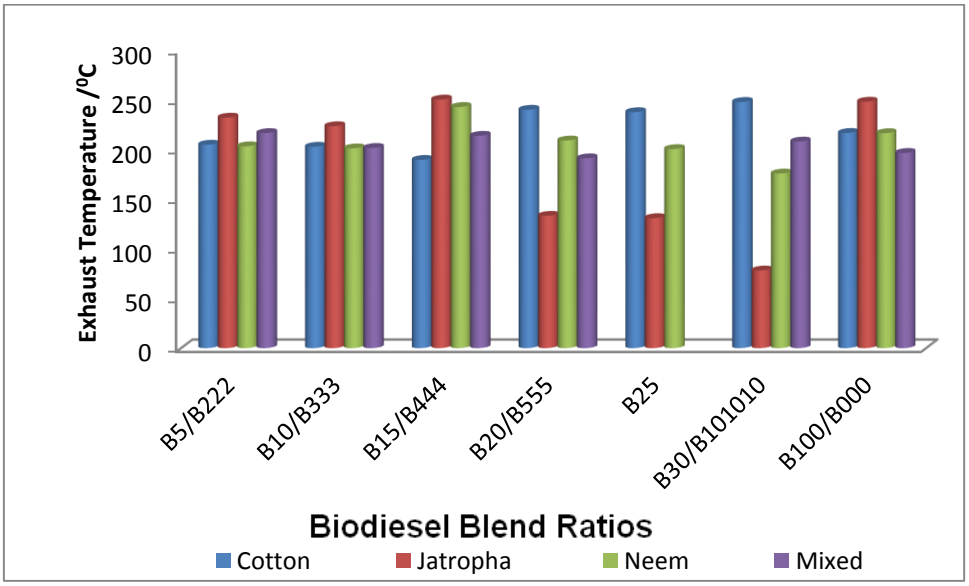


Figure 4.22: Exhaust Gas Temperature at 2500 rpm

Similarly, at the speed of 1500 rpm, 2000 rpm and 2500 rpm, 30 % Jatropha blend B30J has the lowest exhaust temperature in each case. The highest temperatures were recorded by B100J, in most cases except at the speed of 2500 rpm where B15J almost compete with the B100J with a slightly higher value. The exhaust temperatures for pure diesel

(B000) were recorded as 195 ^{0}C, 198 ^{0}C, 185 ^{0}C, and 196 ^{0}C for engine speeds of 1000 rpm, 1500 rpm 2000 rpm and 2500 rpm, respectively.

According to Hellier *et al. (*2015), the rates of soot oxidation increase with temperatures, this is because; the exhaust emission of soot is sensitive to the in-cylinder temperatures. Hence, the exhaust temperatures are proportional to the in-cylinder temperature.

4.4.2 Brake power

Figures 4.23, 4.24, 4.25 and 4.26 present the brake powers of the binary and mixed-blends of biodiesel from cotton, Jatropha and Neem seeds oil. A similar experiment was reported by Atabani *and Ceser* (2014) with a binary blend of biodiesel from Jatropha and diesel. They observed that, the maximum increase in power was at 50 % Jatropha biodiesel blend with diesel. From the experimental results herein presented, at the speed of 1000 rpm, the maximum brake power was given by B10J followed by B25N and the minimum brake power was portrayed by B25J followed by B30J, B222 of the mixed blend mixture of cotton, Jatropha and Neem biodiesel with diesel and B20J. For cotton and Neem binary biodiesel blend however, there is a significant difference in all the brake power values for various percentages of the respective biodiesels in diesel fuels. Only the binary blends of Jatropha and mixed blends of the three show fluctuations in values of the brake power. Most of the blends have brake power values higher than B 000 (Pure diesel) which has brake power values of 2.42 kW at 1000 rpm, 3.12 kW at 1500 rpm, 3.12 kW at 1000 rpm and 2.42 kW at 2500 rpm.

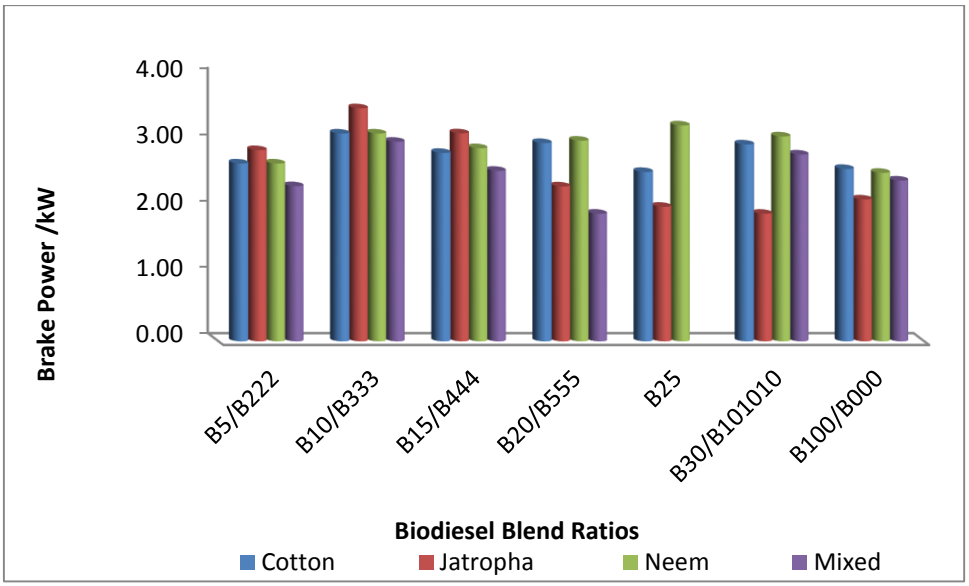


Figure 4.23: Brake Power at 1000 rpm

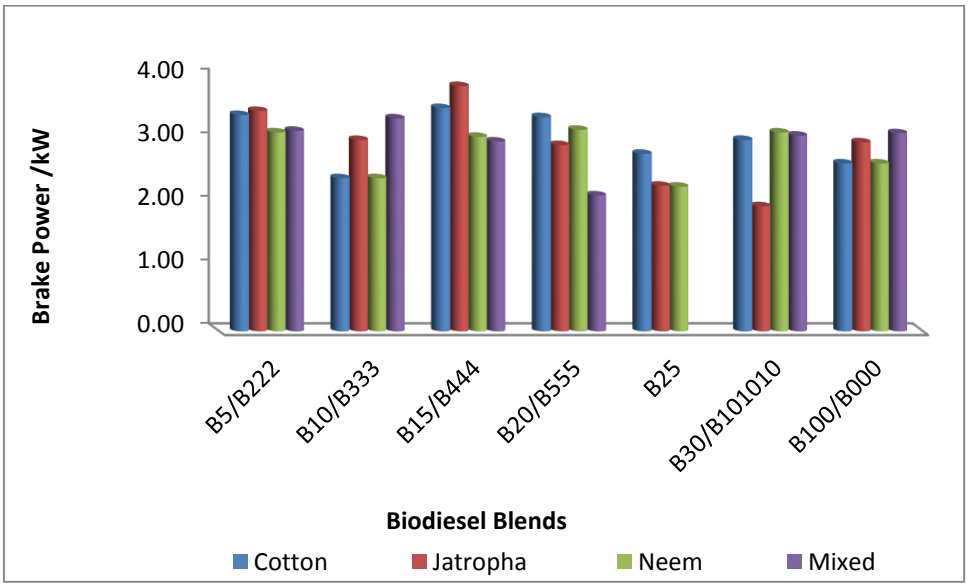


Figure 4.24: Brake Power at 1500 rpm

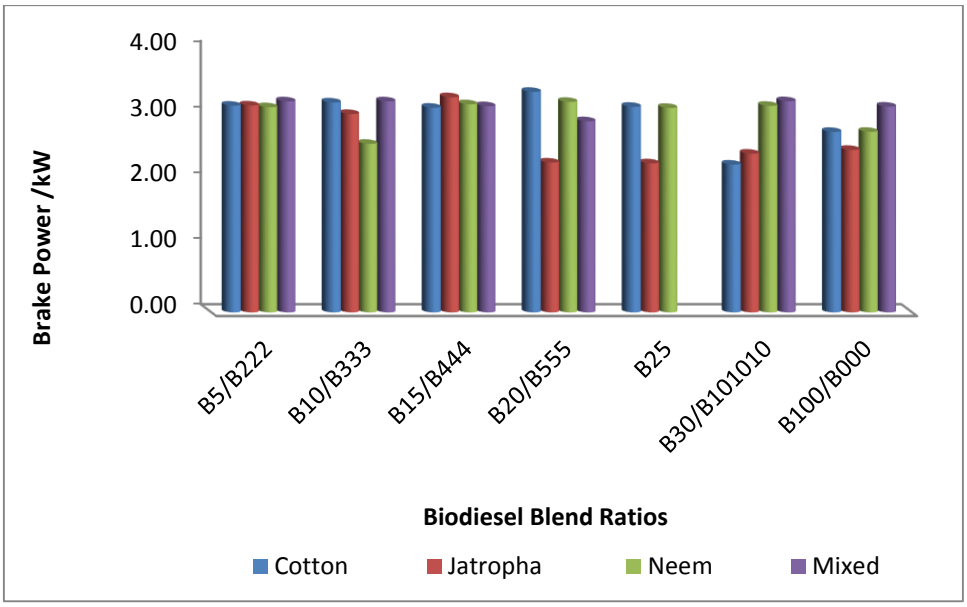


Figure 4.25: Brake Power at 2000 rpm

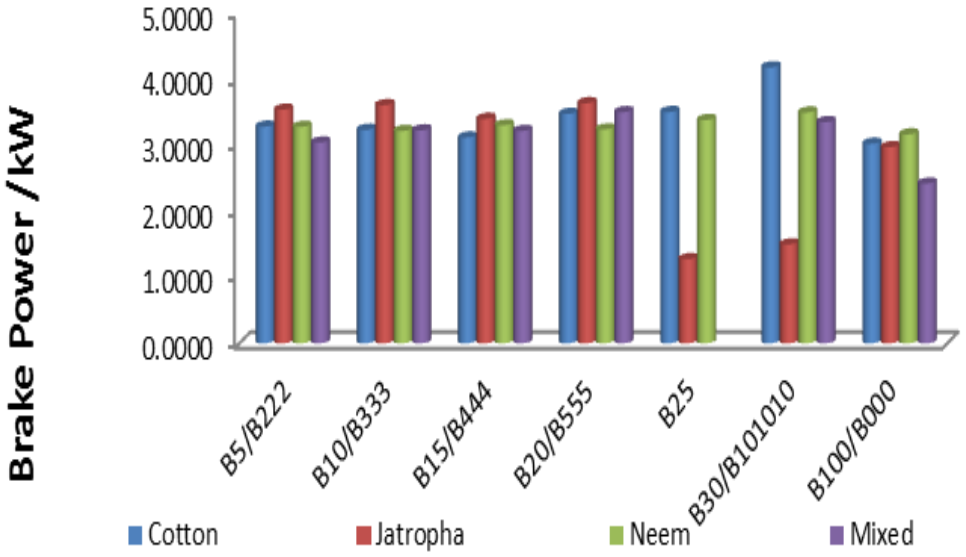


Figure 4.26: Brake Power at 2500 rpm

Furthermore, from figure 4.23, at a constant speed of 1500 rpm, B15J has the highest brake power followed by B15C, B5C, B5J, B20C and B333 respectively. The lowest value of brake power was for B30J, most of the other binary and mixed-blends have significant values of brake power. From figure 4.25 and at constant speed of 2000 rpm, almost all the biodiesel binary and mixed-blends except B20J, B25J, B30C, B30J and

have significant brake power values. The maximum value was achieved by B20C, while most of the biodiesel pure samples, binary blends and mixed-blends as well as fossil diesel values are within a significant range (1.92 kW to 4.19 kW) of the brake power values. This is similarly consistent with the findings at a speed of 2500 rpm. Most of the binary and multi-blends from Cotton, Jatropha and Neem have consistent values of brake power within a close substantial range. The lowest values of brake power were portrayed by B25J and B30J, whilst the maximum value was given by B30C. Conclusively, B25J and B30J are not suitable blends to be used in CI engines especially when brake power is the prime parameter under consideration. The maximum brake power values were achieved by the combustion of B30C, B20J and B20C at 2500 rpm, 1500 rpm, and 2000 rpm respectively (Maximum speed values). This is contrary to the findings of Mofijur *et al.* (2014) on the palm biodiesel blends in CI engines where the pure diesel has higher brake power than all the blends, although, this findings agree with same authors (Mofijur *et al.*, 2014) where they established that the brake power increases steadily with increase in engine speed for both the binary and multi-blends.

Additionally, Enweremadu *et al.* (2014) reported that, fossil fuel has a higher brake power than sunflower and canola biodiesel at all engine speeds. This is not consistent with the findings of this work, because, at lower engine speed, Jatropha blends of B10J and B15J have the maximum brake power at 1000 rpm and 1500 rpm respectively. While at the higher engine speed, cotton methyl ester blends of B20C and B30C give the maximum brake power at 2000 rpm and 2500 rpm congruently.

4.4.3 Brake specific fuel consumption (bsfc)

Figures 4.27, 4.28, 4.29 and 4.30 illustrate the variation in specific fuel consumption for all the fuel samples at 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm respectively. The lowest value of the bsfc of 0.15 kg/kW-h at engine speeds of 100 rpm and 1500 rpm was

depicted by B30J followed by B25J with bsfc values of 0.23 kg/kW-h and 0.28 kg/kW-h at 1500 rpm, and 2500 rpm. Other fuel samples show reasonable bsfc values at all speeds except B25C which shows a very high bsfc values for the speeds of 1000 rpm, 1500 rpm and 2500 rpm, followed by B15C at 1500 rpm. Therefore, in terms of bsfc B25J is the overall best blend although the least bsfc value was generated by B30J, while B25C is not a recommended blend for CI engine operation in terms of fuel consumption.

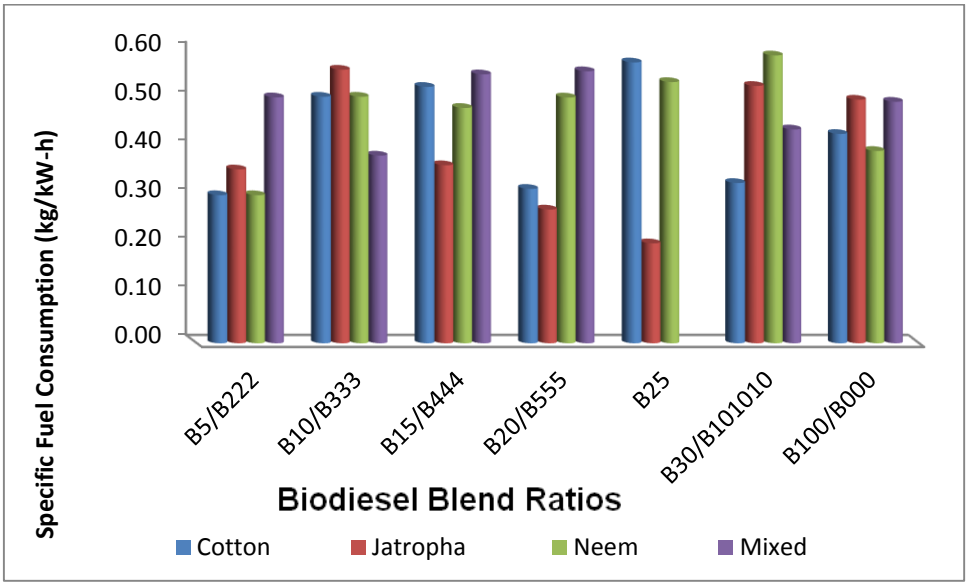


Figure 4.27: Brake Specific Fuel Consumption at 1000 rpm

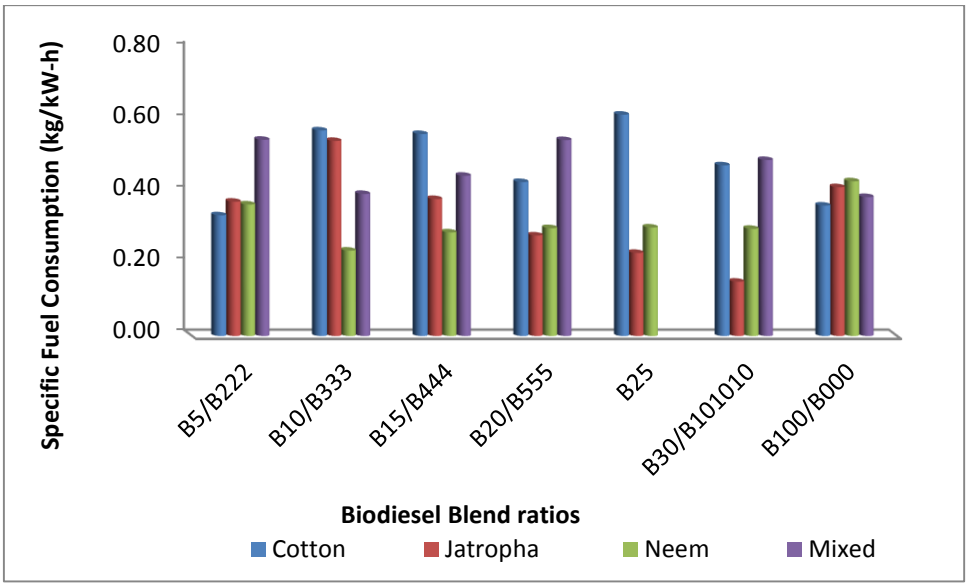


Figure 4.28: Brake Specific Fuel Consumption at 1500 rpm

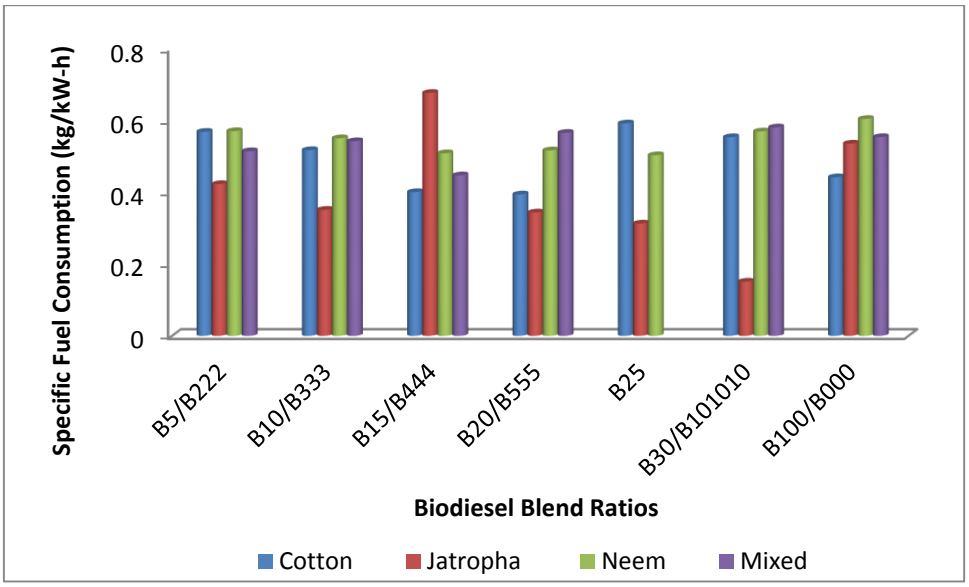


Figure 4.29: Brake Specific Fuel Consumption at 2000 rpm

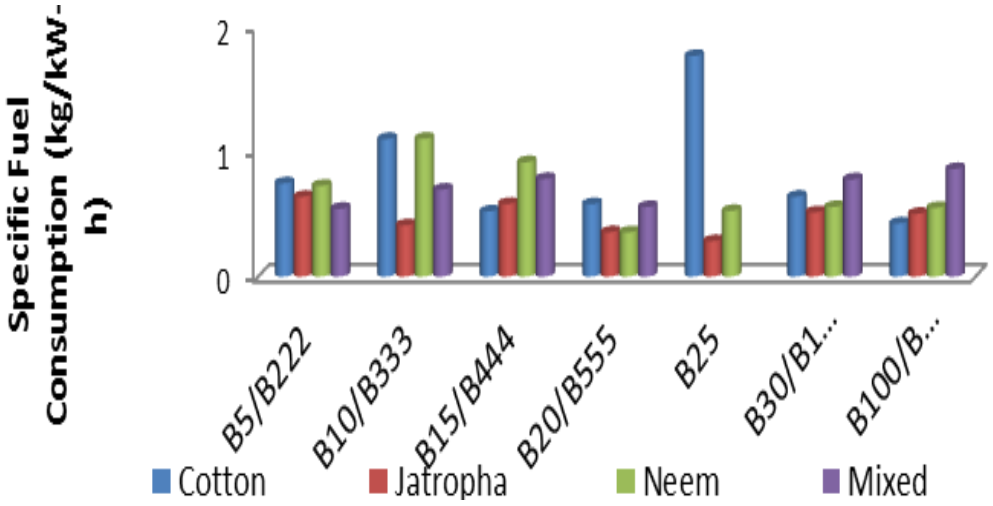


Figure 4.30: Brake Specific Fuel Consumption at 2500 rpm

Finally, the variation of brake specific fuel consumption with engine speed for B25J biodiesel blend is shown in figure 4.31. Since B25J gives the best blend for brake specific fuel consumption, then it has become paramount to investigate the particular speed at which the fuel consumption is more economical as compared with the others. From the figure, it could be observed that the bsfc is highest at the speed of 2000 rpm. The graph has shown an increamental trend on bsfc from 1000 rpm to 2000 rpm and it suddenly began to decrease with increase in the engine speed from 2000 to 2500 rpm.

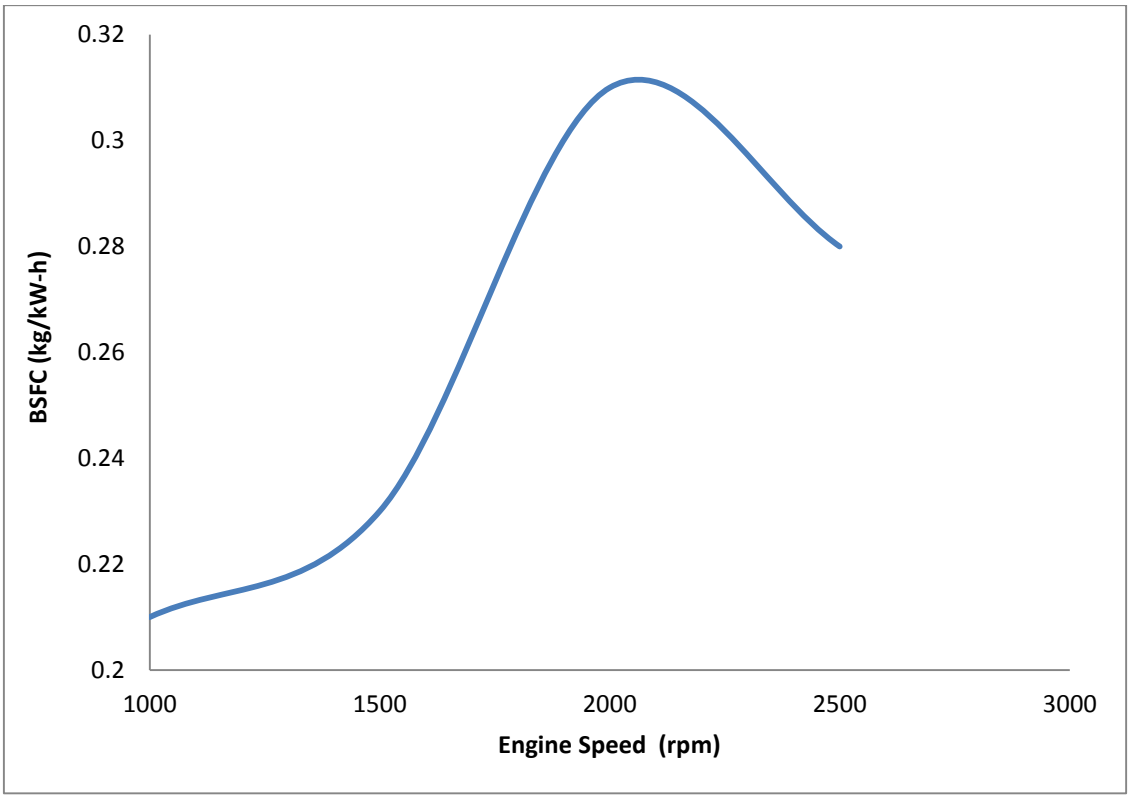


Figure 4.31 Variation of BSFC with Engine Speed for B25J

4.4.4 Brake mean effective pressure (bmep)

Figures 4.32, 4.33, 4.34 and 4.35 present the brake mean effective pressure of all the 27 fuel samples comprising of pure diesel, pure biodiesel from Cotton oil, Neem oil and Jatropha oil, binary and mixed-blends of the biodiesel-diesel samples at the respective speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm. The lowest value of the bmep was given by B25J at 1000 rpm, B15J at 1500 rpm, B20J at 2000 rpm, and 2500 rpm then B30J which has very low bmep at all speeds. The highest values of bmep were recorded by B30C at the maximum speed of 2500 rpm, B20C at 2000 rpm followed by B15J and B10j at 1500 rpm and 1000 rpm respectively.

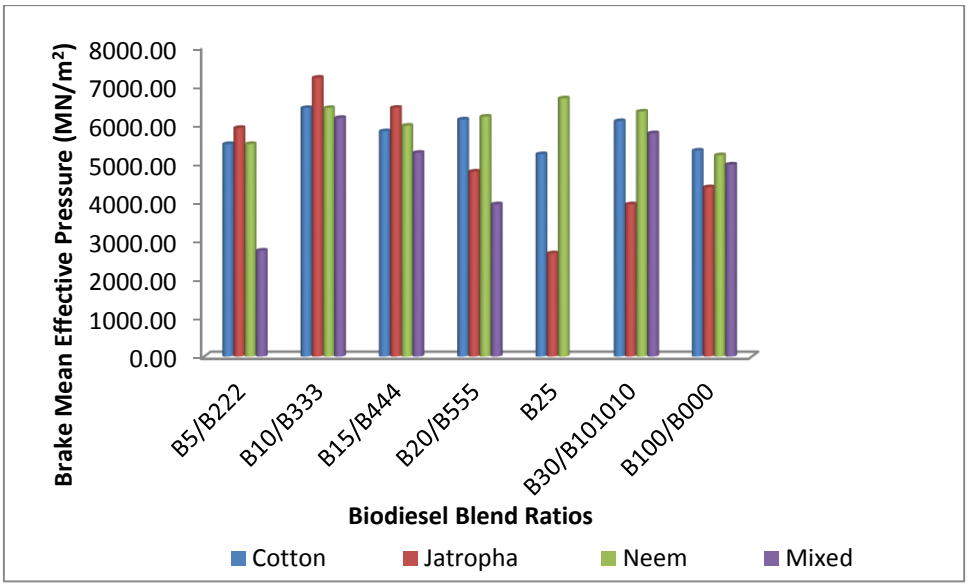


Figure 4.32: Brake Mean Effective Pressure at 1000 rpm

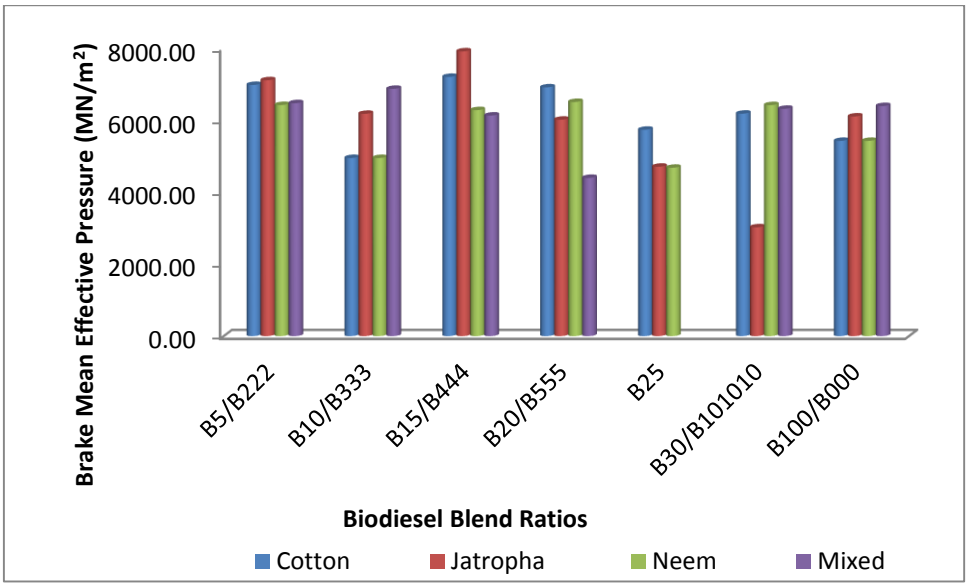


Figure 4.33: Brake Mean Effective Pressure at 1500 rpm

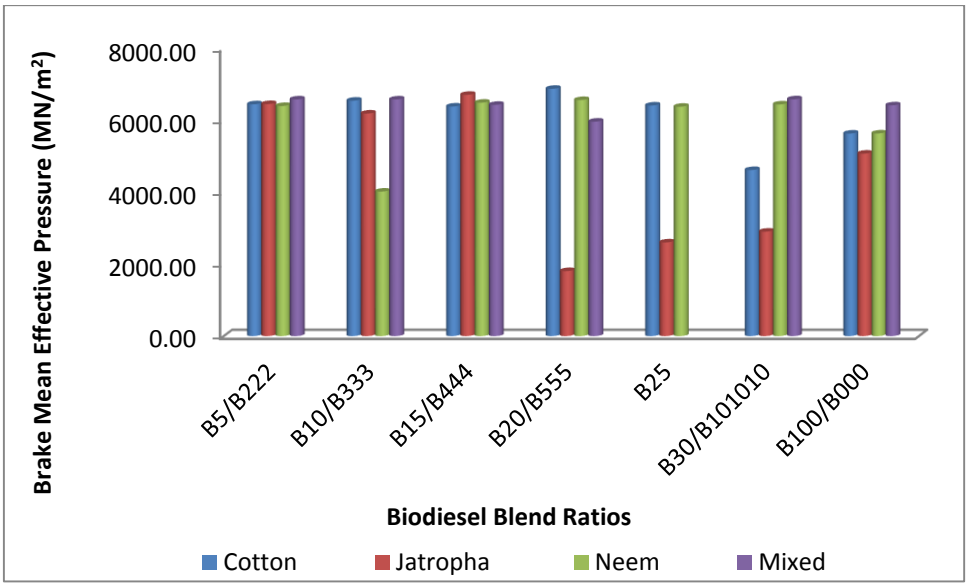


Figure 4.34: Brake Mean Effective Pressure at 2000 rpm

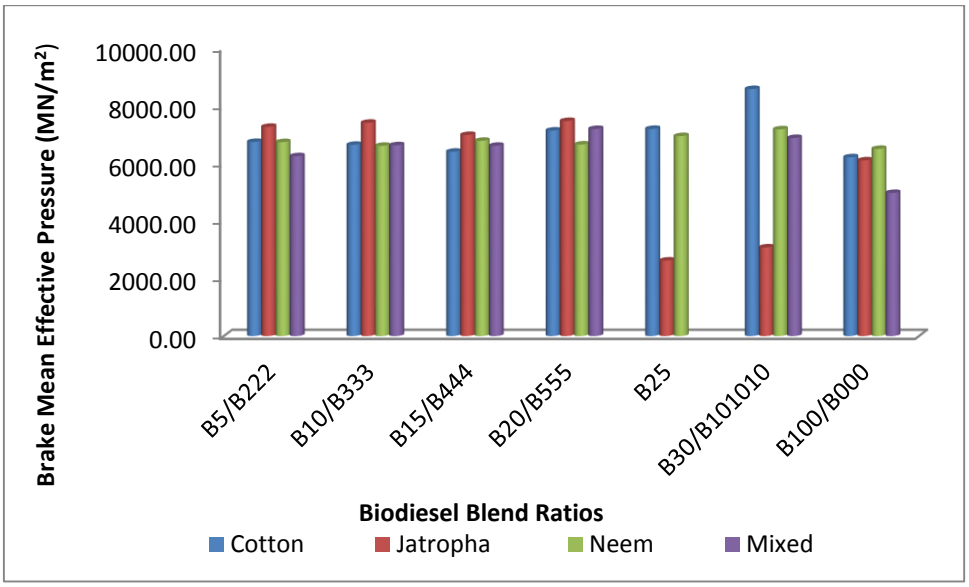


Figure 4.35: Brake Mean Effective Pressure at 2500 rpm

4.4.5 Brake thermal efficiency (bte)

The brake thermal efficiency values are presented in figures 4.36, 4.37, 4.38 and 4.39. The mixed blends, Cotton seed biodiesel and Neem biodiesel blends have lower values of brake thermal efficiency at the speeds of 1000 rpm, 1500 rpm and 2500 rpm, although at the speed of 1000 rpm, the mixed-blend B222 was lowest in terms of the brake thermal

efficiency. At 2000 rpm, B30N gave the lowest value of brake thermal efficiency similar to B25C at 1500 rpm. At 2500 rpm, B15N and B555 gave the least values for thermal efficiency. The maximum values of brake thermal efficiency were recorded by most of the Jatropha biodiesel blends in most cases at varying speeds; this is the general outlook of the figures. Specifically, B25J followed by B20J are the peak values of brake thermal efficiency at the corresponding speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm.

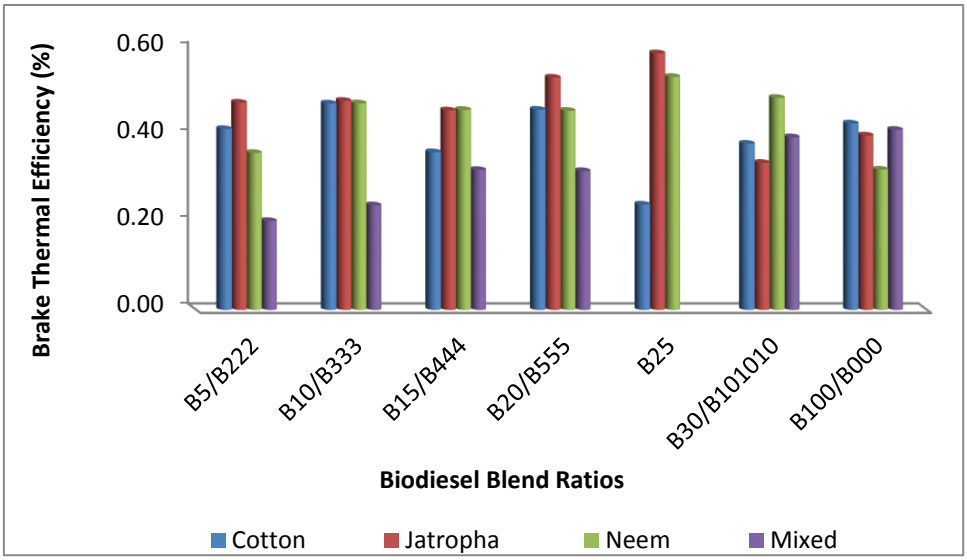


Figure 4.36: Brake Thermal Efficiency at 1000 rpm

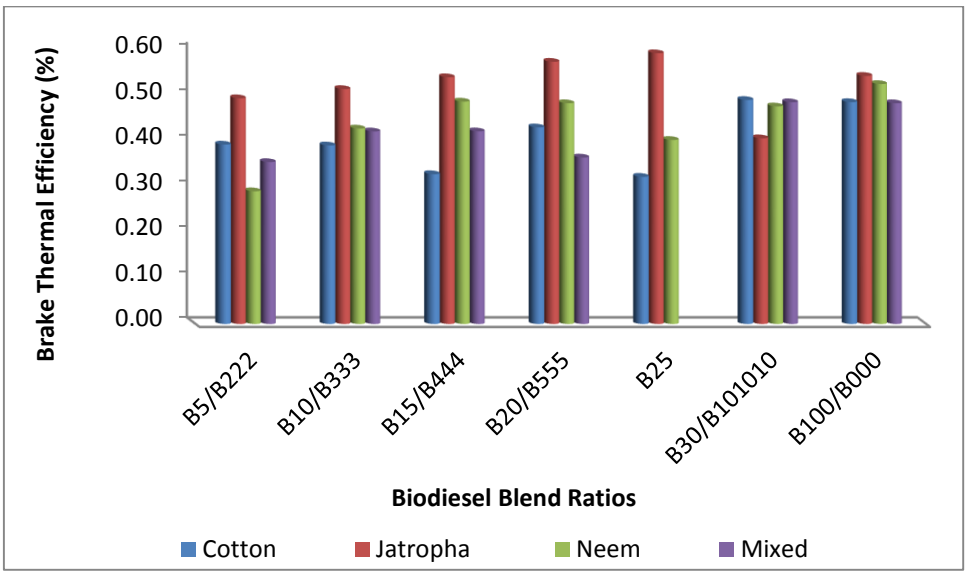


Figure 4.37: Brake Thermal Efficiency at 1500 rpm

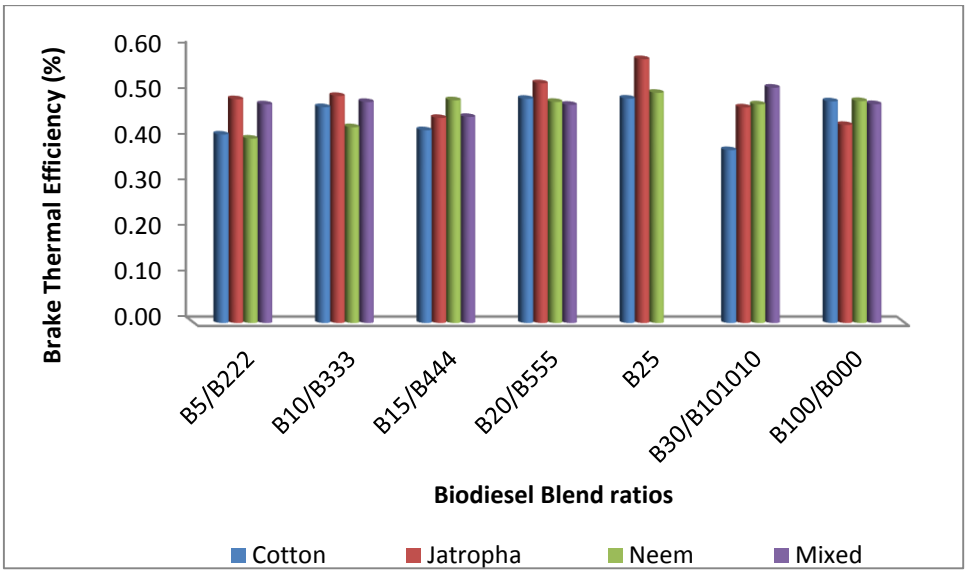


Figure 4. 38: Brake Thermal Efficiency at 2000 rpm

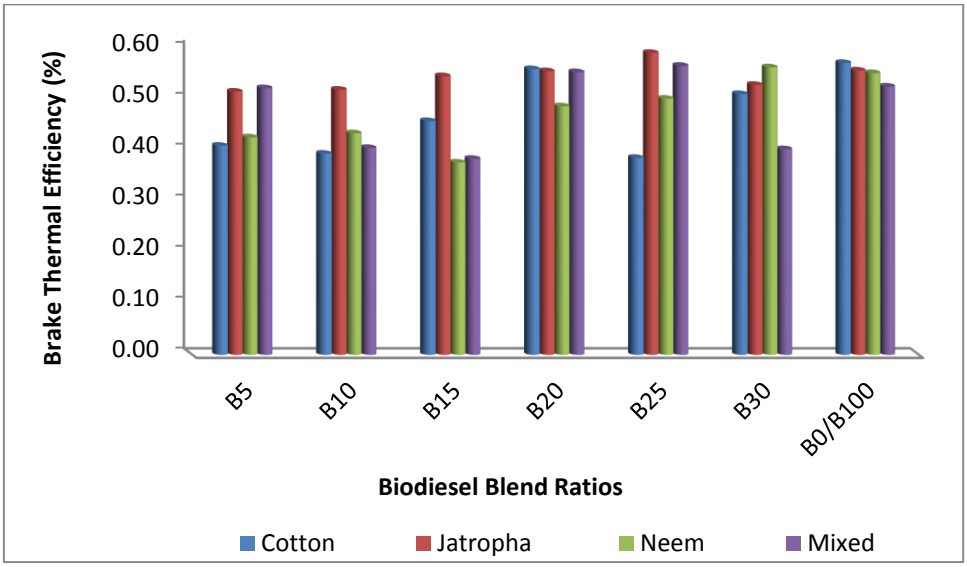


Figure 4.39: Brake Thermal Efficiency at 2500 rpm

It has been established in the literature that, the higher the compression ratio, the higher the brake thermal efficiency of a CI engine (Prasath *et al.*, 2012). It can be observed that in most cases of this work, the brake thermal efficiencies of the biodiesel blends are higher than that of the diesel fuel, this is consistent with the findings of Senthilkumar and Sivaprakasam (2013) and Atabani and Cesar (2014). In other words, it can be established that, the thermal efficiencies of the binary blends and multi-blends of the biodiesel from

Cotton, Jatropha and Neem oil are comparable with that of diesel; this is consistent with the findings of Tira *et al. (*2014).

4.5 Exhaust Emissions Results Using Cotton, Jatropha and Neem Biodiesel

Exhaust Emissions Results Using Cotton, Jatropha and Neem Biodiesel binary and multi-blends are presented in the figures. 4.40 to 4.69.

4.5.1 Combustion efficiency

Figures 4.40, 4.41 and 4.42, present the combustion efficiencies at the engine speeds of 1500 rpm, 2000 rpm and 2500 rpm correspondingly. From figure 4.40, the cotton biodiesel blend of 20 % (B20C) gives the highest value for combustion efficiency followed by the mix blend at B555. On figure 4.41, the same B20C shows the highest combustion efficiency followed by B10J, B5J and B25C. There is no any significant difference between the combustion efficiencies of the binary and multi blends of biodiesel from Neem, Jatropha and cotton with diesel. In figure 4.42, B5J, B10J, B15J, B15N and B20C took the lead in combustion efficiency at 2500 rpm. There are no much significant differences between the fuels in terms of combustion efficiency. It can be deduced that B20C leads in combustion efficiency although it has lowest exhaust temperatures. This implies that, the combustion efficiency is inversely proportional to the exhaust gas temperature of a given biodiesel/blend.

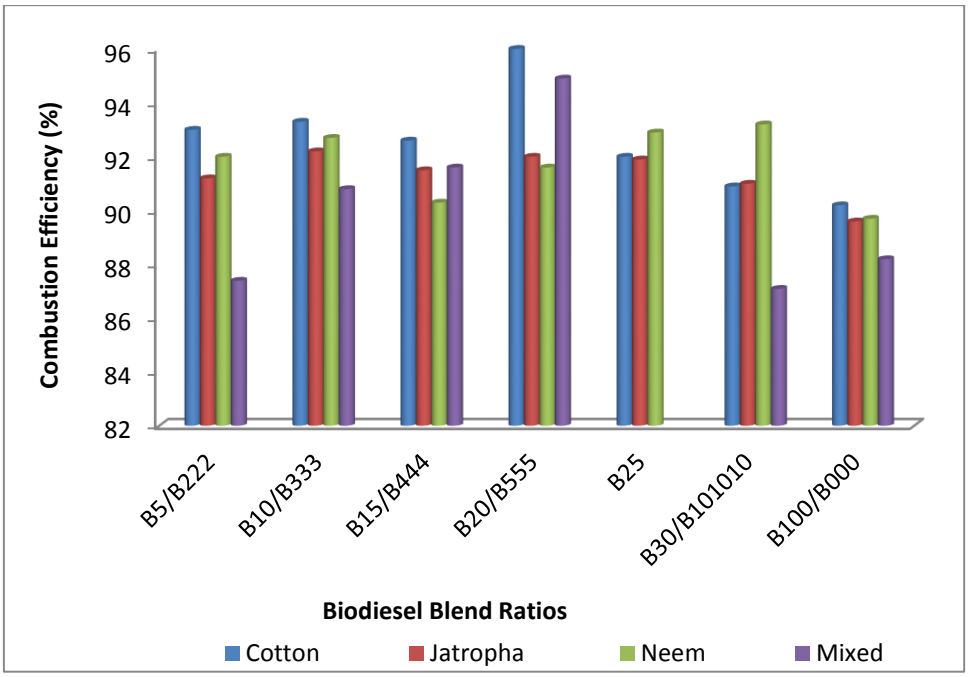


Figure 4.40: Combustion Efficiency at 1500 rpm

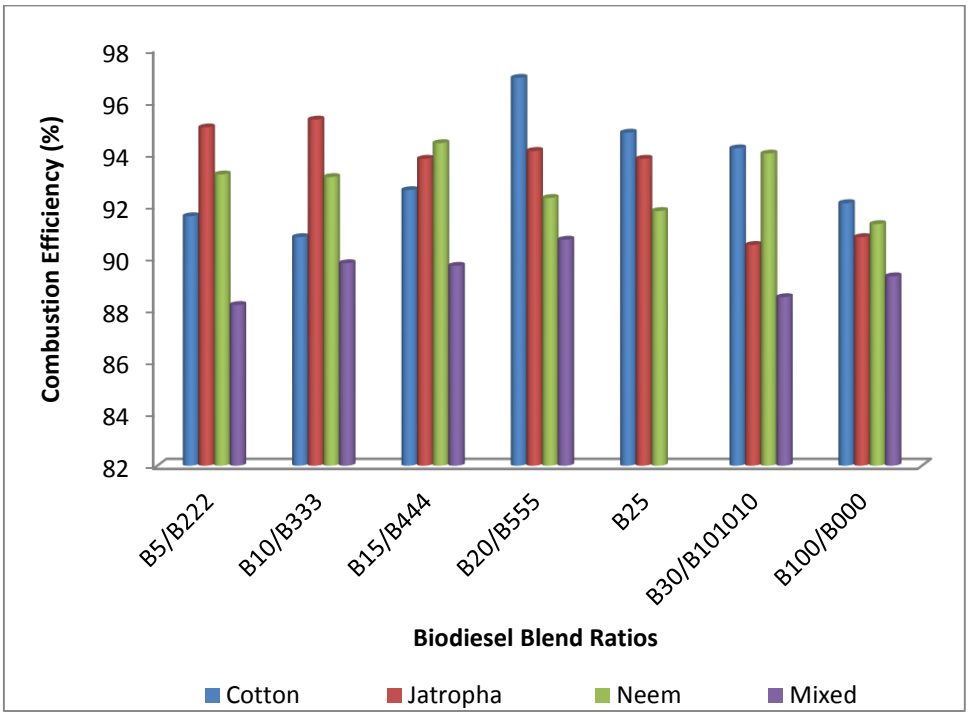


Figure 4.41: Combustion Efficiency at 2000 rpm

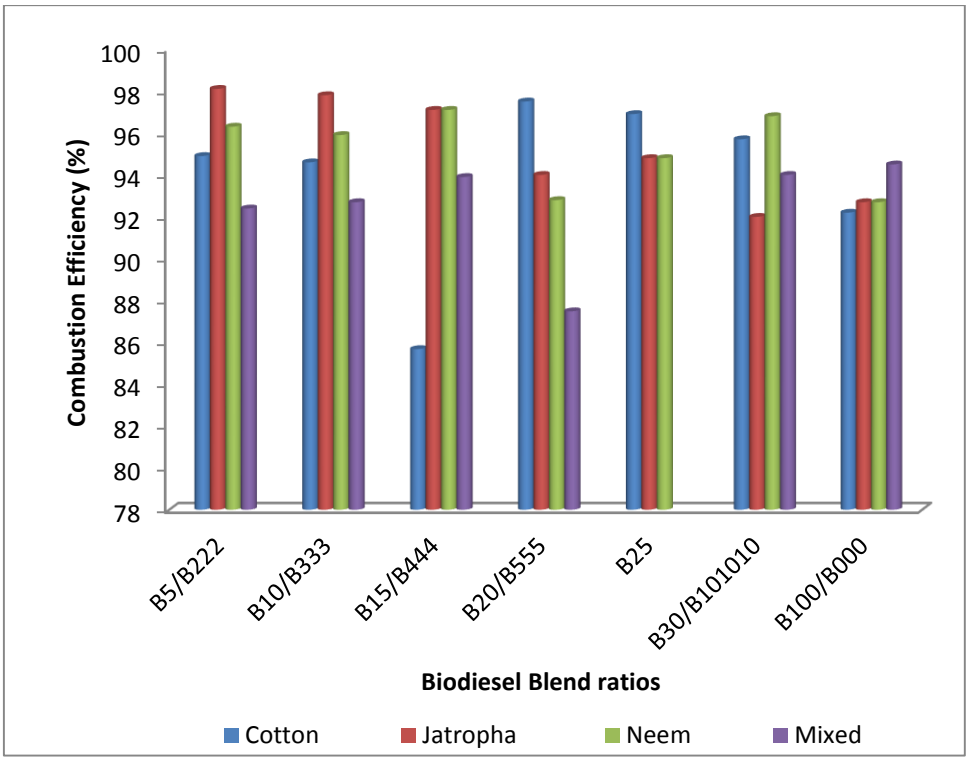


Figure 4.42: Combustion Efficiency at 2500 rpm

4.5.2 Carbon monoxide (CO) emissions

Figures 4.43, 4.44 and 4.45, portrayed the CO emission of the fuel samples at 1500 rpm, 2000 rpm and 2500 rpm. Similarly, figures 4.46, 4.47 and 4.48correspondingly show the CO emissions of same CO at 0 % oxygen at the respective speeds of 1500 rpm, 2000rpm and 2500rpm.

From the figures 4.43 to 4.45, at the speed of 1500 rpm, B20C has the least CO emission followed by B100N, B100J and B100C respectively as portrayed in figure 4.43. The peak values of CO emissions were given by the mixed-blends in all cases. At 2000 rpm, B15C has the lowest CO emissions, followed by B100C, B100N and B101010 which is a multi-blend. The peak emission values were given by B222, B10N, B555, B101010, B30J and pure diesel respectively. B20J gives the best value of CO emissions followed by B100C, B100N and B100J at 2500 rpm. The peak CO emission values were given by the multi-blends and B20N, which replaces B555, then the pure diesel. All the multi-blends except

B555 give a high percentage of CO emissions. While all the pure biodiesels, except B100J at 2000 rpm gives a very low CO emission ahead of the pure biodiesel samples, B15C, B20C and B20J have the lowest values of exhaust emissions.

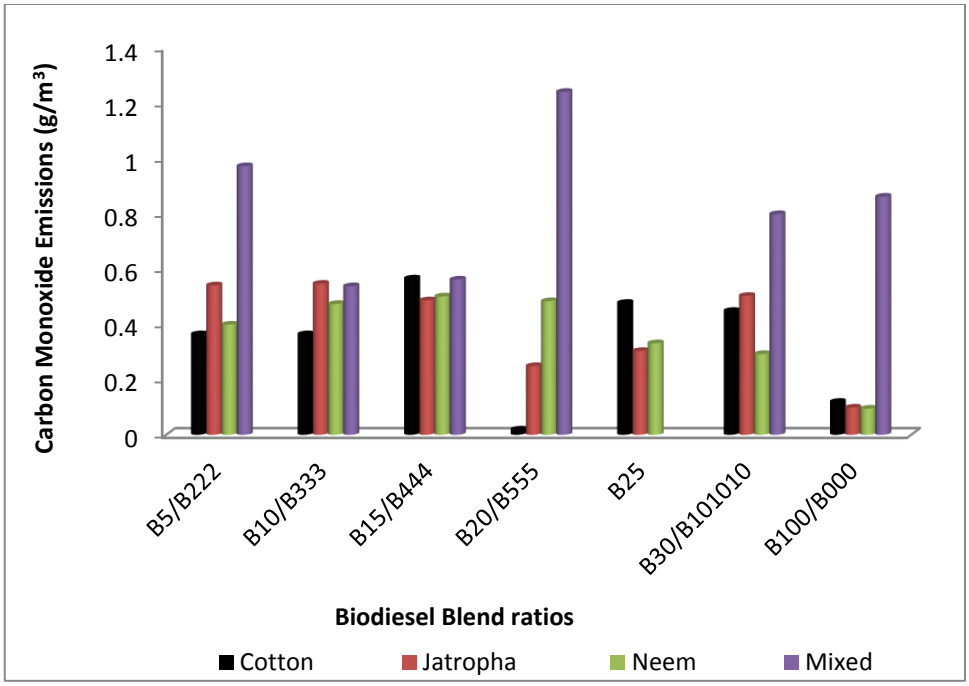


Figure 4.43: CO Emission at 1500 rpm

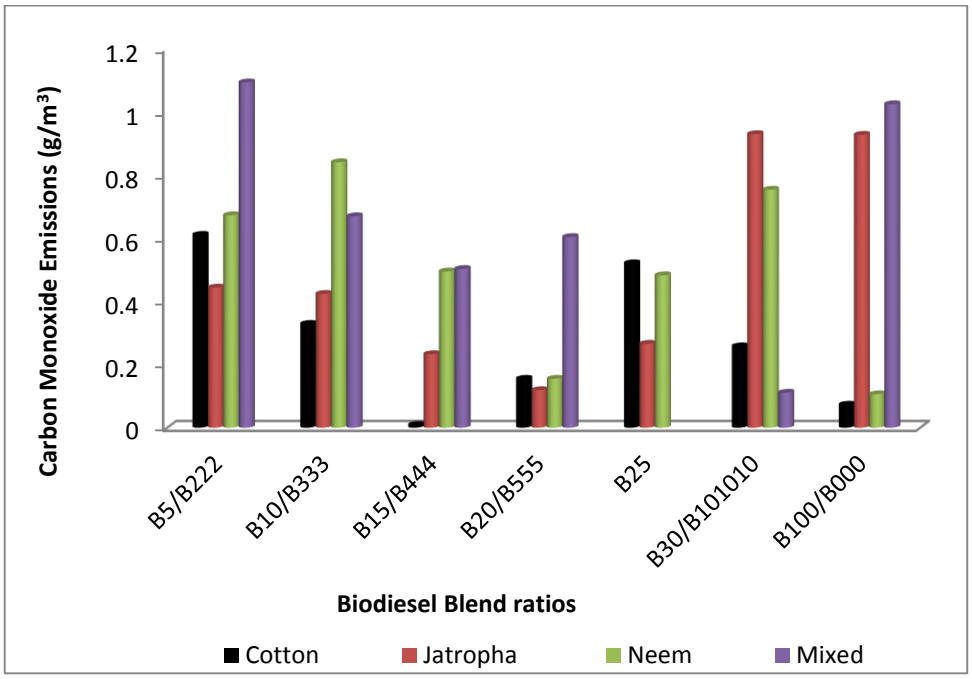


Figure 4.44: CO Emission at 2000 rpm

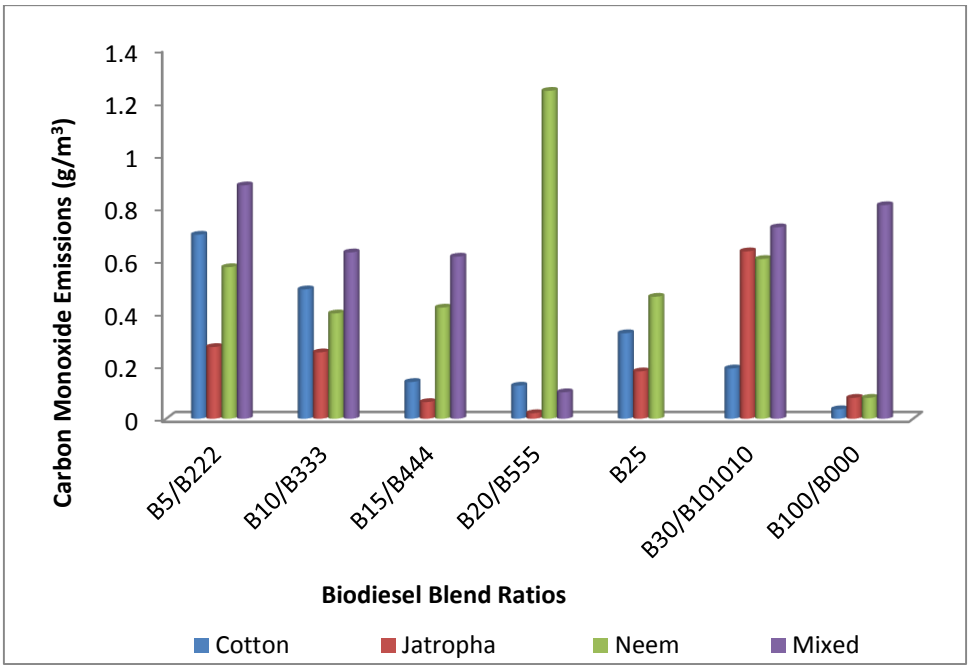


Figure 4.45: CO Emission at 2500 rpm

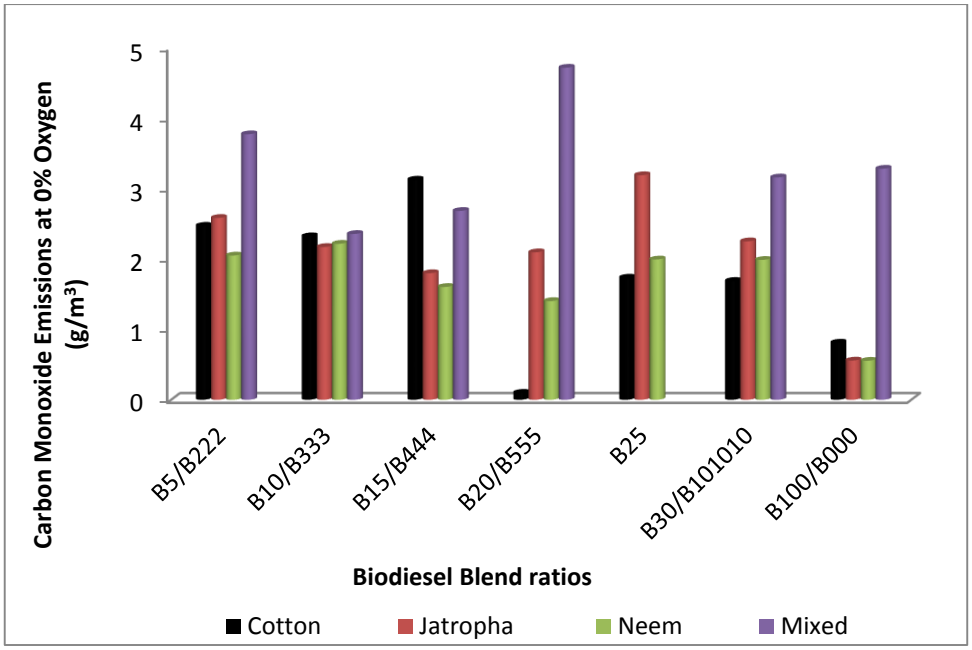


Figure 4.46: CO Emission at 0 % O_2 at 1500 rpm

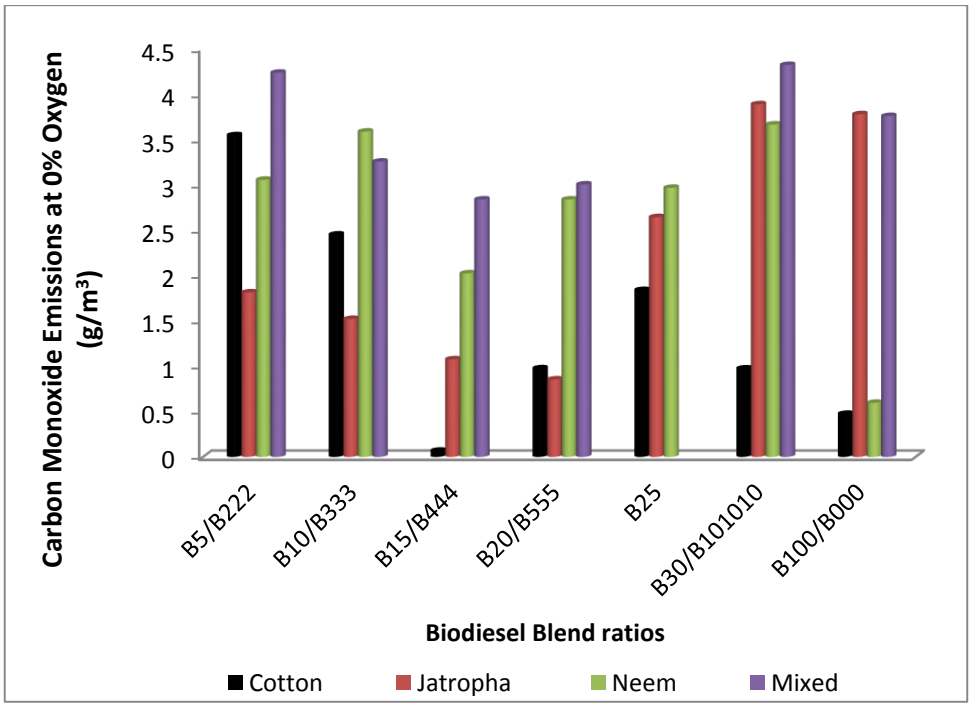


Figure 4.47: CO Emission at 0 % O_2 at 2000 rpm

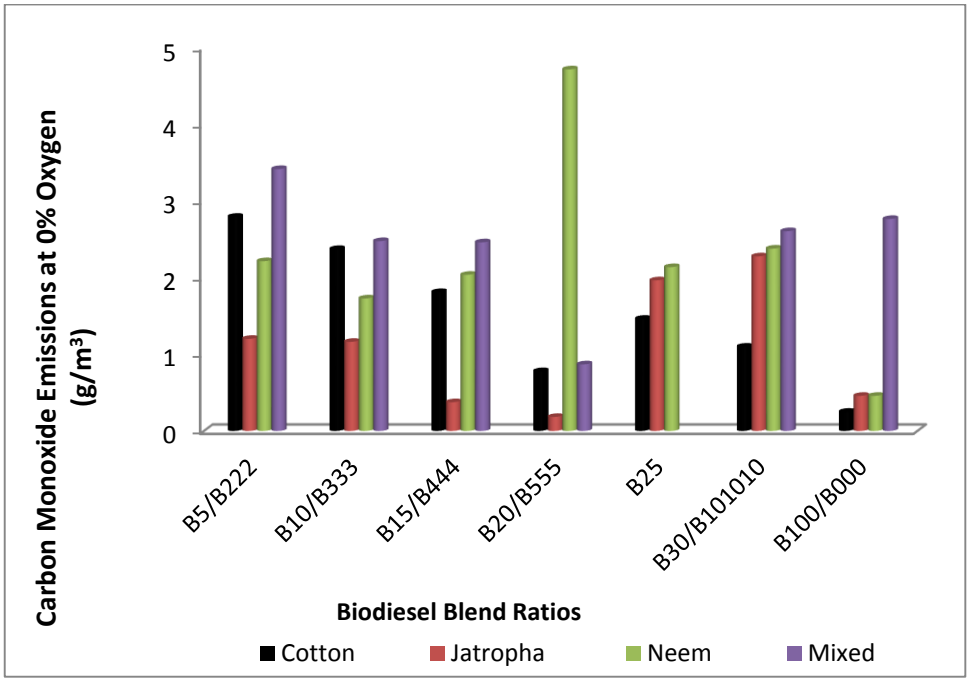


Figure 4.48: CO Emission at 0 % O_2 at 2500 rpm

Furthermore, from figures 4.46, 4.47, and 4.48, at 0 % oxygen, at the speed of 1500 rpm B20C has the lowest CO emissions, followed by B100J, B100N and B100C. The peak

values have been the multi blends, the pure diesel and B15C. This is similar to the trend shown on figure 4.43. Similarly, at 2000 rpm and at 0 % oxygen (figure 4.47), B15C has the lowest CO emission followed by B100C and B100N. The peak values of CO emissions were portrayed by the multi blends and B20N, then the pure diesel. This figure is almost identical to figure 4.44. Conclusively, biodiesel blends, B20C, B15C, B20J and B555 at 2500 rpm are very effective in reducing CO emissions. All the multi blends except B555 are not too good in terms of CO emissions.

Additionally, Atabani and Cesar (2014) found out that B20 of *Calophyllum inophylum* biodiesel lower CO emissions; this is consistent with this work considering the behaviour of B20C and B20J.

At elevated temperatures, performance of the engine improved with relatively better burning of the fuel (Senthikumar and Sivaprakasam 2013), resulting in CO emission decrease. This is not consistent with the findings of Hellier *et al. (*2015), CO is a product of incomplete combustion, the levels of which could be higher at the maximum in cylinder temperatures. Because biodiesels are oxygenated fuels and have low in cylinder temperatures, they tend to have lower CO emissions. This accounts for the best performance found in B100C, B100N and B100J, as well as B20C, B15C and B20N which all have low exhaust temperatures in most cases. This is also applicable to bioethanol's combustion in spark ignition engines where the pure bioethanol and blends give lower CO emissions (Zhang *et al.*, 2013). The findings of this work are similar and consistent with the work of Prasad *et al. (*2011). Formulation of CO is due to the insufficient oxygen and time in the combustion chamber during combustion process. Due to intrinsic oxygen content in the biodiesel, the oxygen availability for the oxidation of CO is higher in the biodiesel and their blends compared to pure diesel, only that the mixture of the biodiesels put together does not obey this phenomenon.

4.5.3 Nitrogen oxide (NOx) emissions

The values of NOx emissions are depicted in figures 4.49, 4.50…4.53 and 4.54:

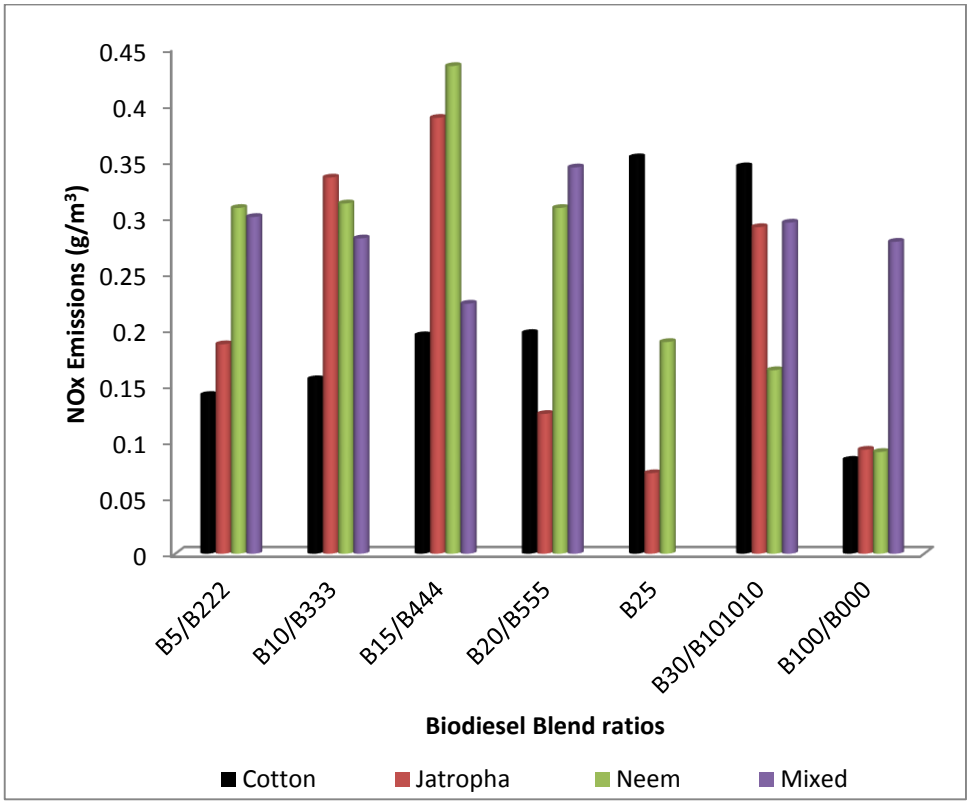


Figure 4.49: NOx Emission at 1500 rpm

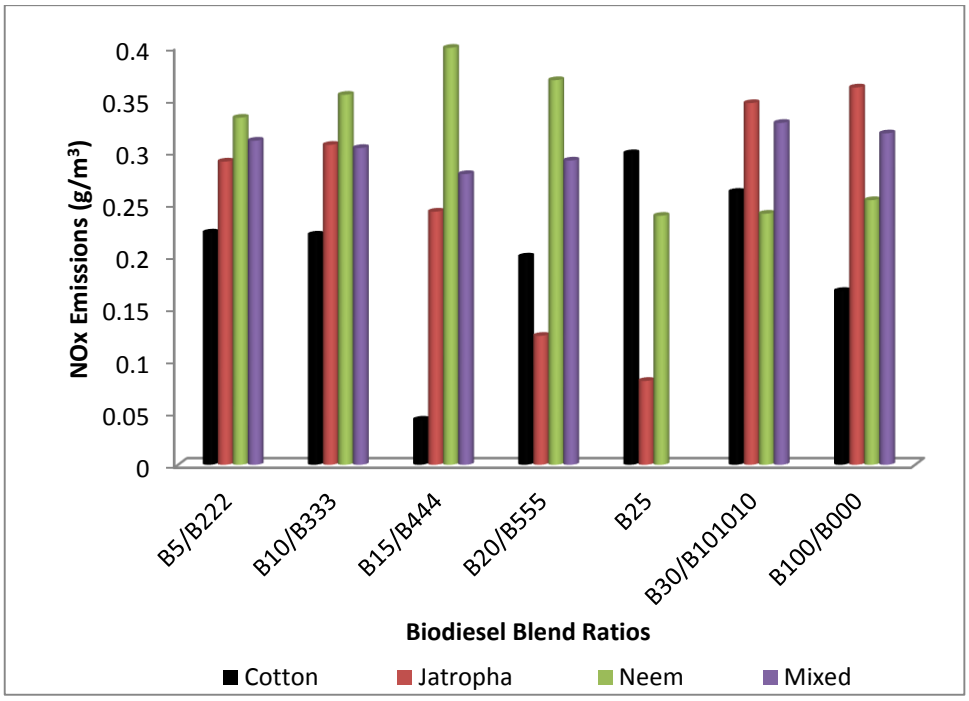


Figure 4.50: NOx Emission at 2000 rpm

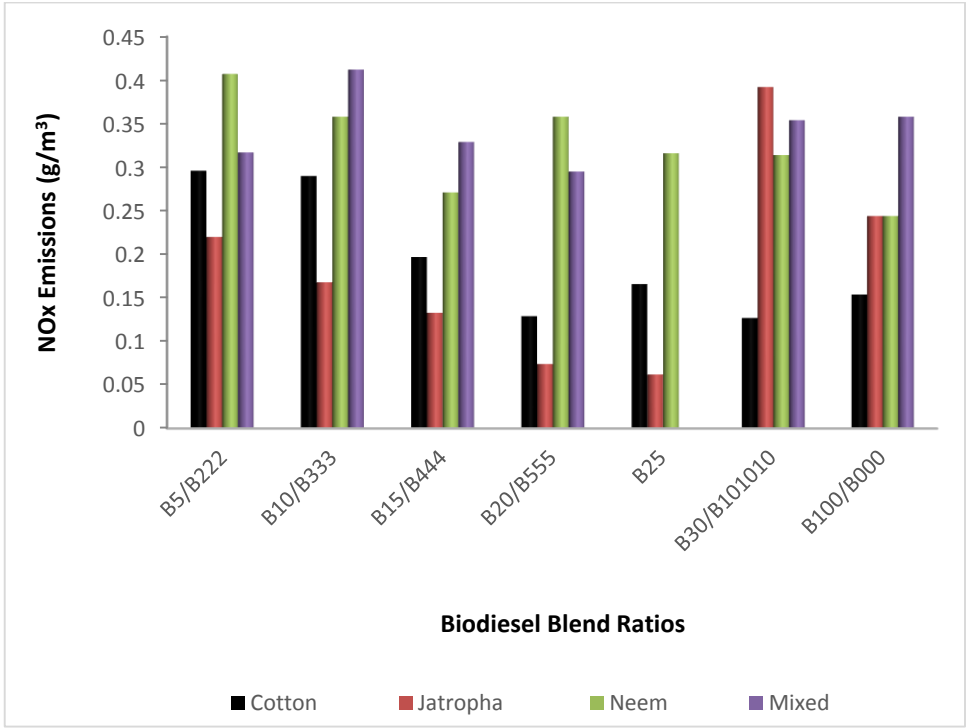


Figure 4.51: NOx Emission at 2500 rpm

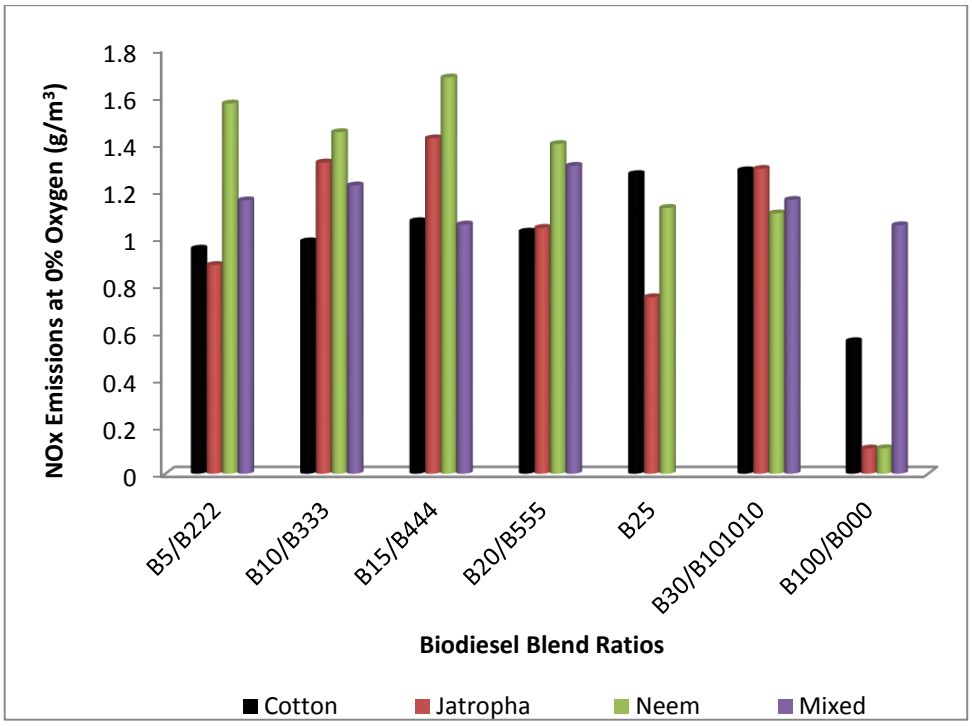


Figure 4.52: NOx Emission at 0 % O_2 at 1500 rpm

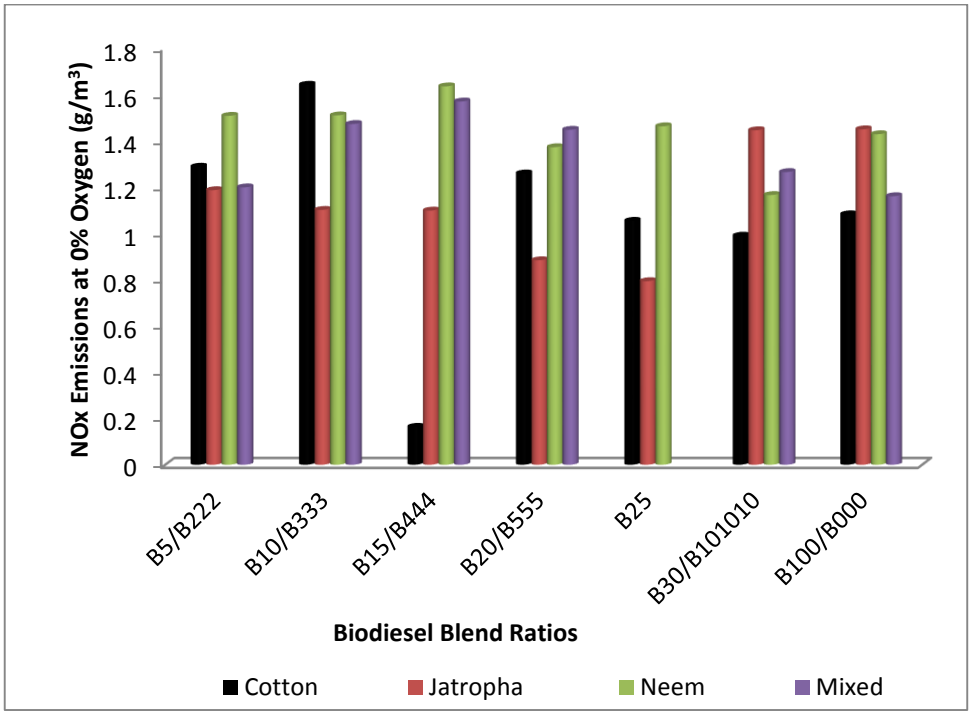


Figure 4. 53: NOx Emission at 0 % O_2 at 2000 rpm

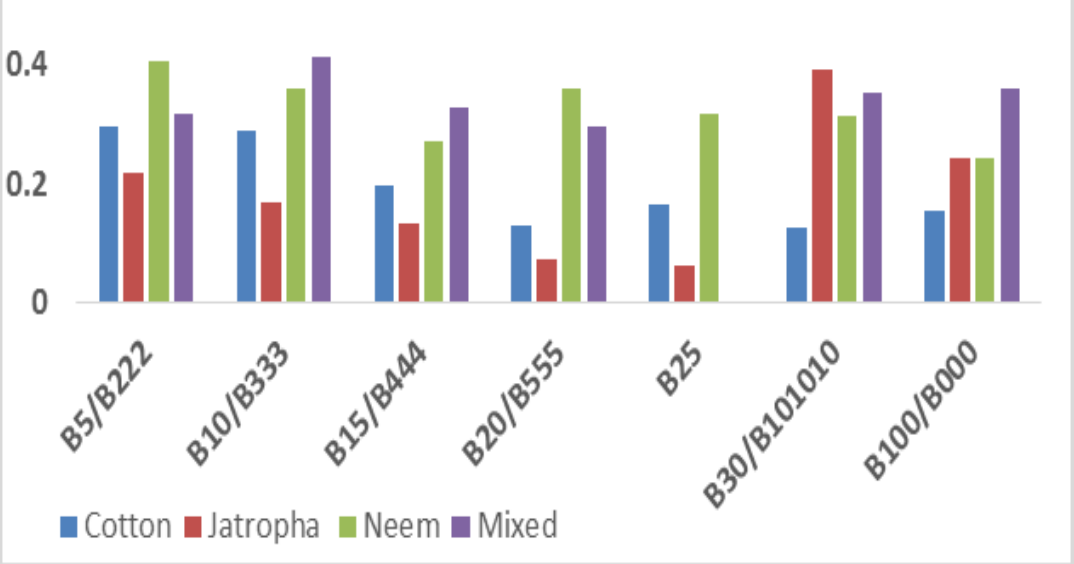


Figure 4.54: NOx Emission at 0 % O_2 at 2500 rpm

Figures 4.49, 4.50 and 4.51 depict the percentage of NO_X emissions against the blends of cotton, Jatropha, Neem and diesel at varying speeds of 1500 rpm, 2000 rpm and 2500 rpm respectively. Similarly, figures 4.52, 4.53 and 4.54 portrayed the NO_X emissions at 1500 rpm, 2000 rpm and 2500 rpm at 0 % oxygen.

From figure 4.49, the highest peak of NO_X emission was exhibited by B15N followed by B15J. Surprisingly, B100C, B100N and B100J have the lowest NO_X emission tendencies comparatively. At 2000 rpm as shown on figure 4.50, the lowest NO_X emission percentage was achieved by B25J, B15C and B20J. The peak values were portrayed by Neem, mixed blends and pure diesel. It is clear that Neem and mixed blends are not better in terms of NO_X emissions as compared to pure diesel. This is not consistent with the findings of Mofijur *et al. (*2014); Khan *et al. (*2014); Ong *et al.*, 2014a); Ong *et al. (*2014b); Prasad *et al. (*2011), although the results are consistent with the findings of Senthikumar and Sivaprakasan (2013; Atabani & Cesar (2014). The NOx emissions for the pure diesel (B000) were 0.28 g/m^3, 0.32 g/m^3 and 0.34 g/m^3 at the respective speeds of 1500 rpm, 2000 rpm and 2500 rpm.

4.5.4 Oxygen emissions

The amounts of oxygen produced during the combustion processes are presented in figures 4.55, 4.56 and 4.57. The figures portrayed the percentage oxygen emissions against the fuels at the respective speeds of 1500 rpm, 2000 rpm and 2500 rpm. There is about 25 % difference between the percentages of oxygen for some of the fuels at different engine speeds. The oxygen content of biodiesel and blends is higher than that of the diesel in all instances; this is consistent with Topare *et al. (*2011).

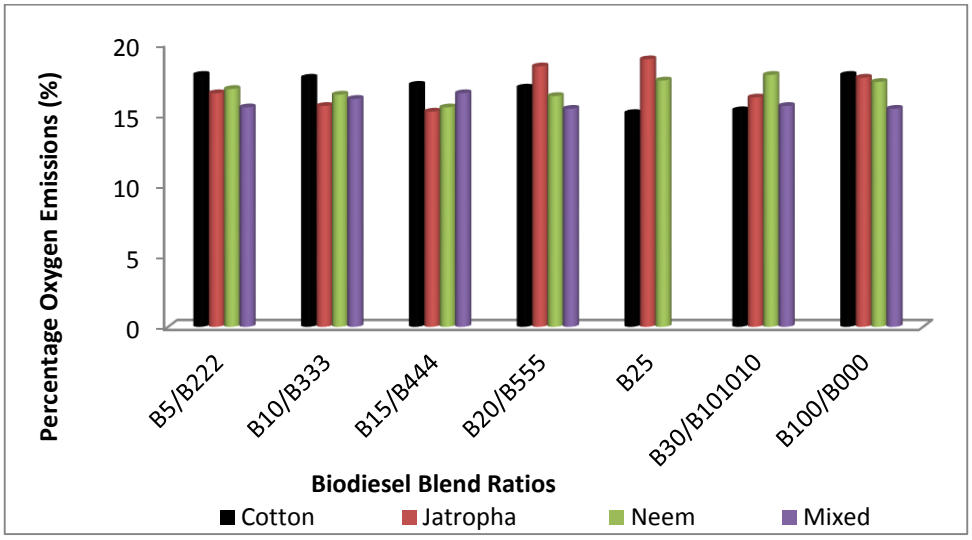


Figure 4.55: Percentage O_2 Emission at 1500 rpm

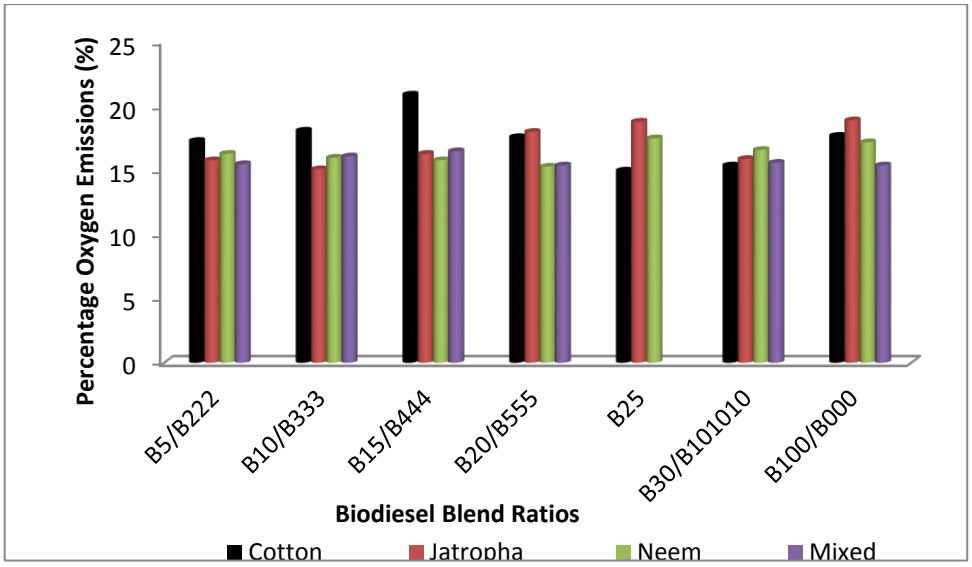


Figure 4.56: Percentage O_2 Emission at 2000 rpm

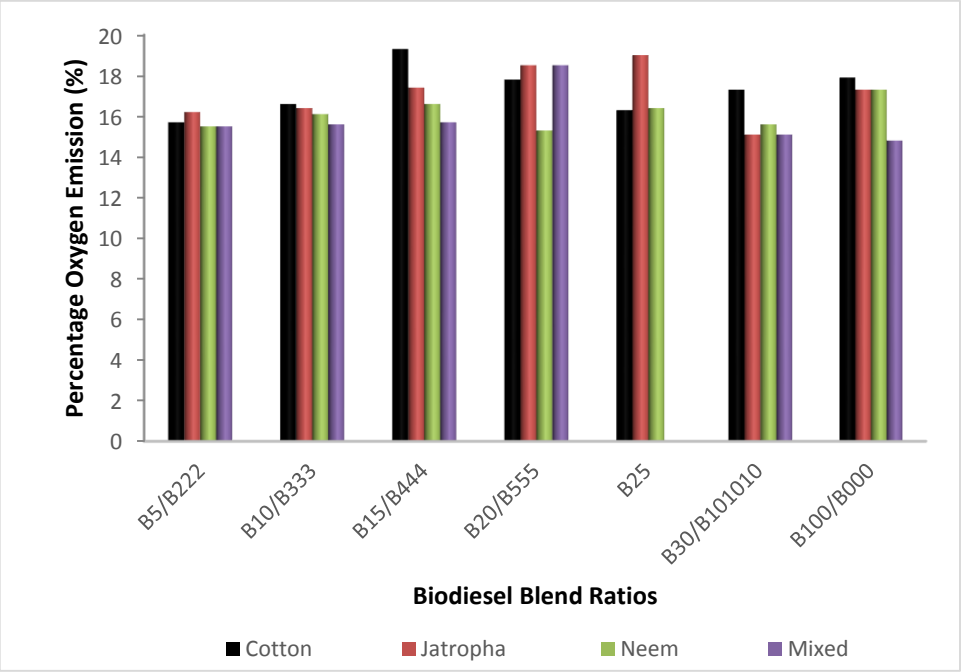


Figure 4.57: Percentage O_2 Emission at 2500 rpm

4.5.5 Carbondioxide (CO_2) emissions

Figures 4.58, 4.59 and 4.60 respectively present the percentage CO_2 emissions of the biodiesel from cotton, Neem and Jatropha with their binary and multi-blends with diesel fuel at the corresponding speeds of 1500 rpm, 2000 rpm and 2500 rpm. It has been established that, once the engine speed increases, the CO_2 engine-out emissions also increase (Chalatlon *et al.*, 2011; Mofijur *et al.*, 2014). The pure diesel and the multi-blends at 1500 rpm have the peak values of CO_2 emissions alongside Neem blends. These results are replicated at all speeds (2000 rpm and 2500 rpm inclusive). The pure biodiesel samples B100C, B100J and B100N alongside all the binary blends of cotton and Jatropha except B30J give a very low CO_2 emission in all cases.

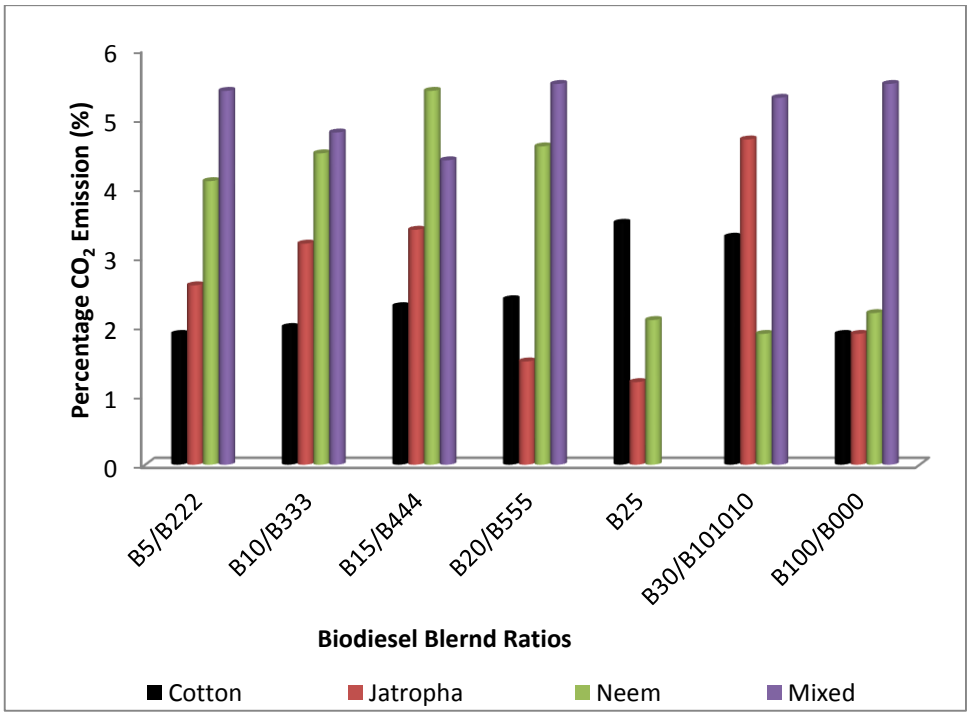


Figure 4.58: Percentage CO_2 Emission at 1500 rpm

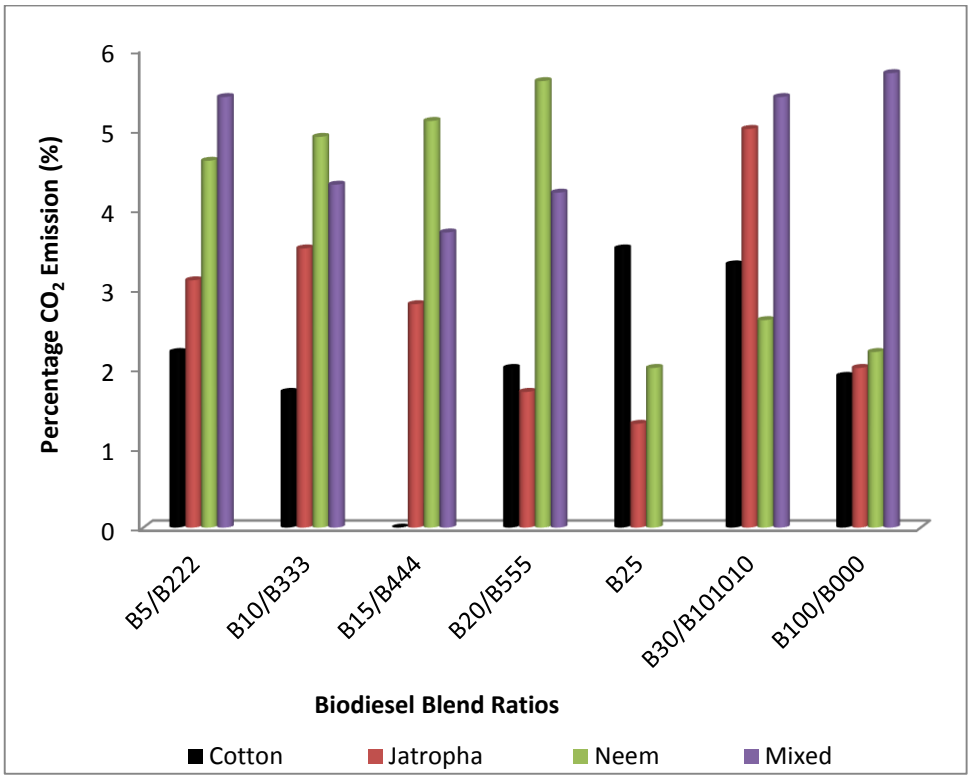


Figure 4. 59: Percentage CO_2 Emission at 2000 rpm

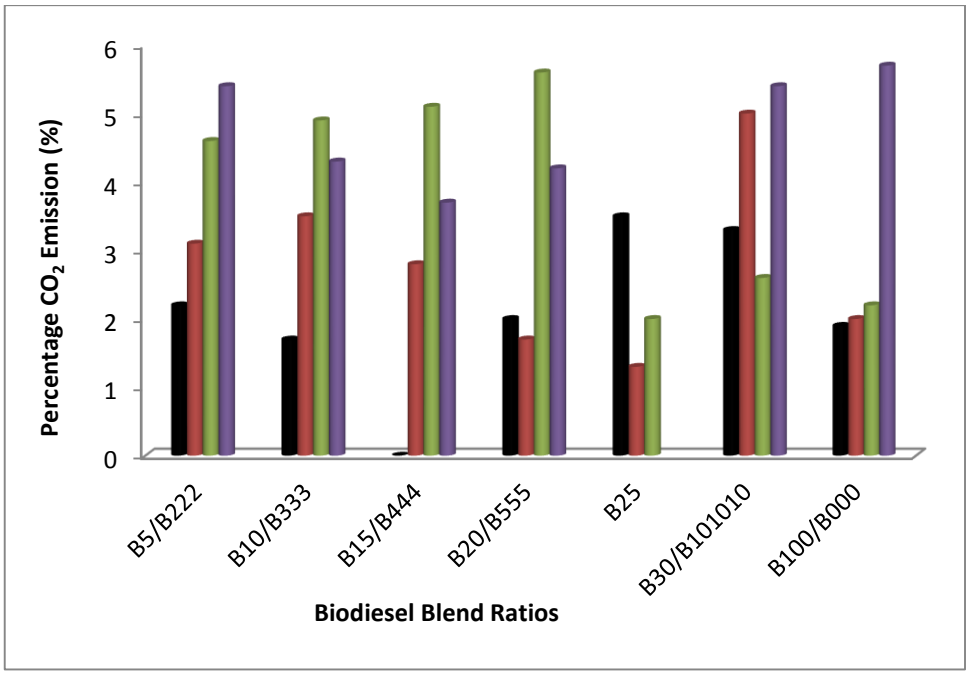


Figure 4.60: Percentage CO_2 Emission at 2500 rpm

4.5.6 Sulphurdioxide (SO_2) emissions

Figures 4.61, 4.62 and 4.63 present the SO_2 emissions of the fuels at 1500 rpm, 2000 rpm and 2500 rpm respectively. Also, at 0 % oxygen, the SO_2 emissions were shown by figures, 4.64, 4.65 and 4.66 respectively. According to Ong *et al. (*2013), biodiesel as an ideal fuel that gains worldwide attention, it is free from Sulphur (SO_2) or aromatic compounds and reduces air pollutions like CO, HC (hydrocarbons) and PM. This is consistent with the findings of this work, it can be seen that the values of SO_2 emissions are null for most of the fuels except B20C at all speeds and B15C at 2500 rpm in both cases which have a negligible SO_2 value of not more than 0.12 % in all cases.

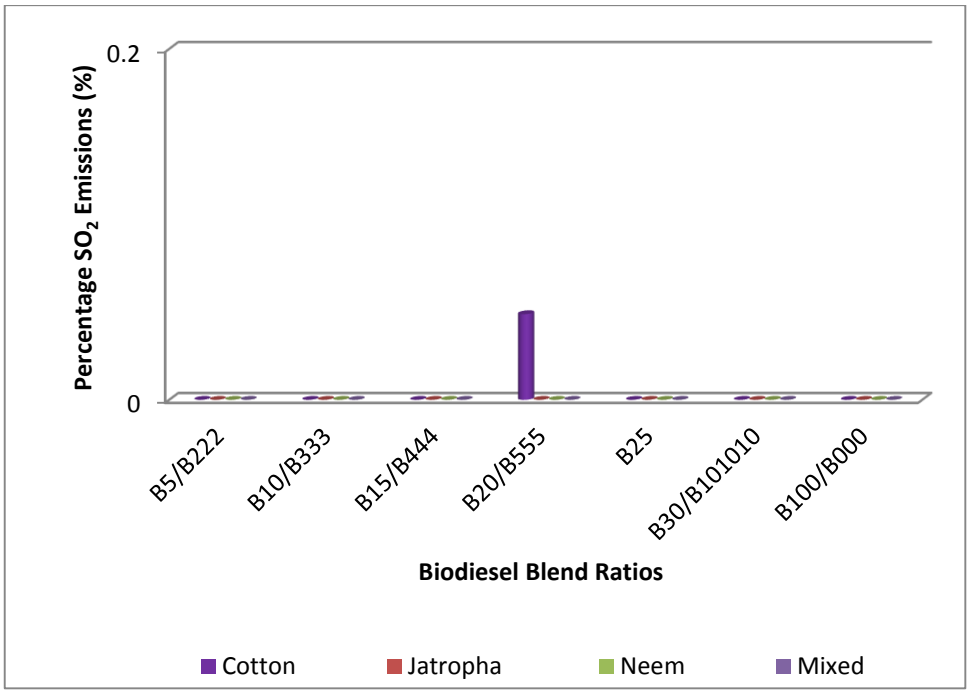


Figure 4.61: SO_2 Emissions at 1500 rpm

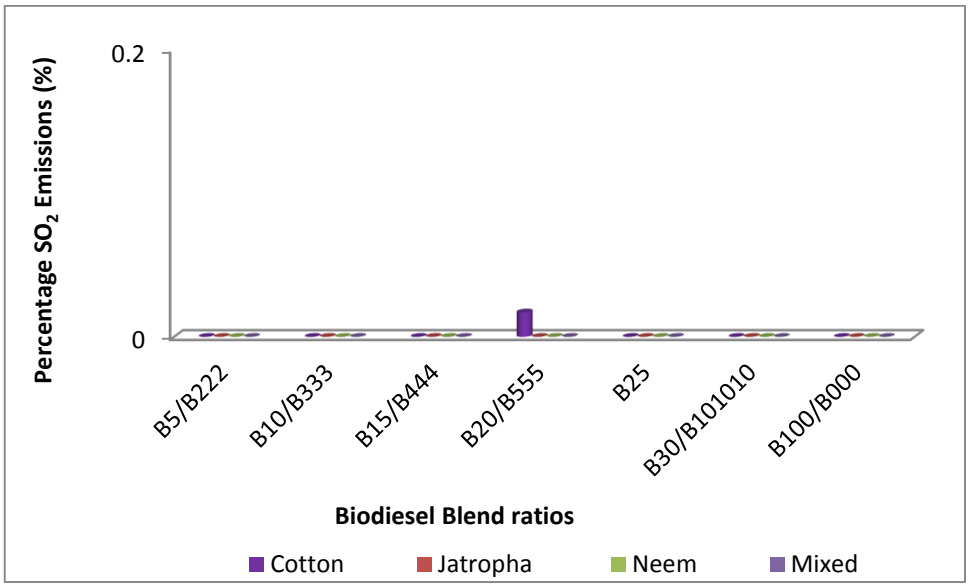


Figure 4.62: SO_2 Emissions at 2000 rpm

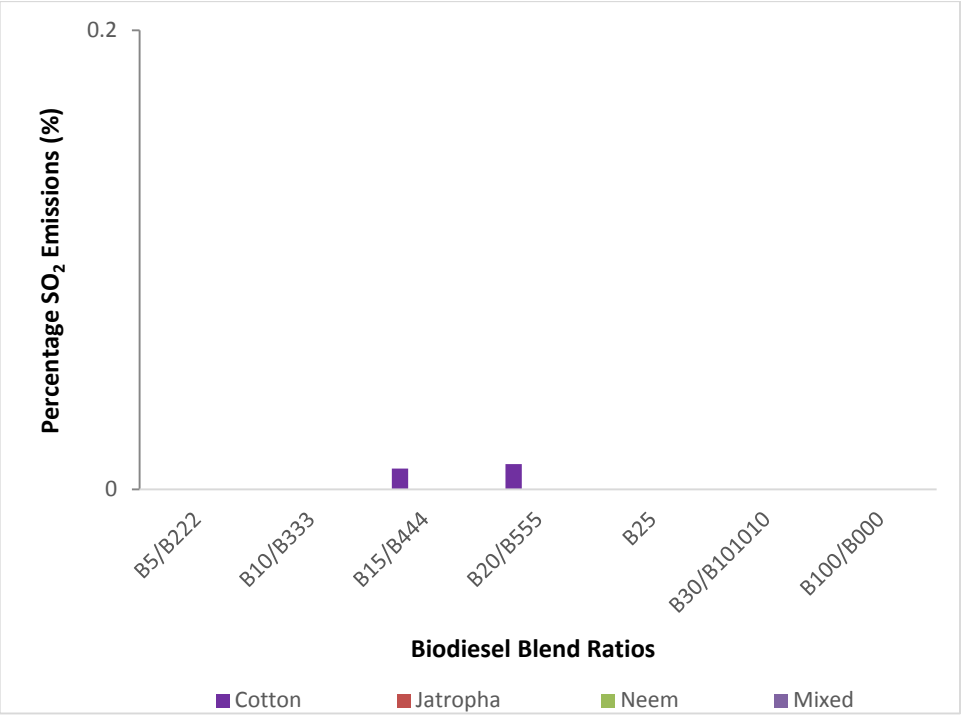


Figure 4.63: SO_2 Emissions at 2500 rpm

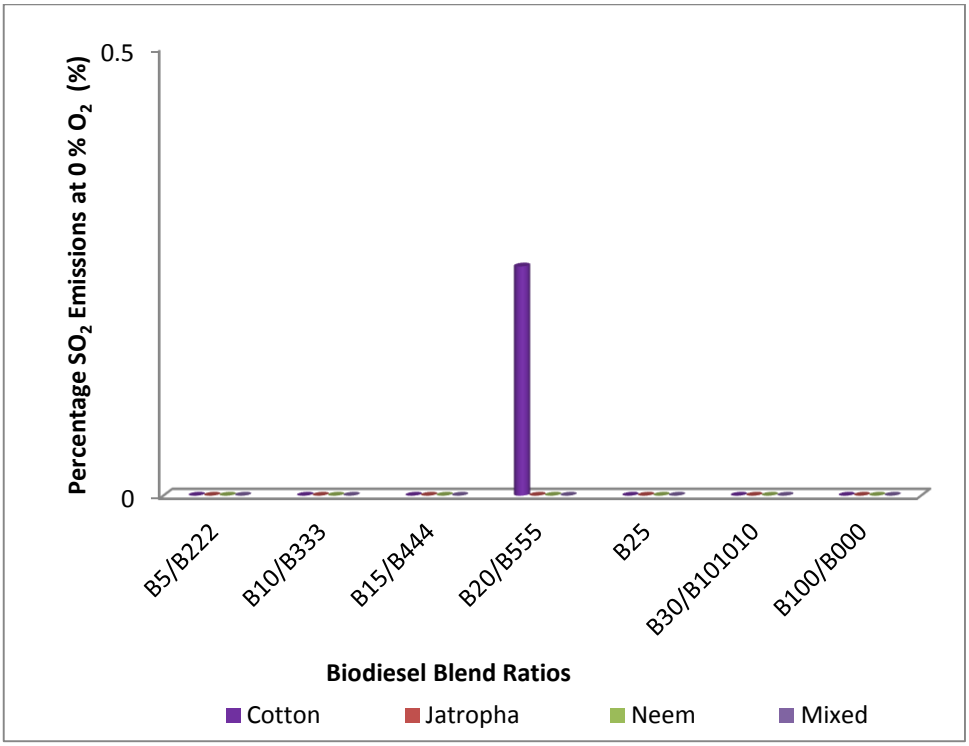


Figure 4. 64: SO_2 Emissions at 0 % O_2 at 1500 rpm

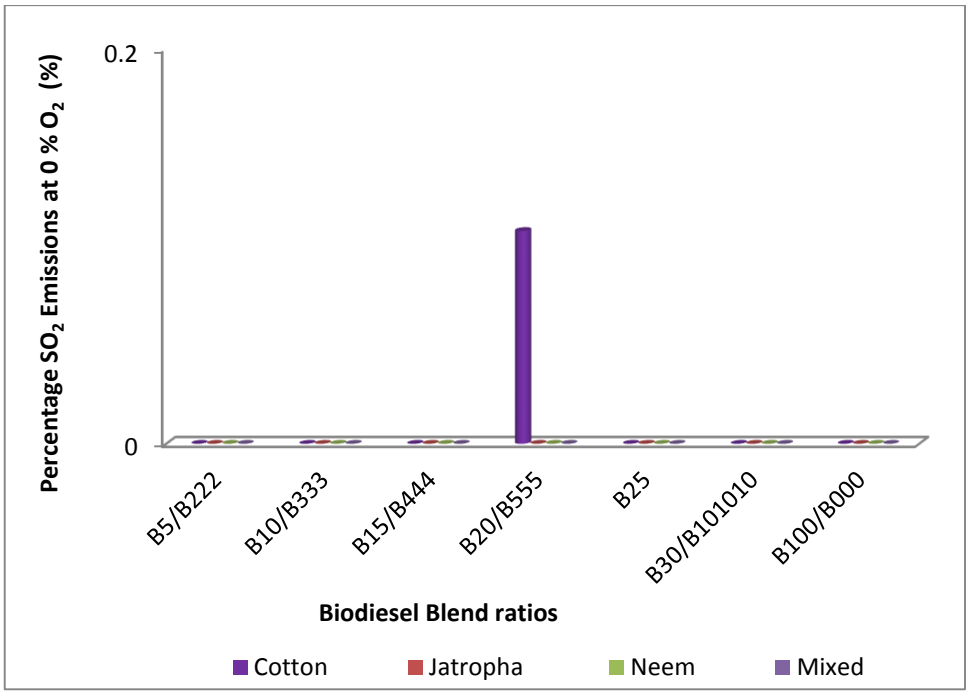


Figure 4.65: SO_2 Emissions at 0 % O_2 at 2000 rpm

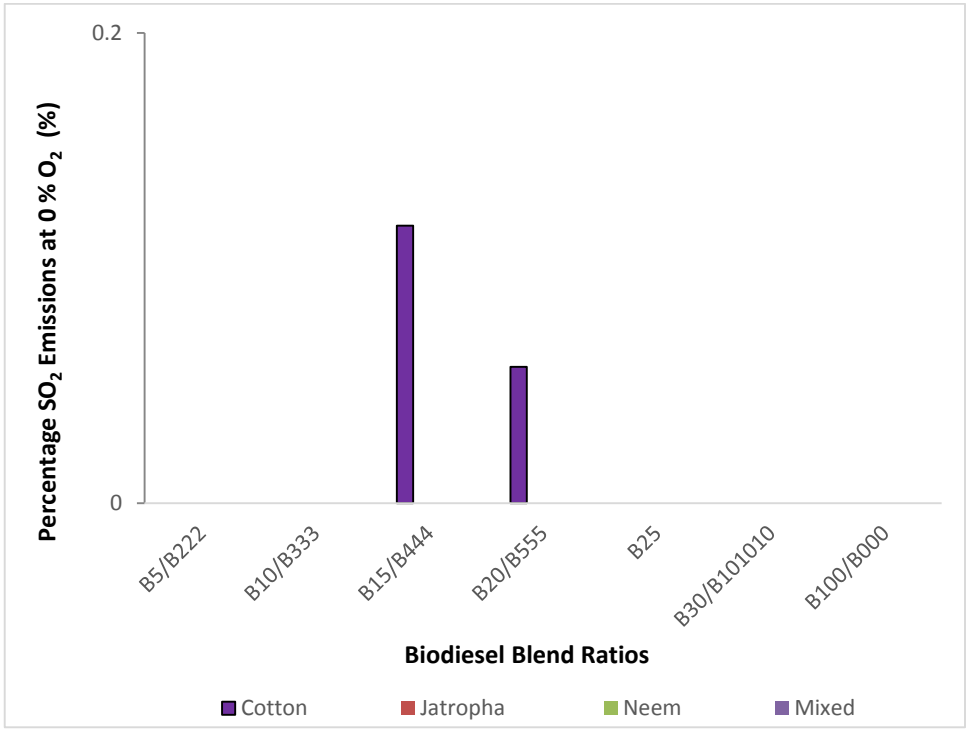


Figure 4.66: SO_2 Emissions at 0 % O_2 at 2500 rpm

4.5.7 Excess Air

The excess air present during the combustion process was presented below in figures 4.67, 4.68 and 4.69, at the engine speeds of 1500 rpm, 2000 rpm and 2500 rpm.

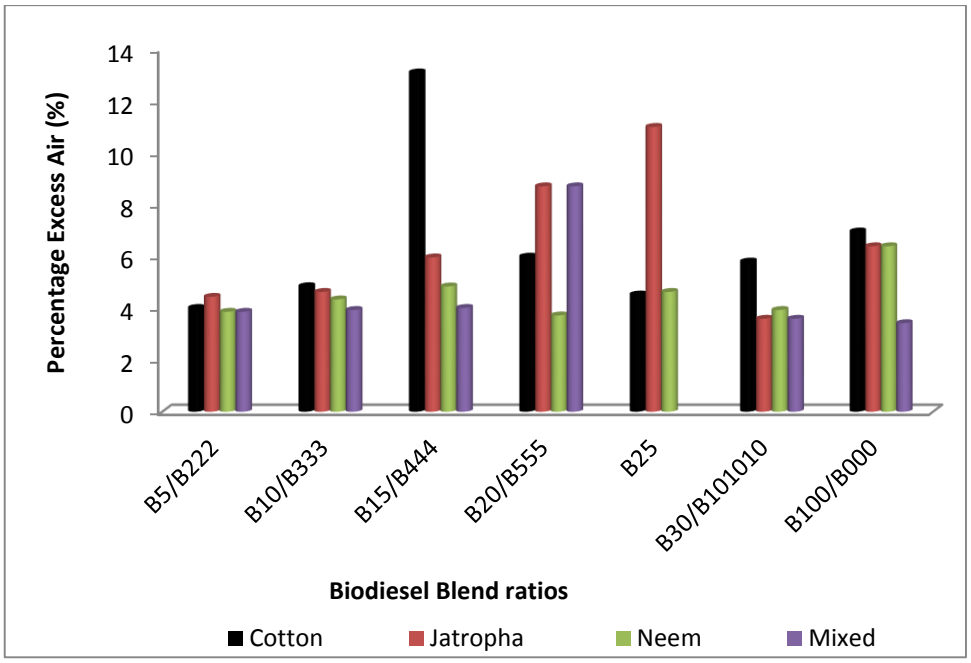


Figure 4.67: Percentage Excess Air at 1500 rpm

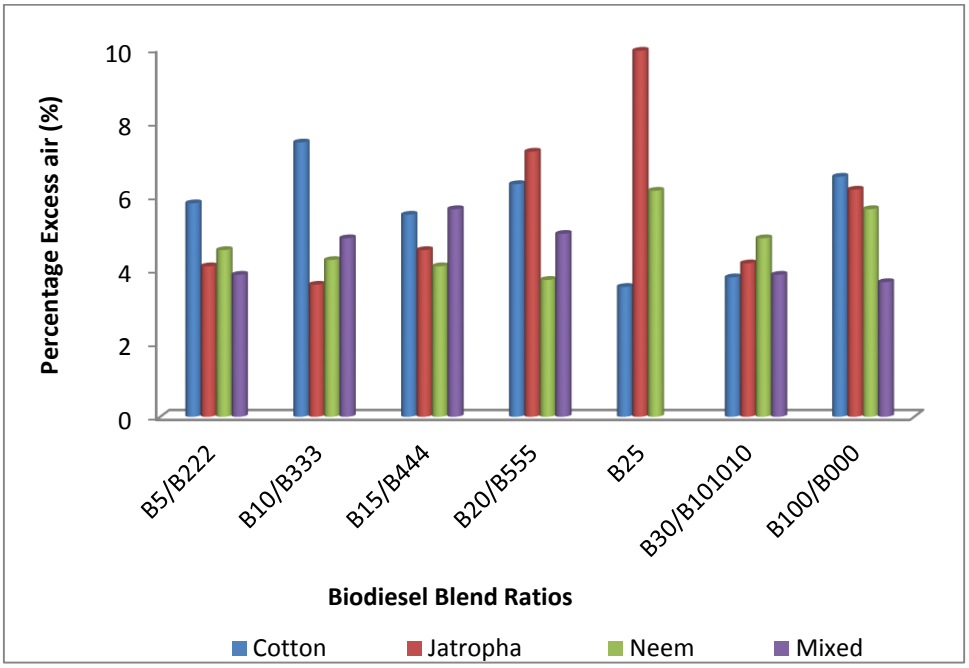


Figure 4.68: Percentage Excess Air at 2000 rpm

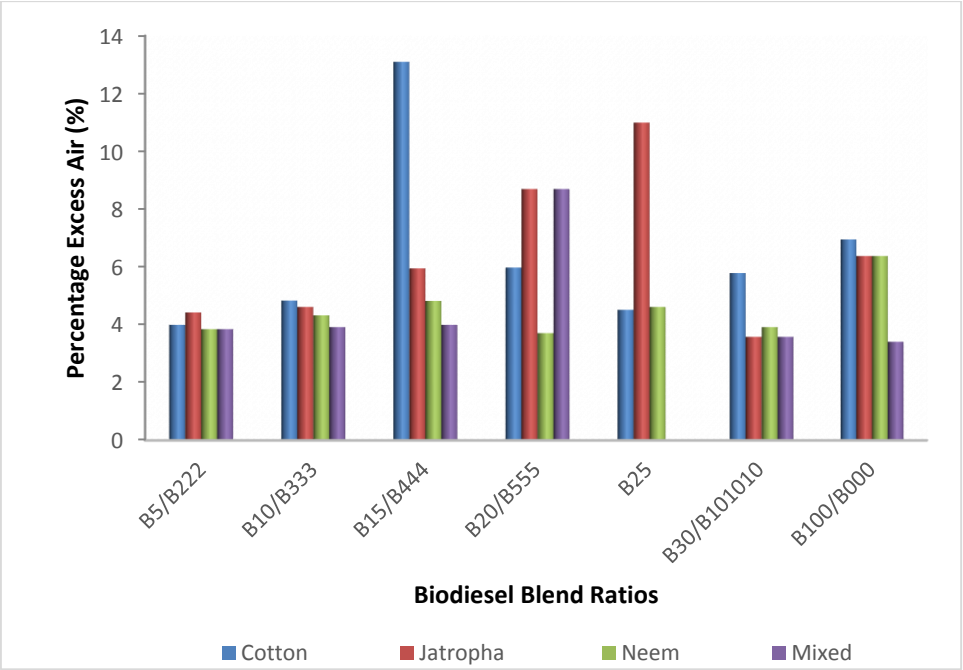


Figure 4.69: Percentage Excess Air at 2500 rpm

There are no much significant differences between the values of excess air for all the blends, pure biodiesels and fossil diesel. B15C and B25J have the peak values of the excess air in most cases as well as B10C at 2000 rpm.

4.6 Modeling and Simulation Using GT Power Software

4.6.1 Model validation

The simulated results of the engine performance were compared with the result of the engine test obtained, and presented in figures 4.70, 4.71 and 4.72, for the specific fuel consumption, brake mean effective pressure and brake thermal efficiency respectively. The pictures of the result window sample displayed on the GT-Post (From the GT-Suit software) are shown in plates 4.1 and 4.2.

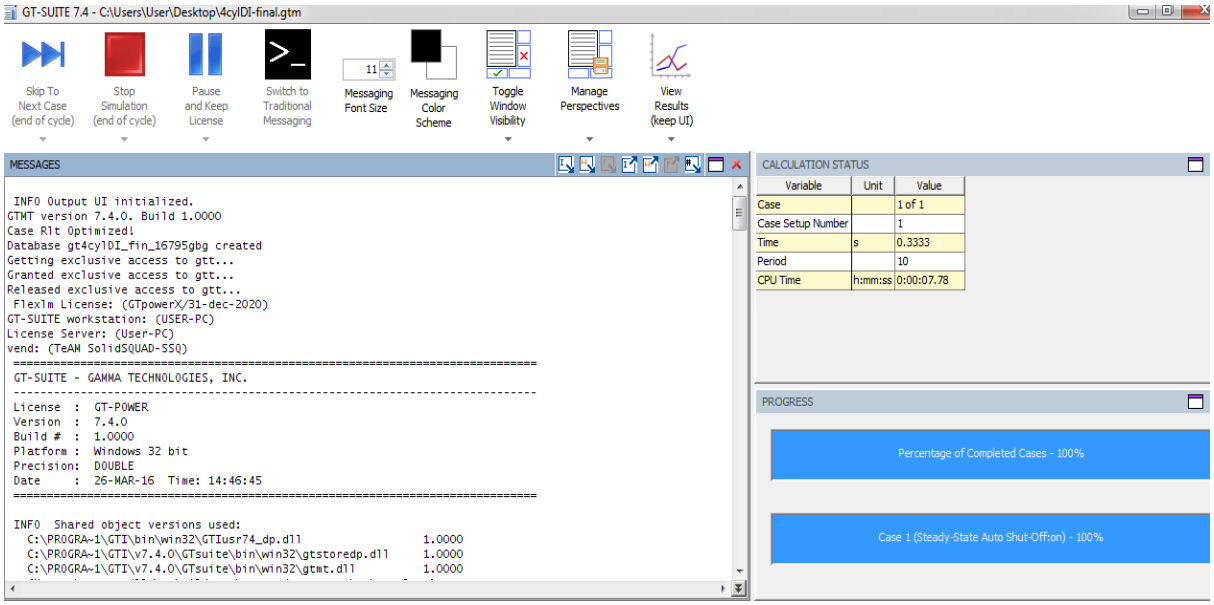


Plate 4. 4: Sample Simulation Results in GT-Post, Percentage Simulation Competed

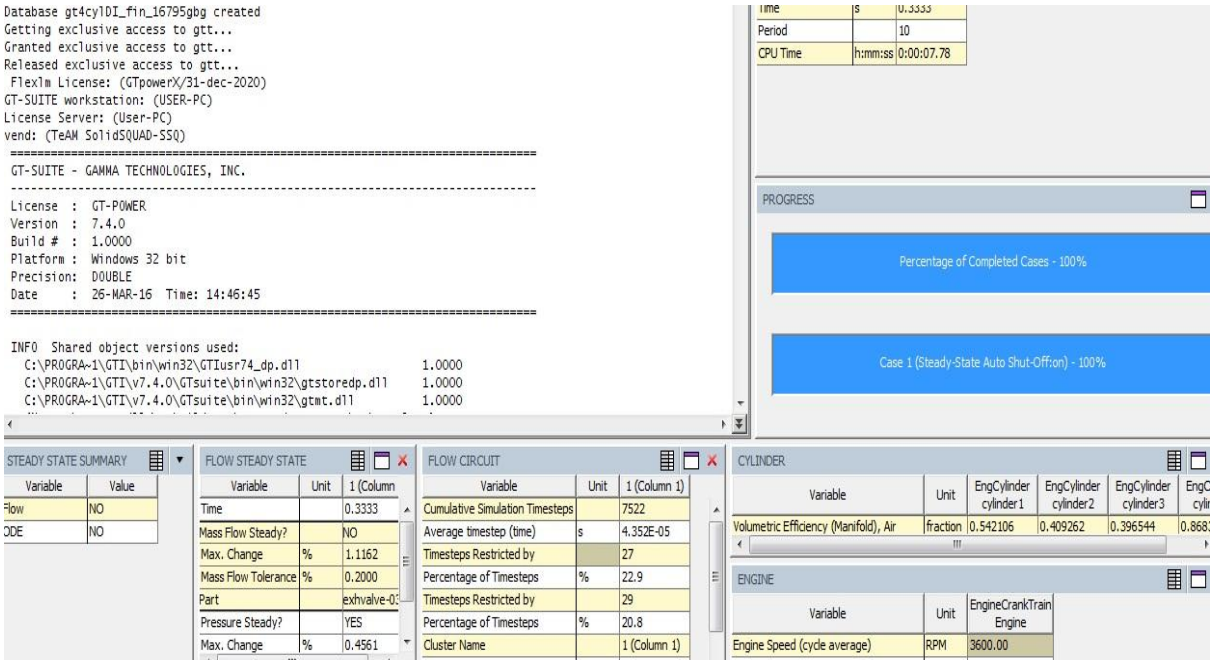


Plate 4. 5: Sample Simulation Results for Thermal Efficiency in GT-Post

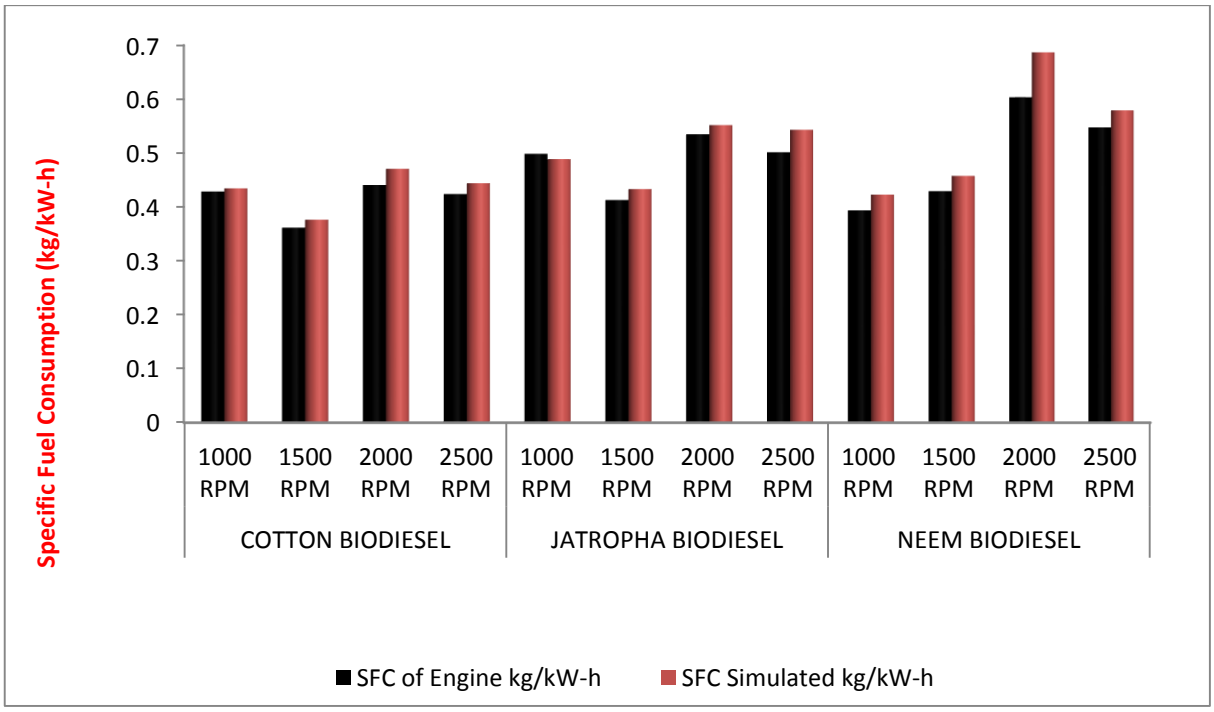


Figure 4.70: Comparative of Specific Fuel Consumption of Experimented and Simulated Results

The experimented and simulated specific fuel consumption of cotton, Jatropha and Neem biodiesel at respective speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm are shown in figure 4.70. It could be observed that, there is no significant difference between the experimental values and the simulated values. The bsfc at 1000 rpm for cotton biodiesel has a difference of 1.37 % been the lowest difference between the experimented and simulated values, while the bsfc of Neem biodiesel at 2000 rpm has a difference of 13.75 % been the highest difference between the experimented and simulated values. The remaining values are in between the former two and are less than 10 % each, which makes them acceptable in accordance with the findings of Okoro *et al. (*2015); Ihme *et al. (*2009) and Llewillin (2010). The bsfc for the experimented and simulated data show relative correspondence in each case and at all speeds. The simulated results increase with corresponding increase in experimented results and reduce with corresponding decrease

in experimented results in all cases of specific fuel consumption. This makes the GT-Post findings to be real since they are very consistent with the experimented data.

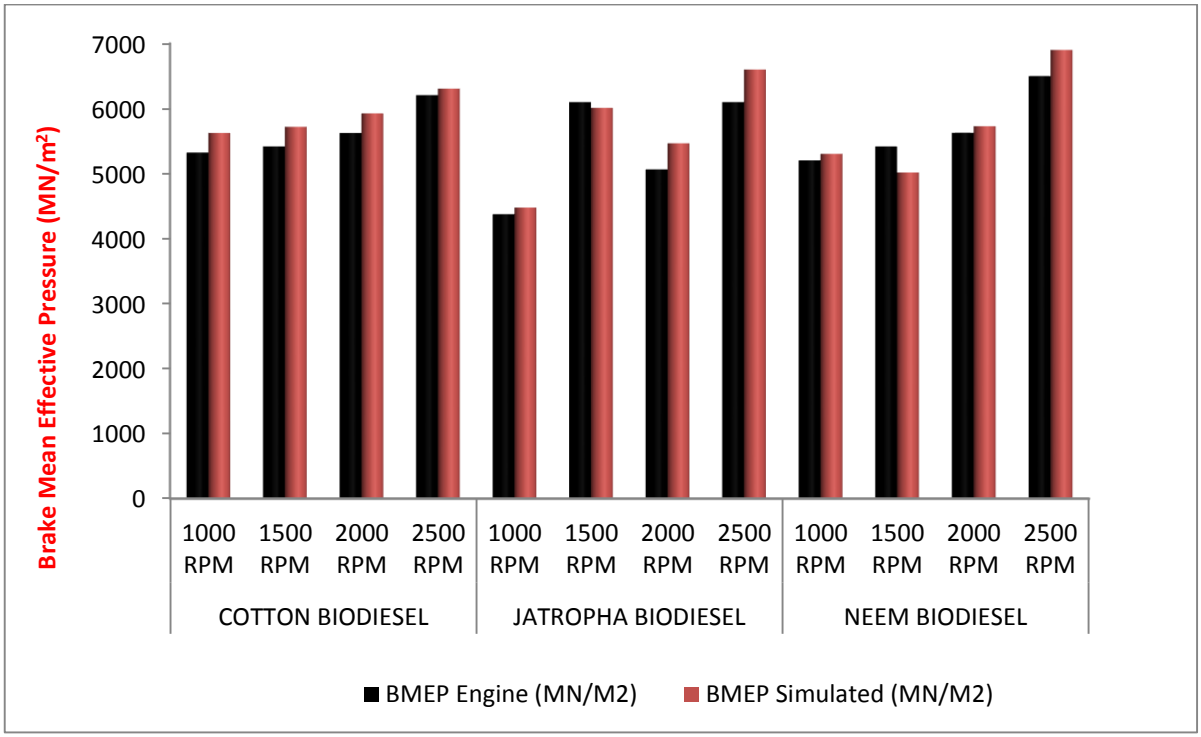


Figure 4.71: Comparative of Brake Mean Effective Pressure of Experimented and Simulated Results

Furthermore, Figure 4.71 depicts the experimented and simulated values of brake mean effective pressure of cotton, Jatropha and Neem biodiesel at respective speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm. It can be perceived that, there is no significant difference between the experimental values and the simulated values. The bmep at 2500 rpm for cotton biodiesel has a difference of 1.44 % been the lowest difference between the experimented and simulated values, while the bsfc of Jatropha biodiesel at 1500 rpm has a difference of 8.20 % been the highest difference between the experimented and simulated values. The remaining values are in between the former two and four of them are just slightly above 1 % difference each, this makes them acceptable in accordance with the findings of Okoro *et al. (*2015); Freitas (2002); Ihme *et al. (*2009) and Llewillin

(2010). The bmep for the experimented and simulated data show relative correspondence in each case and at all speeds. The simulated results increase with corresponding increase in experimented results and reduce with corresponding decrease in experimented results in all cases of specific fuel consumption. This makes the GT-Post findings to be real since they are very consistent with the experimented data.

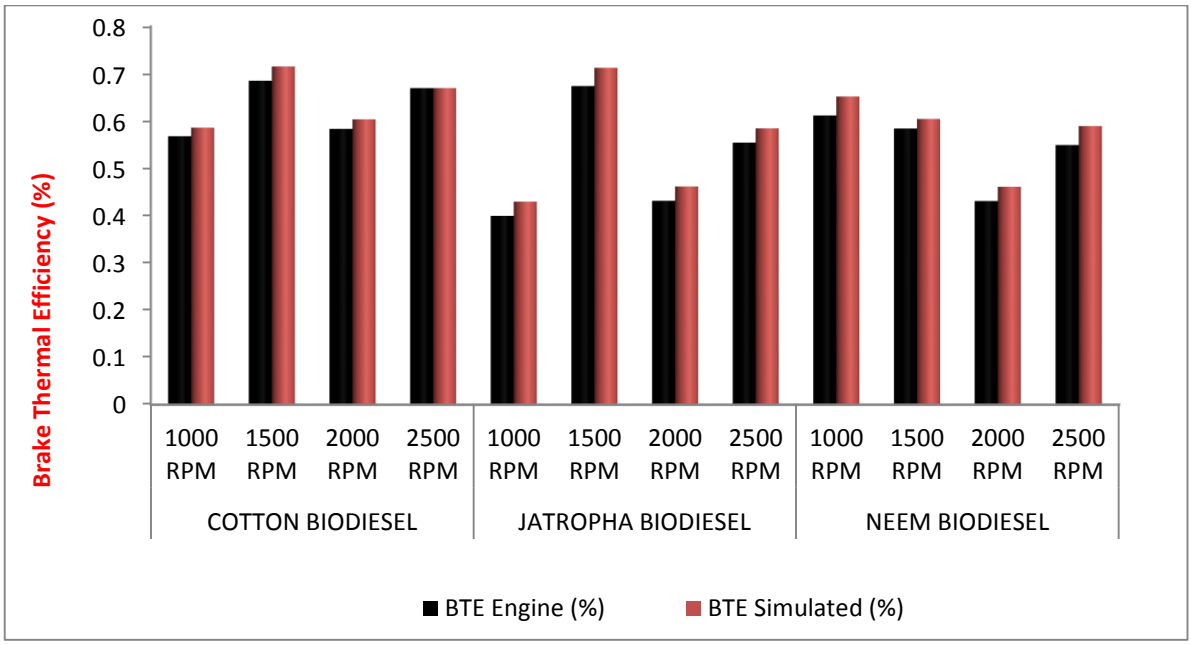


Figure 4.72: Comparative between Brake Thermal Efficiencies of Experimented and Simulated Results

Similarly, Figure 4.72 illustrates the experimented and simulated values of brake mean effective pressure of Cotton, Jatropha and Neem biodiesel at respective speeds of 1000 rpm, 1500 rpm, 2000 rpm and 2500 rpm. Just like the two earlier cases, there are no any significant differences between the experimented and simulated data in brake thermal efficiencies of biodiesels from Cotton, Jatropha and Neem at all speeds. At the speed of 2500 rpm, for cotton biodiesel, the brake thermal efficiencies are exactly the same values for both experimented and simulated results. This can be explained by the fact that, engine performance models are often dependent of the experimental setup in which they were determined, thus giving slightly different results depending on the context where they are

used. This is consistent with the findings of Abbe *et al. (*2013); Kolhe *et al. (*2015). This makes the GT suit very reliable software in engine performance simulations. Therefore, the software can be used to determine the performance of CI engines with any biodiesel fuel at any speed.

Statistical analyses confirmed that, the mean value of the experimental brake specific fuel consumption was 0.465 kg/kW-h and the mean value for the simulated brake specific fuel consumption was 0.491 kg/kW-h. The standard deviation in brake specific fuel consumption between the experimented and simulated values was 0.078. A similar trend was shown in the values of brake thermal efficiencies. The experimented brake thermal efficiency values gave an average 0.563 while the simulated values gave a mean of 0.589. The standard deviation was 0.094. This implies that there is a strong tie between the experimented and simulated values and hence, the GT Suite can be used to replace a typical engine rig.

4.6.2 Simulation of biodiesel in CI engine

Figure 4.73, 4.74 and 4.75 present the simulated results for brake specific fuel consumption, brake mean effective pressure and brake thermal efficiencies respectively for biodiesels from various feedstocks such as yellow grease, palm, rapeseed, soy, canola, sunflower, tallow, corn, algae, coconut, camelina, safflower, waste cooking oil, castor, and others (Peanut, karanja, rice bran, sorghum, lard, poultry fat, mustard, peanut, babarsu, fish oil, kusum, beheda and groundnut) in a stationary 4 cylinder water cooled compression ignition engine.

In figure 4.73, the simulated specific fuel consumptions of the biodiesel from the stated feedstock were displayed. The least specific fuel consumption was exhibited by safflower, followed by palm and then corn. The highest bsfc was depicted by castor followed by coconut and then tallow. While the bsfc of safflower was recorded as 0.335

kg/kW-h, the bsfc of castor was 0.614 kg/kw-h on the other hand. All the remaining values fall between 0.37 and 0.614 kg/kW-h for all the feedstock. The bsfc values are consistent with the findings of Ong *et al. (*2014); Chalatlon *et al. (*2011); Mofijur *et al. (*2014); Enweremadu *et al. (*2014) and Rahim *et al. (*2012). Factors such as the volumetric fuel consumption system, kinematic viscosity, cetane number, density of the fuel and calorific value of the fuel affect the brake specific fuel consumption (Mofijur *et al., 2*014). At this constant speed of 2500 rpm, the brake specific fuel consumptions are 0.449, 0.373, 0.474, 0.450, 0.0.491, 0.436, 0.594, 0.394, 0.498, 0.602, 0.518, 0.335, 0.482 and 0.614 kg/kW-h for yellow grease, palm, rapeseed, soy, canola, sun flower, tallow, corn, algae, coconut, camelina, safflower, waste cooking oil and castor respectively. The least value of bsfc as portrayed by the safflower biodiesel is in agreement with the results obtained by findings of Enweremadu *et al. (*2014).

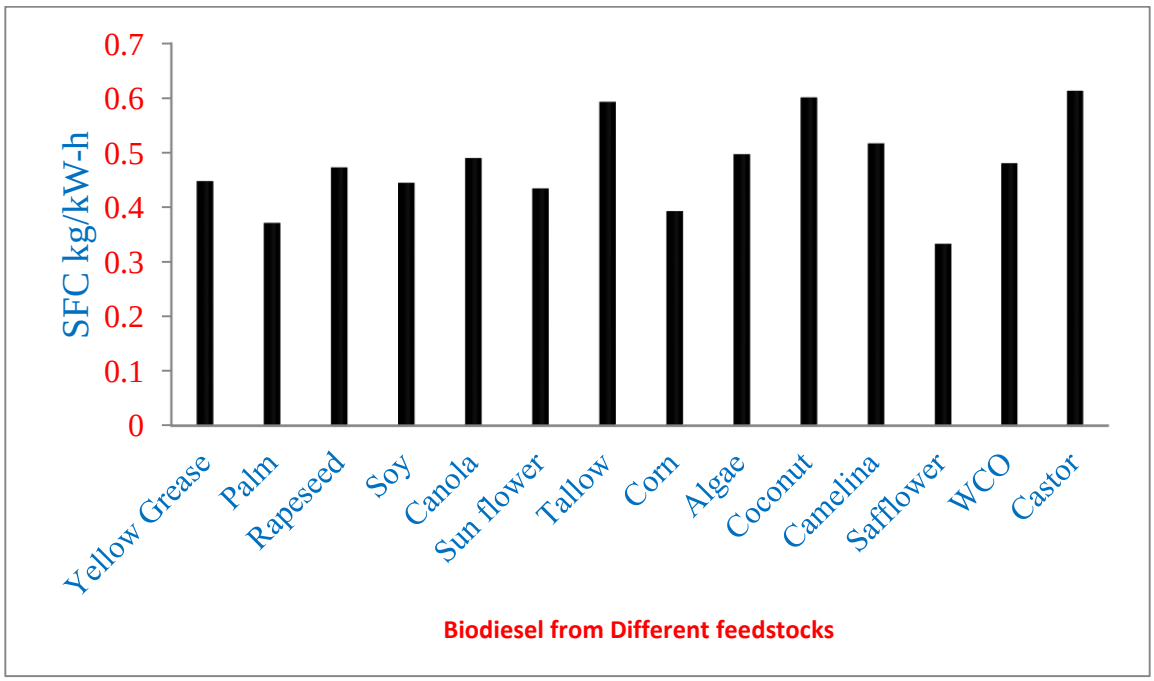


Figure 4.73: Simulated Specific Fuel Consumption of Different Biodiesel Feedstocks

Accordingly, the simulated results of brake mean effective pressure for various biodiesel feedstocks were presented in figure 4.74. Their corresponding values are 5125, 5220,

5266, 6106, 4581, 6199, 6158, 5420, 5448, 5228, 5312, 5685, 6101, and 4538 MN/m^2 for yellow grease, palm, rapeseed, soy, canola, sun flower, tallow, corn, algae, coconut, camelina, safflower, waste cooking oil and castor respectively. Castor has the least bmef followed by canola, while the highest bmep was observed during the simulation of the CI engine performance with sun flower, tallow, waste cooking oil and soy biodiesels in that order. The bmep values obtained during the simulation are in close range with the results of Rahim *et al. (*2012) and Mohiuddin *et al. (*2007). Brake mean effective pressure is the average mean pressure, the measured brake power output has generated, when the pistons uniformly imposed from the top to the bottom of each power stroke (Rahim *et al.*, 2012a).

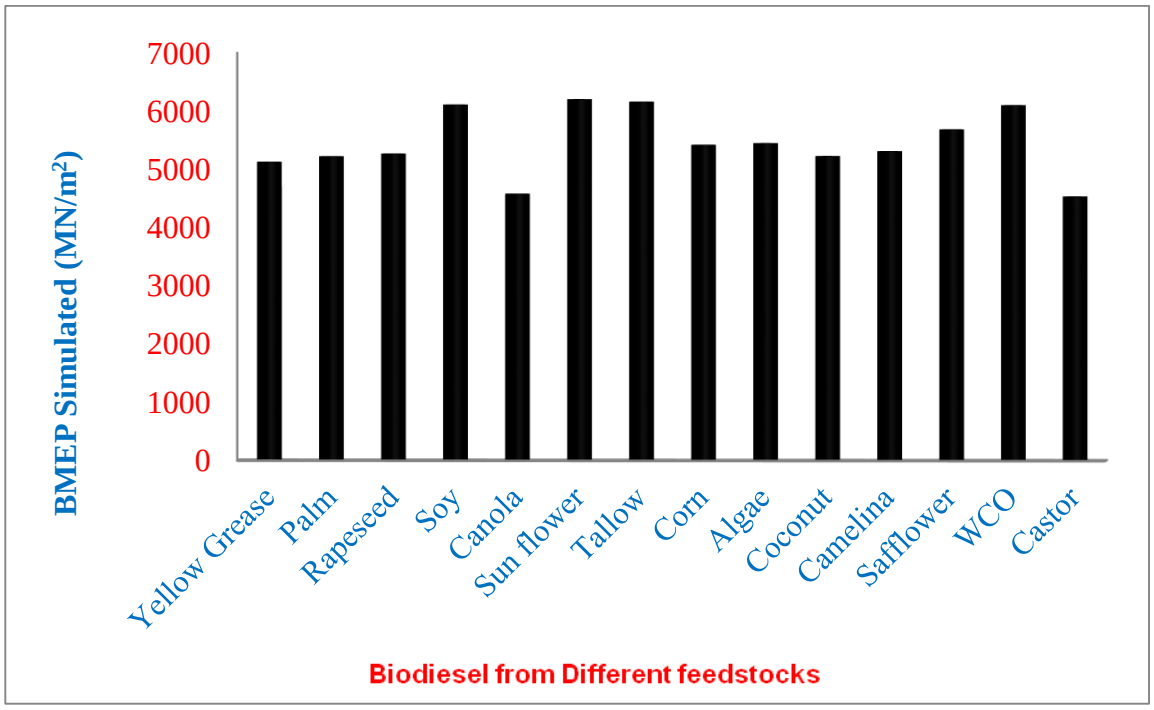


Figure 4.74: Simulated Brake Mean Effective Pressure of Different Biodiesel Feedstocks

Finally, the simulated results for brake thermal efficiencies of yellow grease, palm, rapeseed, soy, canola, sun flower, tallow, corn, algae, coconut, camelina, safflower, waste cooking oil and castor are presented in figure 4.75. Their corresponding values are 0.55, 0.65, 0.51, 0.70, 0.46, 0.69, 0.57, 0.62, 0.55, 0.43, 0.57, 0.64, 0.48 and 0.59

respectively. The brake thermal efficiency values are consistent with the findings of Kaisan and Pam (2013); Ong *et al. (*2014); Chalatlon *et al. (*2011); Mofijur *et al. (*2014); Enweremadu *et al. (*2014) and Rahim *et al. (*2012). The brake thermal efficiency is the ratio of brake power to the fuel energy input (Kaisan and Pam, 2013). It is noticed that the use of oxygen-rich biodiesel fuel promotes a better mixture formation and combustion, thus improving the thermal efficiency. The improvement in brake thermal efficiency can be attributed to the enhanced oxygen content, which improves combustion especially during the phase of diffusion combustion, and to the higher lubricity of biodiesel which reduces the friction loss (Kaisan and Pam, 2013). According to Ong *et al.* (2014), higher brake thermal efficiency gives an engine a smoother operation, this enhances the fuel atomisation leading to improved air-fuel mixing. The oxygen content of the biodiesel is sustained in the diffusive combustion and improved ignition delay. Biodiesel has higher cetane number than the fossil diesel Kaisan *et al.* (2014); Ong *et al. (*2014), this gives them good ignition quality. This parameter affects the combustion phasing and reduces the sensitivity of the combustion process on fuels (Ong *et al.*, 2014).

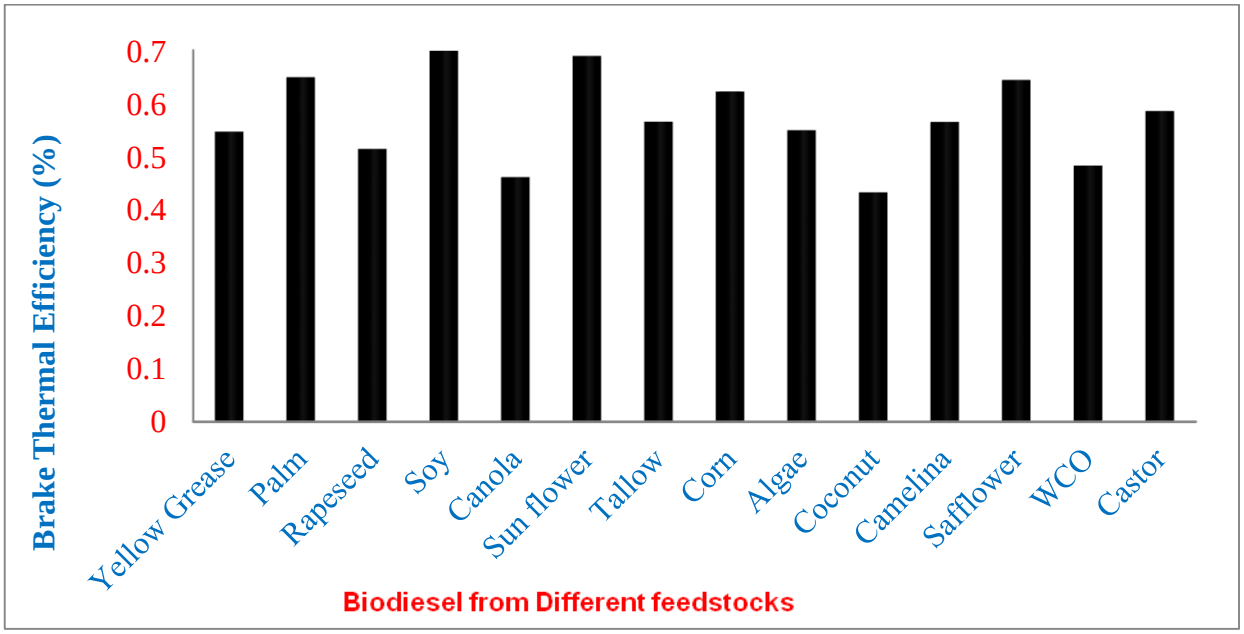


Figure 4.75: Simulated BTE of Different Biodiesel Feedstock

The highest brake thermal efficiency values were given by soy, sun flower, palm and safflower respectively during the Cussons 4-cylinder stationary CI engine simulations with GT-Power. This implies that the four biodiesel can efficiently be used in compression ignition engine. However, the least values of brake thermal efficiency were that of coconut and waste cooking oil, although their values are also acceptable and agree with the findings of Ong *et al.* (2014b).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Biodiesel produces exceptional emissions properties and generates less greenhouse gases emissions. The following inferences were drawn out of the experimental findings aforementioned. The subsequent inferences were made from the discoveries of this work:

1- The calorific values of all the fuels and blends are above the ASTM minimum level and close to the heating values of fossil diesel, this makes them suitable for use in CI engines operations. All fuel samples have flash points above ASTM minimum standards and 27 out of 28 are consistent with the ASTM standards both minimum and maximum, only the pure biodiesel from Neem (B100N) has a flash point slightly above the ASTM maximum level. Therefore, these fuels are safer to handle during storage or transportation because they cannot easily flash when exposed to flame or spark and hence they are recommended for use in the CI engines. All the 28 fuel samples are consistent with the ASTM standards for cetane number. They will have shortest possible ignition delay when they burn in the CI engines. Most of the viscosity values of the binary blends are consistent with the ASTM standard; the pour points of most of the fuel samples conformed with the ASTM standards. However, for the multi-blends, only a few is consistent with the ASTM limit. The specific gravity of the binary blends of cotton, Jatropha and Neem increases with the percentage increase of the biodiesel content in the blends. All the blends conform to the ASTM standards for specific gravity. The quality of atomisation, combustion, fuel droplets and air-fuel mixing can be improved in CI engines by using these blends. The acid values are very low and slightly lower than the ASTM maximum standards which are presumed to cause no harm on the fuel pumps and filters. All

the 27 fuel samples and the pure diesel are consistent with the ASTM standards for total sulphur, copper strip and colour index except B100N for colour index.

2- From the secondary data obtained, the viscosity values for all the biodiesel from various feedstocks under review except the castor oil biodiesel conform to the ASTM standards, the kinematic viscosity of all the biodiesel fall within the ASTM standards except that of castor oil. The densities of all biodiesel from all feedstock except the algae conform to the ASTM and EN standards. The flash points of most biodiesel from various feedstocks fall within ASTM limits. The flash points of soy, safflower and corn biodiesel are slightly higher, while that of coconut, algae and tallow are slightly lower than the ASTM min. The heating values of all biodiesel except that of the castor confirm with EN minimum standards. All the specific gravity values except that the algae conform to ASTM minimum and maximum standards, most of the biodiesel values of pour point fall within ASTM limits except the palm and tallow biodiesel, with high positive values of 12.90 ^{0}C and 10.86 ^{0}C respectively. All the feedstock's used in this review do not conform to the ASTM standards for sulphur content.

   All the average cetane values under consideration conformed with the ASTM standards. There has been a substantial work in Nigeria with respect to policy issues especially as it relates to bio-energy the following incentives are clearly stated: Tax holidays, withholding tax on interest and dividends, waiver on imports, custom duties and value added tax and long term loan facilities. Hence Nigeria is a very good target for investors on biofuel crops, biodiesel refineries as well as blending plants for diesel/ biodiesel fuels.

3- The Jatropha 30 % blend B30J has the lowest exhaust temperature at 1500 rpm, 2000 rpm and 2500 rpm, while B25J has the lowest exhaust temperature at 1000

rpm. The highest temperatures were recorded by B100J at 1000 rpm, 1500 rpm and 2000 rpm, followed by B15J at 2000 rpm, biodiesel blends of Jatropha especially B20J, B25J, and B30J have the tendencies of reducing overheating in CI engines, B25J, B30J and B555 have the poorest values of brake power. The best performances in terms of brake power were recorded by B10J, B20C B20J, and B30C. In terms of brake specific fuel consumption, the least value was generated by B30J, the Jatropha blend B5N is the overall best blend at most speeds while B25C has the highest specific fuel consumption. B20J has very low brake mean effective pressure at engine speed of 2000 rpm, while at maximum speed the highest value of brake mean effective pressure was generated by B30C. The lowest values of brake thermal efficiency were recorded by B25C at three different speeds and B222 at one speed.

4- All the binary and multi-blends including the pure biodiesel samples have very good values for combustion efficiencies. B25J gives the best combustion efficiencies. B20C, B15C and B20J have the lowest CO emissions followed by the pure biodiesels. All multi-blends except B555 are not too good in terms of CO emissions. Pure biodiesel samples and the 15 %, 20% and 25 % of binary blends of Cotton and Jatropha give the lowest NOx emissions and CO_2 emissions. B20C has the highest SO_2 emissions although within a negligible value. There is no significant difference on the excess air values of all the fuel samples.

5- The engine performance simulation in GT-power confirms that the software is valid to be used in CI engine simulation with biodiesel from any feedstock and at all speeds. The highest bsfc was depicted by castor followed by coconut and then tallow, the highest bmep was observed during the simulation of the CI engine performance with sun flower, tallow, waste cooking oil and soy biodiesels in that

order. The highest brake thermal efficiency values were given by soy, sun flower, palm and safflower respectively during the Cussons stationary 4-cylinder CI engine simulations with GT Power software.

5.2 Conclusion

1- The biodiesels produced from Cotton seed oil contained 89.75 % methyl-ester, the biodiesels produced from Jatropha contained 91.97 % methyl-ester, and the biodiesels produced from Neem contained 70.2 % methyl-ester. Therefore, Jatropha oil gives the best biodiesel in terms of percentage of methyl esters. Their dominant esters are methyl octadecanoate, methyl hexadecanoate and methyl pentadecanoate, hence, it could be inferred that, Cotton, Jatropha and Neem biodiesels are sustainable, renewable, reliable, combustible and suitable for use in compression ignition engines

2- The fuel properties of biodiesels and mixed-blends with diesel mostly conform to the ASTM standards. The quality of atomisation, combustion, fuel droplets and air-fuel mixing can be improved in CI engines using these blends Therefore, the profile of methyl esters in the biodiesel produced and the fuel properties indicate that they have the potential to refill the partial energy demands in an eco-friendly way and its likelihood to be a viable fuel source for CI engines

3- All the feedstocks reviewed conform to ASTM and EN Standards except: castor for viscosity and heating value; algae for density and specific gravity; and palm and tallow for pour point.

4- The 25 % Jatropha blend (B25J) is the overall best blend for specific fuel consumption with least Nox emission; biodiesel produces exceptional emissions properties and generates less greenhouse gases emissions, and pure biodiesel samples, B15C, B25J and B20J give the lowest NOx and CO_2 emissions.

5- Compression ignition engine simulation in GT-power confirms that the software is suitable for simulation of biodiesel from any feedstock. The lowest bsfc was depicted by safflower followed by palm and the highest value was castor. The highest brake thermal efficiency values were given by soy, sun flower, palm and safflower

5.3 Recommendations

Based on the established facts obtained from this thesis, the following recommendations are hereby made:

1- Further research should consider the simulation of biodiesel blends with oil additive and alcohols like butanol and ethanol in CI engines

2- Further research should be conducted to determine the particulate matter (PM) present in the flue gases during fuel combustion

3- The GT-Suit Manufacturers should look at the possibility of adding biodiesel data to the software library

REFERENCES

Abbe, C. V. N., Nzengwa, R., Danwe, R., Ayissi, Z. M. Obounou. M. (2013). Simulation of a Direct Injection Diesel Engine Performance Fuelled on Biodiesel Using a Semi-Empirical 0D Model. *Energy and Power Engineering*. 5: 596-603

Abdulrahim, A. (2006). *Quick Note Bio-energy Potential*. Retrieved on 11th September, 2012 from http://news. Mongabay. Com/bioenergy200608nigerias-biogas-potential-estimated-at

Adams, C. Peters, J. F. Schroer, B. J. and Ziemke, M. C. (1983). Investigation of Soybean Oil as a Diesel Fuel Extender: Endurance *Test. Journal of the American Oil Chemists' Society*. 60(8): 1574-1579

Adebayo GB, Ameen OM, and Abbas LT (2011). Physicochemical properties of biodiesel produced from *Jatropha curcas oil and fossil diesel.* Journal of Microbiology Biotechnology Resource. 1(1): 12-16

Adejuwon, A. O., Olorunfemi, A. (2010). Synthetic Production of Amylase from Aspergillus Niger Isolated from Citrus Fruit. *African Journal of Basic and Applied Sciences.*2 (5-6). 158-160

Ahmad, F. Khan, A. U., and Yasa,. A. (2013). Transesterification of oil extracted from different species of algae for biodiesel production. *African Journal of Environmental Science and Technology*. 7(6): 358-364

Akande, S. O. Olarunfemi, A. (2009). Research and Development Potentials in Biofuels Production in Nigeria. A*frican Research Review: An International Multi Dissiplinary Journal, Ethiopia*, 3 (3): 34-45

Akindale, D. (2011). Biofuels for Green Transportation in Nigeria, Paper Presented at the 'Summit on Energy and Sustainable Economic Growth, held at the Sheraton Hotel and Towers, Abuja, Nigeria'. 9-11 March

Albuquerque, M. C. G., Machado, Y. L., Torres, A. E. B., Azevedo, D. C. S., Cavalcante, C. L. (2009). Firmiano LR, and Parente EJS. Properties of biodiesel oils formulated using different biomass sources and their blends. *Renewable Energy*. 34 (3): 857-859.

Ali, Y., Hanna, M . A., Cuppett, S. L. (1995). Fuel Properties of Tallow and Soybean Oil Esters. *JAOCS*. 72 (12): 1557-1564.

Alleman. T. L., Mc Cormick, R. L. (2006). Analysis of Coconut-Derived Biodiesel and Conventional Diesel Fuel Samples from the Philippines.*NREL/MP*. 540-38643

Allen, C . A. W., Watts, K. C., Ackman, R . G., Pegg M. J. (1999). Predicting the viscosity of biodiesel fuels from their fatty acid ester composition. F*uel*. 78(11): 1319-1326

Alptekin E, and Canakci M. (2009). Characterization of the key fuel properties of methyl ester-diesel fuel blends. *Fuel*. 88(1), 75-80..

Amin, A., Gadallah, A., El Morsi, A. K., El-Ibiari, N. N., Eldiwani, G. I. (2016). Experimental and emperical study of diesel and castor biodiesel blending effect, on kinematic viscosity, density and calorific value. *Egyptian Journal of Petrol. http://dx. Doi. Org/10.1016/j. Ejpe.2015.11.002*

Aoyagi, Y., K. Shimada, H. Osada, A. Noda, Y. Goto, and H. Ishii; Diesel Emissions (2008). Improvement by RME in a High Boost and EGR Single Cylinder Engine. *SAE Technical Paper Series*. 2008-01-1376.

Armas, O., Hernandez, J. J., and Cardenas, M. D (2006). Reduction of diesel smoke opacity from vegetable oil methyl esters during transient operation. *Fuel*. 85(17-18): 2427-2438.

Ashrafu, A. M. Masjuki, M. A. Kalam, M. A. RizwanulFattah, I. M.,Imtenan, S. Shahir, S. A. Mobarak,H. M. (2014). Production and Comparison of Fuel Properties, engine Perfornance and emission characteristics of biodiesel from various non-edible vegetable oil. *Energy Conversion and management*. 80:202-228

Atabani, A. E. and Cesar, AS. (2014). Calophyllum inophyllum L.- A prospective non-edible biodiesel feedstock. Study of biodiesel production, properties, fatty acid composition, blending and engine performance. R*enewable and Sustainable energy Review*. 37:644-655

Atabini, A. E. Mofijur, M. Masjuki, H. H. Kalam, M. A. Masum, B. M. (2013). Study on the effect of promising edible and non-edible biodiesel feedstock on engine performance and emission production. *Renewable and Sustainable Energy Review*. 23:391-404

Avella, F., Galtieri, A. Fiumara, A. (1992). Chatacteristics and Utilization of Vegetable Derivatives as Diesel Fuels. Rivista dei Combustibili, 46 (6): 181-188.

Ayhan, D. (2008). Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. E*nergy Conversion and Management*. 49(1): 2106–2116

Bachler, C., Schober, S., Mittelbach, M. (2009). Simulated Distillation for Biofuel Analysis. *Energy & Fuels*. 24(3): 2086-2090.

Bamgboye, A. I. and Hansen, A. C. (2008): Prediction of Cetane number of Biodiesel Fuel from the fatty acid methyl ester composition. *International Journal of Agrophy*. 22: 21-29.

Banks, J. Carson, J. Nelson, B. and Nicol D. (2001). Discrete-Event System Simulation. *Prentice Hall.*1(3): 1-3

Bannister, C. D., J. G. Hawley, H. M. Ali, C. J. Chuck, P. Prince, A. J. Brown, and W. Pickford (2009). Quantifying the Effects of Biodiesel Blend Ratio, at Varying Ambient Temperatures, on Vehicle Performance and Emissions. *SAE Technical Paper Series*. 2009-01-1893.

Barnwal, B. K. and M. P. Sharma (2005). Prospects of biodiesel production from vegetables oils in India. *Renewable & Sustainable Energy Reviews*. 9 (4): 363-378.

Beczewski K, and Szezawinski P. (2011). Investigation of properties of rapeseed oil methyl esters/aviation turbine fuel jet A-1 blends. *Journal of KONES Power train and Transport*. 18(1): 15-22

Beeren, P. Eijck, JV. (2009). Oil Pressing and Purification. Jatropher hand Book. 4(6): 4–22p.

Belewu, M. A. (2011). Biofuel Production in Nigeria: Challenges and Prospects. Paper presented at the '12th National / International Conference of the Students' Chemical Society of Nigeria—Fountain University, Oshogbo, Osun State, Nigeria' 29-30 June

Belewu, M. A., Adekola, F. A., Adebayo, G. B., Ameen, O. M., Muhammed, N. O., Olaniyan, A. M. (2010). Physico-chemical characteristics of oil and biodiesel from Nigerian and Indian Jatropha Curcas seeds. *International Journal of Bio Chemical Science.* 4(2): 524-529

Bello, R. A. (2014). Model Building and Usage in Social Science Research. L*eading Issues in General Studies, University of Ilorin*. 1: 1-5

Benjumea, P. J., Agudelo, and Agudelo, A. (2009). Effect of altitude and palm oil biodiesel fuelling on the performance and combustion characteristics of a HSDI diesel engine. *Fuel*. 88 (4): 725-731.

Bhatnagar, A. K., S. Kaul, V. K. Chhibber, and A. K. Gupta.(2006). HFRR studies on methyl esters of nonedible vegetable oils. *Energy & Fuels*. 20(3): 1341-1344.

Bhave, A. Kraft, M. Montorsi, L. Fabian, M. (2004). Modelling a Dual Fuelled Multi Cylinder HCCI Engine Using a PDF based Engine Cycle Simulator. *SAE International*. 01(0561). PP 1-14

Bielaczyc, P., A. Szczotka, P. Gizynski, and I. Bedyk. (2009). The Effect of Pure RME and Biodiesel Blends with High RME Content on Exhaust Emissions from a Light Duty Diesel Engine. SAE Technical Paper Series, 2009-01-2653, 2009

Boz, N., Kara, M., Sunal, O., Alptekin, E., and Degirmanbasi, N. (2009). Investigation of fuel properties of biodiesel produced over an Alumina based catalyst. *Turkish Journal of Chemistry*. 33: 433-442

BP (2012). B*P statistical review of world energy, London, United Kingdom*, Retrieved on 6th July, 2012 from:www. Bp. Com/statisticalreview

Bugaje, I. M. (2014). B*iofuels Production in Northern Nigeria*. Retrieved on 30th May, 2014, from www. Gamji. Com

Caprita R, Maior V and Caprita A. (2005). Ecological fuel production from waste vegetable oil and agricultural seeds oil. Scientifical Researches. A*groalimentary Process and Technologies*. 11(1): 179-184

Carraretto, C., Macor, A., Mirandola, A., Stoppato, A. and Tonon, S. (2004). Biodiesel as Alternative Fuel: Experimental Analysis and Energetic Evaluations. *Energy*. 29: 2195-2211

Chalatlon, V. Roy, M. M. Dutta, A and Kumar, S. (2011). Jatropha oil production and experimental investigation of its use as an alternative fuel in a DI Diesel Engine. *Journal of Petroleum Technology and Alternative Fuels*. 2(5): 76-85

Chatpalliwar, A. S. Vishwas, S. D. Jayant P. M. and Nileshsingh V. T (2011). An Overview and Approach for Evaluation of Biodiesel Production Plant Design. *Science Academy Transaction on Renewable Energy System Engineering and Technology (SATRESET)*. 1 (3): 96-101.

Chhetri AB, Watts KC, and Rafiqul-Islam M. (2008). Waste cooking oil as an alternative feedstock for biodiesel production. E*nergy*. 1: 3-18

Choudhury, S. and P. K. Bose. (2008). Jatropha derived Biodiesel - its suitability as CI engine fuel. SAE Technical Paper Series, 2008-28-0040.

Coronado, M. Yuan, W. Wang, D. and Dowell, F. E. (2009). Predicting the Concentration and Specific Gravity of Biodiesel-Diesel Blends Using Near-Infrared Spectroscopy. Applied Engineering in Agriculture. American Society of Agricultural and Biological Engineers. 25(2): 217-221

Curran, S., and Irick, D. (2009). On-Road Emissions Evaluation of Student-Produced Biodiesel. SAE Technical Paper Series, 2009-01-2674x

Cussons Technology (2011). Multi Cylinder Engine Test Bed Manual. Manchester M7 1RH. Pp 18-34

da Cunha, M. E., L. C. Krause, M. S. A. Moraes, C. S. Faccini, R. A. Jacques, S. R. Almeida, M. R. A. Rodrigues, and E. B. Caramao. (2009). Beef tallow

biodiesel produced in a pilot scale. *Fuel Processing Technology*. 90(4): 570-575.

Dardiotis, C. G. F., Alessandro, M., Giorgo, M., Urbano, M. (2015). Emissions of modern loght duty ethanol flex fuel vehicles over different operating and environmental conditions. *Fuel.* 140:531-540.

de Oliveira, J. S., P. M. Leite, L. B. de Souza, V. M. Mello, E. C. Silva, J. C. Rubim, S. M. P. Meneghetti, and P. A. Z. Suarez; Characteristics and composition of Jatropha gossypiifolia and Jatropha curcas L. oils and application for biodiesel production. Biomass & Bioenergy, 33, (3), 449-453. 2009.

Demirabas, A. (2005). Biodiesel Production from Vegetable Oils via Catalytic and non-Catalytic Supercritical Methanol Trans-esterification Methods. *Progress in Energy and Combustion Sciencei.* 31:466 487.

Demirabas, A. (2008a). Biofuel sources, Biofuel Policy, Biofuel Economy and Global Biofuel Projection. *Energy Convertion Management.* 49: 2106 – 2116.

Demirbas, A. (2008b). Relationships derived from physical properties of vegetable oil and biodiesel fuels. Fuel, 87, (8-9), 1743-1748.

Demirbas, A. (2009). Prediction of Higher Heating Values for Biodiesels from Their Physical Properties. *Energy Sources Part A-Recovery Utilization and Environmental Effects*. 31(8): 633-638.

Department of Petroleum Resources. (2009). Procedures Guides for the Importation, Storage, Transportation, and Distribution of Biofuels & Biofuels Blended Gasoline and Establishment of Biofuels Plant in Nigeria, *Report* PP. 1-23 Department of Petroleum Resources, Nigeria National Petroleum Corporation, Nigeria

Divani GEL. Attia N. K. Hawash, S. I. (2009). Development and Evaluation of biodiesel fuel and byproduct from jatropha oil. *International journal of science and technology*. 6(2):219-224

EIA. (2011). *Department of Energy (EIA DOE), United States of America,* Retrieved on 5th April, 2012, from http://www. Eia. Doe. Gov

EIA. (2013). US Energy Information Administration, Countries, Nigeria, Full Report. Last Updated 30th December, 2013. Retrieved on 25th July, 2014from http://www. Eia. Doe. Gov

EIA. (2016). US Energy Information Administration,Short-Term Energy Outlook (STEO). Retrieved on 7th July, 2016, from http://www. Eia. Doe. Gov

El Diwani, G.,. Attia, N. K.,and Hawash, S. I. (2009). Development and evaluation of biodiesel fuel and by-products from Jatropha oil. *International Journal of Environmental Science and Technology*. 6(2): 219-224.

Encinar, J. M., Gonzalez, J. F., Pardal, A, and Martinez, G.(2010). *Transesterification of rapeseed oil with methanol in the presence of various co-solvents*.3rd International Symposium on Energy from Biomass and Waste. Venice, Italy: 1-17

Enweremadu, C. C. and M. M. Mbarawa.(2009). Technical aspects of production and analysis of biodiesel from used cooking oil-A review. *Renewable & Sustainable Energy Reviews*. 13(9): 2205-2224.

Enwerenmadu C. C., Omodolu,C., Mustapha. T.,Rutto, L. (2014). Effects of feedstock-related properties on engine performance of biodiesel from canola and sunflower oils of South African Origin. *Journal of Industrial and Mechanical engineering:* 15-16

Erol K. (2005). *Analysis of Hydrogen Fuelled Internal Combustion Engine*. Unpublished M. Sc. Thesis, Graduate School of Engineering and Sciences, Izmir Instute of Technology, Izmir, Turkey

Fernandes D. M., Serqueira, D. S., Portela, F . M., Assuncao, R. M. N., Munoz, R. A. A., and Terrones, M. G. H. (2012). Preparation and characterisation of methylic and ethylic biodiesel from cotton seed oil and effect on tetra-butyl-hydro-quinine on its oxidative stability. *Fuel*. 97: 658-661

Fernandoa, S., Karraa , P., Hernandezb, R., Jhaa, S. K. (2007). Effect of incompletely converted soybean oil on biodiesel quality. *Energy*. 32: 844–851

Frohlich, A. and B. Rice.(2005). Evaluation of Camelina sativa oil as a feedstock for biodiesel production. *Industrial Crops and Products.* 21(1): 25-31.

Fukuda, H., A. Kondo, and H. Noda. (2001). Biodiesel Fuel Production by Transesterification of Oils. *Journal of Bioscience and Bioengineering*. 92(5): 405-416.

Gao, Zhiming Stuart Daw, C. Robert Wabner, M. Dean Edwards, K. David Smith, E.(2012). Simulating the impact of premixed charge compression ignition on light- duty diesel fuel economyand emission of particulates and NOX. *AJournal of Automobile Engineering.* 4: 121-132

Garpen, J. V. Shanks, B. Pruszko, R. Clements, D. and Knothe, G. (2004). Biodiesel Production Technology. R*eport of* National Renewable Energy Laboratory Press, Cole Boulevard, Golden, Colourado, USA, PP. 1-27

Georgogianni, K. G., M. G. Kontominas, E. Tegou, D. Avlonitis, and V. Gergis. (2007). Biodiesel production: Reaction and process parameters of alkali-catalyzed transesterification of waste frying oils. *Energy & Fuels*. 21: 3023-3027.

Ghorbani, H. Nickbakt, A. M. Tabatebaei, M. Hoseini, M. Mohammadi, P. (2011). Application of Modelling Technique for Prediction and Optimisation of Biodiesel Process. I*nternational Conference on Biotechnology and Environmental Management.* 18: 1-8

Giakoumis E. G. (2012). A statistical investigation of biodiesel effect on regulated exhaust emission during transient cycles. *Applied Energy*. 98:273-291

Gopinath, A. Sukumar, P. and Nagarajan, G (2010). Effect of biodiesel structural configuration on its ignition quality. *International Journal of Energy and Environment.* 1(2):395-306.

Graboski, M. S., McCormick, R. L.,Alleman, T. L.,and Herring. A. M. (2003)*The Effect of Biodiesel Composition on Engine Emissions from a DDC Series 60 Diesel Engine, Final Report*: Report 2 in a series of 6. NREL, 2003.

Green Building Advisor (2014). *Musing of an Energy Nerd: Energy Modelling isn't Very Accurate*. Retreived on 23rd July, 2014 from http://greenbuildingadvisdor.com/blogs/dept/musing/energy-modelling-isn't-very-accurate

GTI Soft (2014). G*T Power Engine Simulation Software*. Retrieved on 14th August, 2014 from http://www. Gtisoft. Com/applications/a_Engine_Performance. Php

Haresh, K. (2008). Production of Biodiesel. T*ransesterification Process. R*etrieved on 23rd July, 2012, from http://www. Brighthub. Com/environment/renewable-energy/articles/6718. Aspx

Hari Prasad, T., Reddy, K. H. C., and Rao, M. M. (2011). Combustion, performance and emission analysis of diesel engine fuelled with methyl ester of fish oil. *International Journal of Science and Technology*. 1(1): 32-37

Hasegawa, M., Sakurai, Y.,Kobayashi, Y.,Oyama, N., Sekimoto, M., and Watanabe,H.(2007). Effects of Fuel Properties (Content of FAME or GTL) on Diesel Emissions under Various Driving Modes. S*AE International*. 2007-01-4041

Hellier. P., NicosL., Talal, Y. (2015). the influence of straight vegetable oil fatty acid composition on compression ignition combustion and emissions. *Fuel.*143:131-143.

Holden, B., J. Jack, W. Miller, and T. Durbin(2006). E*ffect of Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions*. Technical Report TR-2275-ENV

Hossain, A. B. M. S., and Boyce, A. N. (2009). Biodiesel production from sunflower cooking oil as an environmentally recycling process and renewable energy. Bulgarian Journal of Agricultural Secience. 15(4): 312-317

Hosseinzadeh, S. Bandpy, M. G. Rad, G. J. and Keshavarz, M. (2012). Experimental and Numerical Study of Impact of Air Filter Holes Making on Altitude at Heavy-Duty Diesel Engine. M*odern Mechanical Engineering*. 2:157-166

http://www. Eia. Gov/forecasts/steo/pdf/steo_full. Pdf

Hu, Q. Sommerfeld, M., Jarvis, E., Ghirardi, M., Posewitz, M., Seibert, M. (2008). Micro Algal Tri-acyl-glycerol as feedstock for biofuel production: perspectives and advances. *Plant J.* 54: 621–39

Huo, Ming Shenlun Lin, HiafergLiv, Chia-fon Lee. F. (2014). Study on the spray and combustion characteristics of water emulsified diesel. *Fuel*. 123:218-229.

I. M. R (2013). IMR 1400 Gas analyser user manual. St Petersburg FL pp (8-42)

Idusayi, N. Ajide, O. O. and Abu, R. (2014). Biodiesel as an Alternative Energy Resource in South West Nigeria. I*nternational Journal of Science of Technology*.2(5): 3232-327

Ihme, M., Schmitt, C., Pitsch, H. (2009). Optimal artificial neural networksand tabulation methods for chemistry representation in LES of a bluff-body swirl-stabilized flame. *Proceedings of the Combustion Institute*. 32 (2009) 1527–1535

Imahara, H., E. Minami, S. Hari, and S. Saka. (2008). Thermal stability of biodiesel in supercritical methanol. *Fuel*. 87, 1-6.

Imperial Oil. (2009). L*ow Temperature Storage Test Phase 2 - Identification of Problem Species*. R498-2009

Ireland, J., R. McCormick, J., Yanowitz, and Wright. S. (2009). Inproving Biodiesel Emissions and Fuel Efficiency with Fuel-Specific Engine Calibration. S*AE Technical Paper Series*. 2009-01-0492,

Isigigur, A., F. Karaosmanoglu, H. Aksoy, F. Hamdullahpur, and O. L. Gulder. (1994). Performance and emission characteristics of a diesel engine operating on safflower seed oil methyl ester. *Applied Biochemistry and Biotechnology*. 45-46 (1): 93-102.

Isioma, Nwadike Yahaya Muhammad, D′Donnell Sylvester, Demshemino innocent, Okoro Linus (2013). Cold flow properties and kinematic viscosity of Biodiesel. *Universal Journal of Chemistry*. 1(4): 135-141

Izah, S. C. and Ohimian, E. I. (2012). The Challenges of Biodiesel Production from Oil Palm Feedstock in Nigeria. G*reener Journal of Biological Sciences*. 3(1): 1-12

Jaroonjitsathian, S., N. Akarapanjavit, S. Siangsanorh, R. In-ochanon, A. Wuttimongkolchai, C. Tipdecho, K. Tsuchihashi, and H. Shirakawa. (2009). Evaluation of 5 to 20 % Biodiesel Blend on Heavy-duty Common-rail Diesel Engine. *SAE Technical Paper Series*. 2009-01-1894,

Kaisan, M. U. (2013). The Secrets of Wild Grape Seeds Oil in Diesel Engine. *Lambert Academic Publishing*. Heinrich – Bucking - Str. 6-8 Saarbrucken, Ductchland / Germany. PP 17-18.

Kaisan, M. U. (2014). Determination of Physico-Chemical Properties of Biodiesel from Wild Grape seeds/Diesel Blends and their Effects on The Performance of a Diesel Engine. Unpublished M. Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Kaisan, M. U. And Pam, G. Y. (2013). Determination of Engine Performance Parameters of a Stationary Single Cylinder Compression Ignition Engine Run on Biodiesel from Wild Grape Seeds/Diesel Blends of Engine Performance Parameters Using Biodiesel From Wild Grape Seeds. *Journal of Energy, Environment and Carbon Credit*. 3(3): 15-21

Kaisan, M. U. Pam, G. Y. and Kulla, D. M. (2013). Physico-Chemical Properties of Biodiesel from Wild Grape seeds Oil and Petro-Diesel Blends. *American Journal of Engineering Research.*02(10): 291-297

Kaisan, M. U. Yusuf, B. H. and Nafiu, T. (2010). Carbon Capture Storage and Processing As a Means of Enhancing Renewable Energy Sources in Nigeria. R*enewable and Alternative Energy for Sustainable National Development.*1: 219-225.

Kaisan, M. U., Pam, G. Y., Kulla, D. M. and Kehinde, A. J. (2015). Effects of Oil Extraction Method on Biodiesel Production from Wild Grape Seeds: A Case Study of Soxhlet Extraction Method and Mechanical Press Engine Driven Expeller Method. *Journal of Alternate Energy and Technologies*. 6 (1): 35-41.

Kakee, A. H. and Pishgoogie M. (2011). Determination of Optimal Valve Timing for Internal Combustion Engines Using Parameter Estimation Method. I*nternational Journal of Automotive Engineering*. 1(2):130-140

Kalbande, S.R. (2009). Production of biodiesel from multi feed stock vegitable oil and its utilization for power generation in diesel engine. Green farmingb2(10):709-712

Kannahi, M. and Arulmozhi, R. (2013). Production of Biodiesel from Edible and Non Edible Oils UsingRizopusOryzae and Aspergillus Niger. P*alagia Research Library. Asian Journal of Plant Science and Research*, 3(5): 60-64

Karabas H. (2012). Investigation of biodiesel from canola oil using various reaction parameters. I*nternational Journal of Automotive Engineering and Technologies*. 2(3): 85-91

Karavalakis, G., D. Karonis, and S. Stournas.(2009). Evaluation of the Oxidation Stability of Diesel/Biodiesel Blends using the Modified Rancimat Method. S*AE Technical Paper Series*, 2009-01-1828.

Karavalakis, G., E. Tzirakis, S. Stournas, F. Zannikos, and D. Karonis. (2010). Biodiesel Emissions from a Diesel Vehicle Operated on a Non-legislative Driving Cycle. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 32(4): 376-383.

Karavalakis, G., Stournas, S., and Bakeas,E. (2009b). Light vehicle regulated and unregulated emissions from different biodiesels. *Science Total Environment*. 407(10): 3338-3346.

Karavalakis, G., Stournas, S., and Bakeas,E.(2009a). Effects of diesel/biodiesel blends on regulated and unregulated pollutants from a passenger vehicle operated over the European and the Athens driving cycles. A*tmosphere and Environ*ment. 43(10): 1745-1752.

Karavalakis, G., Stournas, S.,Ampatzoglou, D.,Bakeas, E.,and A. Spanos.(2009). Regulated and Unregulated Emissoins of a Euro 4 SUV Operated with Diesel and Soy-based Biodiesel Blends. S*AE Technical Paper Series*. 2009-01-2690.

Kasiraman, G., Geo, V. E. Nagalingam, B. (2016). Assessment of Cashew nut shell oil as an alternative fuel for CI (Compression ignition) engines. *Energy*. 101: 402-410

Kaul, S., Saxena, R. C.,Kumar, A., Negi, M. S.,Bhatnagar, A. K.,Goyal, H. B. and Gupta,A. K. (2007). Corrosion behavior of biodiesel from seed oils of Indian origin on diesel engine parts. Fuel Processing Technology. 88(3): 303-307.

Khan, T. M. Y. Atabani. A. E., Badruddin, I. A., Khayoon, M. S. Triwahyono, S. (2014). Recent scenario and Technologies to utilize non-edible oil for biodiesel production. *Renewable and Sustainable Energy Reviews*. 37:840-851.

Kocak, M. S., Ileri, E., and Utlu,Z. (2007). Experimental study of emission parameters of biodiesel fuels obtained from canola, hazelnut, and waste cooking oils. *Energy & Fuels*. 21, 3622-3626.

Kofarbai, G. D., Zeng, Q. (2014). Performance of Biodiesel in a Diesel Engine Using GT-Power Software. *Harbin Engineering University, Harbin*, China150001: 1-12

Kolade, B. Morel, T. and Kong S. (2014). Coupled 1-D /3-D Analyses of Fuel Injection and Dieserl Combustion. Retrieved on 9th October, 2014 from https://www. Erc. Wisc. Edu/documents/13-GT-KIVA-Modeling-Meeting. Pdf

Kolhea, M., Kolhea, S.,. Joshib, J. C. (2015). Economic viability of stand-alone solarphotovoltaic system in comparison withdiesel-powered system for India. *Energy Economics*. 24: 155-165

Kousoulidou, M., G. Fontaras, L. Ntziachristos, and Z. Samaras.(2009). Evaluation of Biodiesel Blends on the Performance and Emissions of a Common-Rail Light-Duty Engine and Vehicle. *SAE Technical Paper Series*. 2009-01-0692,

Krahl, J., A. Munack, Y. Ruschel, O. Schröder, and J. Bünger.(2008). Exhaust Gas Emissions and Mutagenic Effects of Diesel Fuel, Biodiesel and Biodiesel Blends. S*AE Technical Paper Series*. 2008-01-2508,

Kyrtatos, P., Obrecht, P. Hoyer, K., and Boulouchos, K. (2010). Predictive Simulation and Experimental Validation of Phenomenological Combustion and Pollutant Models for Medium-Speed Common Rail Diesel Engines at Varying Inlet Conditions. *International Council on Combustion Engines*. 143:1-13

Kywe, T. T. and Oo, M. M. (2009). Production of Bio-diesel from Jatropha Oil in Pilot Plant. W*orld Academy of Science, Engineering and Technology*. 50: 477-483.

Lapuerta, M., Fernandez, J. R.,and Agudelo. J. R. (2009). Diesel particulate emissions from used cooking oil biodiesel. *Bioresource Technology*. 99(4): 731-740.

Lapuerta, M., Herreros, J. M., Lyons, L. L., Garcia-Contreras, R., and Briceno. Y. (2008b). Effect of the Degree of Unsaturation of Biodiesel Fuels on NOx and Particulate Emissions. S*AE International*. 2008-01-1676, 2008.

Lapuerta, M., Herreros, J. M.,Lyons, L. L.,Garcia-Contreras, R., and Briceno. Y. (2008a). Effect of the alcohol type used in the production of waste cooking oil biodiesel on diesel performance and emissions. *Fuel*. 87(15- 16): 3161-3169.

Lapuerta, M., J. Rodriguez-Fernandez, F. Oliva, and L. Canoira; Biodiesel from Low-Grade Animal Fats: Diesel Engine Performance and Emissions. *Energy & Fuels*. 23(1): 121-129. 2009.

Lei, T., Wang, Z., Chang, X., Lin, L., Yan, X., Sun, Y., Shi, X., He, X., Zhu, J. (2016). Performance and emissions characteristics of a diesel engine running on optimized ethyl levulinate-biodiesel-diesel blends. *Energy*. 95: 29-40.

Li, Y., Horsman, M., Wu, N. Lan, C. Q. (2008). Biofuels from Micro Algae. *Biotechnol. Prog.* 24:815-820

Lin, B. F., J. H. Huang, and D. Y. Huang. (2009a). Experimental study of the effects of vegetable oil methyl ester on DI diesel engine performance characteristics and pollutant emissions. Fuel, 88(9): 1779-1785.

Lin, C. Y., and Chiu,C. C.(2009b). Effects of Oxidation during Long-term Storage on the Fuel Properties of Palm Oil-based Biodiesel. *Energy & Fuel.* 23: 3285-3289.

Lin, Y. C., Lee, C. F. and Fang, T. (2008a). Characterization of particle size distribution from diesel engines fuelled with palm-biodiesel blends and paraffinic fuel blends. A*tmosphere and Environ*ment. 42(6): 1133-1143.

Lin, Y. C., Tsai, C. H.,Yang, C. R.,Wu, C. H. J.,Wu, T. Y.,and Chang-Chien,G. P. (2008b). Effects on aerosol size distribution of polycyclic aromatic hydrocarbons from the heavy-duty diesel generator fuelled with feedstock palm-biodiesel blends. A*tmosphere and Environ*ment. 42(27): 6679-6688.

Lin, Y. C., Wu, T. Y., Ou-Yang, W. C.,and ChenmC. B.(2009c). Reducing emissions of carbonyl compounds and regulated harmful matters from a heavy-duty diesel engine fueled with paraffinic/biodiesel blends at one low load steady-state condition. A*tmosphere and Environ*ment. 43(16): 2642-2647.

Lin, Y. F., Wu, Y. P. G. and ChangC. T. (2007). Combustion characteristics of waste-oil produced biodiesel/diesel fuel blends. *Fuel*. 86(12-13): 1772-1780.

Liu, H. Strank, S. Werst, M. Hebner, R. and Osara, J. (2010). Combustion Emissions Modelling and Testing of Conventional Diesel Fuel. A*SME 2010 4th International Conference on Energy Sustainability. Phoenix, AZ, USA*. ES2010-90037:1-10

Llewellin, E. W. (2010). LBflow: An extensible lattice Boltzmann framework for the simulation of geophysical flows. Part II: usage and validation. C*omputers & Geosciences*. 36: 123–132

Lomonaco, D. Maia, F. J. N., Clemente, C. S., Mota, J. P. F., Costa Junior, A. E., and Mazzetto, S. E. (2012). Thermal studies of new biodiesel antioxidants synthesized from a naturally occurring phenolic lipid. *Fuel*. 97: 552-559

Ma, F. Clements, L. D. and Hanna, M. A. (1998). Biodiesel Fuel. T*ransaction of ASAE,* 41(1): 1261-1264

Machado, M., Zuvanov, V. C., Rojas, E. E. G., Zuniga, A. D. G., and Costa, B. (2012). Thermophysical properties of biodiesel obtained from vegetable oils. Corn, soy, canola and sunflower. C*entro Cientifico Conhecer-Goiania*. 8(14): 917-926

Madarasz, J. and Kumar, A. (2011). Stability of Biodiesel from Non Edible Oils. I*nternational Journal of Energy Science.* 1(3): 186-191

Makareviciene, V., Kazencev, K., Kazenceva, I. (2015). Possibilities for improving the cold flow properties of biodiesel fuel by blending with butanol. *Renewable Energy*. 75: 805-807

Mansoupour, M, and Shariati, A. (2012). Optimisation of biodiesel production from sunflower using response surface methodology. *Journal of Chemical Engineering Process Technology*. 3(4): 1-5

McCormick, R. L., Alvarez, J. R.,and Graboski,M. S. (2003).NOx Solutions for Biodiesel, Final Report: Report 6 in a series of 6. National Renewable Energy Laboratory.

Meng, X. M., G. Y. Chen, and Y. H. Wang; Biodiesel production from waste cooking oil via alkali catalyst and its engine test. Fuel Processing Technology, 89, (9), 851-857. 2008.

MLA.(2011). Biodiesel Aditive. Final Report by Meat and Livestock of Australia. A*MDC*. 003: 1-18

Mofijur, M., Masjuki, H. H. ,Kalam, M. A., Atabani, A. E., Rizwanal Fattah, I. M., Mobarak, H. M. (2014). Comparative evaluation of performance and emission characteristics of Moringa Oleifera and palm oil based biodiesel in a diesel engine. *Journal of Industrial Crops and Product*. 53:78-84

Mofijur. M., Atabani A. E., Masjuki, H. H, Kalam, M. A, Masum, B. M. (2013). A study on the effects of promising edible and non-edible biodiesel feedstocks on engine performance and emissions production. A comparative evaluation. *Renewable and sustainable energy Reviews*. 23:391-404.

Mohiuddin, A. K., Ataur-Rahman, M.,and Dzaidin M. (2007). Optimization Design of Automobile Exhaust System Using GT-Power. I*nternational Journal of Mechanical and Material Engineering*. 2(1): 40-47

Monirul, I. M., Masjuki, H. H., Kalam, M. A., Mosarof, M. H., Zulkifli, N. W. M., Teoh, Y. H., How, H. G. (2016). Assessment of performance, emission and combustion characteristics of palm, Jatropha and Callophyllum inophyllum biodiesel blends. *Fuel.http://dx. Doi. Org/10.1016/j. Fuel.2016.05.010*

Moroz, S., Bourgoin, G.,Lujan, J. M. and Pla,B. (2009). Acidic Condensation in Low Pressure EGR Systems using Diesel and biodiesel Fuels. *SAE Technical Paper Series*. 2009-01-2805,

Moser, B. R. (2008). Influence of blending canola, palm, soybean and sun flower oil methyl esters on fuel properties of biodiesel. E*nergy & Fuels*. 22(6): 4301-4306

Moser, B. R. (2009). Biodiesel production, properties and feedstocks. I*n Vitro. Cell. Biol.-Plan*t. 45: 226-229

Moser, B. R., and VaughnS. F.(2010). Evaluation of alkyl esters from Camelina sativa oil as biodiesel and as blend components in ultra low-sulfur diesel fuel. *Bioresource Technology*. 101(2): 646-653.

Muthukumar, A., Elayaraja, S., Ajithkumar, T. T., Kumaresan, S., and Balasubramanian, T. (2012). Biodiesel production from marine micro algae chlorella marina and nanochloropsis salina. *Journal of Petroleum Technology and Alternative Fuels*. 3(5): 58-62

Myo, T., Kinoshita, E., Tsuru, H.,and Hamasaki,K.(2007). Combustion Characteristics of a DI Diesel Engine with Palm Kernel Oil Biodiesel and Its Blend (B20). S*AE International.* 2007: 65-68

Nafiu, T., Zuru, A. A., Kaisan, M. U., Ummi, I. M., and Yusuf, B. H. (2011). Production of Biodiesel from Wild Grapes (*Lannea Microcarpa*) Seeds.*Nigeria Society of Engineers Technical Transaction Journals.*6(1): 1-15

Nakpong, P., and Wootthikanokkhan,S.(2010). High free fatty acid coconut oil as a potential feedstock for biodiesel production in Thailand. *Renewable Energy*.35(8): 1682-1687.

National Biodiesel Foundation (1994). Retrieved on August 03, 2011, from www. Biodieselfoundation. Org

National Energy Master Plan (2007). National Energy Master Plan, Energy Commission of Nigeria, *Federal Republic of Nigeria*

NEP. (2014). National Energy Policy, Energy Commission of Nigeria, *Federal Republic of Nigeria*

Nevase, S. S., Shinde, K. J., Kada, B. D. (2008). Biofuel production from Jatropha oil. *Green farming.* 1(10-11): 102-104

Nigerian Bio-Fuel Policy and Incentives (2011). Unpublished Policy Document of Nigeria National Petroleum Corporation, PP.4-23. NNPC Approved Ethanol Policy Draft, NNPC Towers, Abuja, Nigeria

NNPC (2007).*Nigerian Bio-Fuel Policy and Incentives*. Unpublished Policy Document Nigeria National Petroleum Corporation Approved Ethanol Policy Draft, NNPC Towers, Abuja, Nigeria. PP 4-23

Ohshio, N., Saito, K.,Kobayashi, S.,and Tanaka, S. (2008). Storage Stability of FAME Blended Diesel Fuels. *SAE Technical Paper Series*. 2008-01-2505

Okamoto, T., Nakasato, T., and Konno,M.(2007). Fuel Properties and Engine Performance of Dimethyl Ether- Blended Biodiesel Fuels. *SAE Technical Paper Series*. 2007-01-2016.

Okoro, O. V.,Osuagwu, C., Okeke,I. O.(2015). Analysis of an Intelligent Temperature Transmitter forProcess Control. *Nigerian Journal of Technology (NIJOTECH*). 34 (3): 582 – 590

Ong, H. C. Silitonga, A. S. Masjuki, H. H. Mahlia, T. M. I. Chong, W. T. Boosroh, M. H (2013). Production and comparative fuel properties of biodiesel from non-edible oils: Jatropha curcas, sterculiafoetida and ceibapentadra. *Energy conversion and Management.* 73:243-255

Ong, H. C., Masjuki, H. H. Mahlia, T. M. I., Silitonga, A. S., Chong, W. T., Leong, K. Y. (2014a). Optimization of biodiesel production and engine performance from high free fatty acid Calophylluminophyllum oil in CI diesel engine. *Energy conversion and Management*. 81:30-40

Ong, H. C., Masjuki, H. H. Mahlia, T. M. I., Silitonga, A. S., Chong, W. T.,Talal,Y.(2014b). Engine performance and emission using jatrophacurcas, ceibapentandra and calophylluminophyllum biodiesel in CI diesel engine. *Energy*. 69:427-445

Onyishi, A. O., Eme, O. I., and Emeh, I. E. J. (2012). The Domestic and International Implications of Fuel Subsidy Removal Crisis in Nigeria. K*uwait Chapter of Arabian Journal of Business and Management Review.*1(6): 57-81

Ozsezen, A.N., Canakci, M. And Sayin, C. (2008). Effects of biodiesel from used frying palm oil on the performance, injection, and combustion characteristics of an indirect injection diesel engine. *Energy & Fuels*. 22(2): 1297-1305.

Ozsezen, A.N., Canakci, M.,Turkcan, A.,and Sayin,C. (2009). Performance and combustion characteristics of a DI diesel engine fuelled with waste palm oil and canola oil methyl esters. *Fuel*. 88, (4), 629-636.

Palash, S. M., Kalam, M. A., Masjuki, H. H., Arbab, M. I., Masum, B. M., Sanjid, A. (2014). Impacts of NOx reducing antioxidant additive on performance and emissions of multi-cylinder diesel engine fuelled with Jatropha biodiesel blends. *Energy Conversion and Management*. 77: 577-585

Park C. W., Sung W. L., Gihan L., Young C., Changgi K. (2014). Full load performance and emission characteristics of hydrogen- compressed natural gas engine with valve overlap. *Fuel.* 123:101-106.

Patil, P. D., and Deng,S. G. (2009a). Optimization of biodiesel production from edible and non-edible vegetable oils. *Fuel*. 88(7): 1302-1306.

Patil, P. D., and Deng. S. G. (2009b). Transesterification of Camelina Sativa Oil Using Heterogeneous Metal Oxide Catalysts. *Energy & Fuels*. 23: 4619-4624.

Patil, P. D., Gude, V. G. Camacho, L. M. and Deng. S. (2009d). Microwave-Assisted Catalytic Transesterification of Camelina Sativa Oil. *Energy & Fuels*. 24(2): 1298-1304.

Patil, P. D., Gude, V. G.,and Deng,S. (2009c). Transesterification of Camelina Sativa Oil using Supercritical and Subcritical Methanol with Cosolvents. *Energy & Fuels*. 24(2): 746-751.

Patterson, J., Hassan, M. G.,Clarke, A.,Shama, K., Hellgardt, K.,and Chen,R.(2006). E*xperimental Study of DI Diesel Engine Performance Using Three Different Biodiesel Fuels*. New Diesel Engines and Components and CI Engine Performance for Use with Alternative Fuels. SP-2014, 2006-01-0234.

Perihan, S., and Zeki, Y. (2011). Application of Energy and Exergy Analyses to a CI Engine Using Biodiesel *Fuel. Mathematical and Computational Applications*. 16(4): 797-808

Prasad, H. T., Hema, C. R. . RaoMuralidhara. K. M. (2011). Combustion, performance and Emission Analysis of Diesel Engine Fuelled with Methyl Esters of Fish Oil. *International Journal of Science and Technology*. 1:32-37.

Prasath, B. R., Leelakrishnan, E., Lokes, N., Suriyan, H,. Guru Prakash, E., Ahmed, K. O. M. (2012). Hydrogen Operated Internal Combustion Engines-A New Generation Fuel. *International Journal of Emerging Technology and Advance Engineering*. 2(4): 52-57

Qi, D. H., Chen, H., Ghen, L. M., Bian, Y. Z. (2010). Experimental Studies of the combustion characteristics of biodiesel-diesel-methanol blend fuelled engine. *Applied Energy*. 87: 1679-1686

Rahim, R. Mamat, R. and Taib, M. Y. (2012a). Comparative Study of Biofuels and Biodiesel Blend with Mineral Diesel Using One Dimensional Simulation. M*aterial Science and Engineering*. 36(012009): 1-10

Rahim, R. Mamat, R. Taib, M. Y. and Abdullah, A. A. (2012b). Influence of Fuel Temperature on a Diesel Engine Performance Operating with Biodiesel Blend. I*nternational Journal of Advance Sciences and Technology*. 43:115-126

Ramos, M. J., C. M. Fernandez, A. Casas, L. Rodriguez, and A. Perez.(2009). Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource Technology*.100(1): 261-268.

Rashid, U. and F. Anwar. (2008a). Production of biodiesel through base-catalyzed transesterification of safflower oil using an optimized protocol. *Energy & Fuels*. 22(2): 1306-1312.

Rashid, U. and F. Anwar. (2008b). Production of biodiesel through optimized alkaline-catalyzed transesterification of rapeseed oil. *Fuel*. 87: 265-273.

Rashid, U., F. Anwar, and M. Arif. (2009). Optimization of Base Catalytic Methanolysis of Sunflower (Helianthus annuus) Seed Oil for Biodiesel Production by Using Response Surface Methodology. *Industrial & Engineering Chemistry Research*. 48(4):1719-1726.

Rashid, U., F. Anwar, B. R. Moser, and S. Ashraf. (2008c). Production of sunflower oil methyl esters by optimized alkali-catalyzed methanolysis. *Biomass & Bioenergy*. 32(12): 1202-1205.

Renewable Energy Master Plan (2005). Renewable Energy Master Plan, Energy Commission of Nigeria, *Federal Republic of Nigeria*

Renita, A. A., Bhargav, S. S., and Kumar, P. (2013). E valuation of fuel properties of various biodiesel generated feedstock. *International Journal of Applied Engineering Research.* 8(16):1865-1870

Reyadth, M. (2009). The cultivation of Jatropha curcas in Egypt. Retrieved from http://www. Shirkebiofuel. Com/jatropha

Rice, B., Flohrich, A., and Leonard, R. (1998). Biodiesel production from camelina oil, waste cooking oil and tallow. The Science of Farming and Food, Teagask, EU. ISBN 1 901138 674; PP. 1-11

Roy, M. M., Wang, W., Alawi, M. (2014). Performance and emissions of a diesel engine fuelled by biodiesel-diesel, biodiesel-diesel-additive and kerosene-biodiesel blends. *Energy Conversion and Management*. 84: 164-173

Sahoo, P. K.,. Das, L. M, Babu, M. K. G.,Arora, P.,. Singh, V. P.,Kumar, N. R.,and Varyani,T. S.(2009). Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. *Fuel.* 88(9): 1698-1707.

Saka, S., Kusdiana, D., and Minami, E. (2006).Non-catalytic buodiesel fuel production with superficial methanol technologies. *Journal of Science and Industrial Research*. 65: 420-425

Sambo, A. S. (2011). *Low Carbon Opportunities in the Nigerian Energy Sector*. A paper Presented at the Workshop organized by the World Bank, held in Abuja, Nigeria, 8-9 June

Sani, Y. M., Adeniyi, P., Raji-yahya, A. O., Abdul, A. R., Mohd, W., & Wan, A. (2016). Journal of the Taiwan Institute of Chemical Engineers Facile synthesis of sulfated mesoporous Zr / ZSM-5 with improved Brønsted acidity and superior activity over SZr / Ag, SZr / Ti, and SZr / W in transforming UFO into biodiesel, 60, 247–257. https://doi.org/10.1016/j.jtice.2015.10.010

Schonborn, A., Ladommatos, N., Williams, J., Allan, R., and Rogerson,J. (2009). The influence of molecular structure of fatty acid monoalkyl esters on diesel combustion. *Combustion and Flame*. 156(7): 1396-1412.

Schumacher, L. G., Borgelt, S., and Hires,W. (1995). Fuelling Diesel Engines with Blends of Methyl-ester Soybean Oil and Diesel Fuel. *Applied Engineering in Agriculture*. 11 (1): 37-40.

Schumacher, L., Borgelt, S.,Hires, W., Wetherell, W., and Nevils,A. (1996). 100,000 Miles of Fueling 5.9L Cummins Engine with 100 % Biodiesel. *SAE Technical Paper Series*. 962233.

Senthilkumar. R. and Sivaprakasam . S. (2013) Performance, combustion and Emission characteristics on Direct Injection Diesel Engine using Bio Additive. *International Journal of Applied Energy*.1:(80-85)

Simonyan, K. J. and Fasina, O. (2013). Biomass Resources and Bio-energy Potentials in Nigeria. A*cademic journals: African Journal of Agricultural Research.*8 (40).

Sinnamon, J. F. (2007). Co-Simulation Analysis of Transient Responses and Control for Engines with Variable Valvetrains. *SAE International*. 1223:1-15

Sivarinakrishnan, K, and Ravikumar, P.(2012). Determination of cetane number of biodiesel and its influence on physical properties. *ARPN Journal of Engineering and Applied Science*. 7(2): 205-211

Sokolowski, J. A., Banks, C. M. (2009). Principles of Modeling and Simulation. Hoboken, NJ: Wiley. PP. 6-7

Sokoto, M. A., Hassan L. G., Dangoggo, S. M., Ahmad H. G., Uba, A. (2011). Biodiesel Fuel. *Nigerian Journal of Basic and Applied Science*. 19(1): 81- 86

Soltic, P., Edenhauser, D.,Thurnheer, T., Schreiber, D., and Sankowski, A. (2009). Experimental investigation of mineral diesel fuel, GTL fuel, RME and neat soybean and rapeseed oil combustion in a heavy duty on-road engine with exhaust gas after treatment. *Fuel*. 88(1): 1-8.

Srivastava, A., and Prasad, R. (2000). Triglycerides-based diesel fuels. *Renewable & Sustainable Energy Reviews.* 4(2): 111-133.

Stark, M., Bala, T., Jans, C., Prakash, A., Sousa, R. P., Srivatsan, M. and Upadhyay, M. (2010). Blending Biofuels in the European Union. Retrieved on 28th May, 2014 from www. Accenture. Com

Stevenson, D. G. Eller, F. J. Liping, W. Tong, W. and Inglet, G. E. (2005). Oil and Tocopherol Content and Composition of Pumpkin Seed Oil in 12 Cultivars. Retrieved on 28th July 2011 from http://www.cat.inist.Fr/

Stevenson, D. G., Eller, F. J,. Liping, W., Tong, W., and Inglet, G. E. (2005). Oil and Tocopherol Content and Composition of Pumpkin Seed Oil in 12 Cultivars. Retrieved on 28th July 2011 from http://www. Cat. Inist. Fr/

Suarez- Bertoa, R., Zardini, A. A., Keuken, H., Astorga, C. (2015). Impact of ethanol containing gasoline blends on emission from a flex-fuel vehicle tested over the world wide Harmonized light duty test cycle (WLTC). *Fuel*. 143:173-182

Sundaresan, M.,. Chandrasekaran, S and Tamil,P.(2007). . Analysis of Combustion, Performance and Emissions Characteristics of Blends of Methyl Esters of Jatropha Oil (MEJ) in DI Diesel Engine. S*AE International*. JSAE-20076566

Suryawanshi, J. G., and Deshpande, N. V. (2005). *Experimental Investigations on a Jatropha Oil Methyl Ester Fuelled Diesel Engine*. ASME Internal Combustion Engine Division Spring Technical Conference, ICES2005-1040, 1-8.

Suryawanshi, J. G., and Deshpandem (2006). *The Effects of Combination of EGR, Injection Retard and Injection Pressure on Emissions and Performance of Diesel Engine Fuelled With Jatropha Oil Methyl Ester*. ASME International Mechanical Engineering Congress and Exposition, IMECE2006-13021, 1-12.

Tariq, M., Ali, S., Ahmad, F., Ahmad, M., Zafar, M., Khalid, N., Khan, M A.,. (2011). Identification, FT-IR, NMR (1H and 13C) and GC-MS studies of fatty acid methyl esters in biodiesel from rocket seed oil. Fuel Processing Technology. 92: 336–341

Tesfa, B., Mishra, R., Gu, F., Powles, N. (2013) Prediction models for density and viscosity of biodiesel and their effects on fuel supply system in CI engines. *Renewable Energy*. 35: 2752–2760.

Thanh, L. T., Okitsu, K., Sadanaga, Y.,Takenaka, N.,Maeda, Y., and Bandow,H.(2010). Ultrasound-assisted production of biodiesel fuel from vegetable oils in a small scale circulation process. *Bioresource Technology*. 101(2): 639-645.

Thirumarimurugan, M., Sivakumar, V. M., Xavier, A. M., Prabhakan, D., and Kannadasan, T. (2012). Properties of biodiesel from sunflower oil by

tranesterification. I*nternational Journal of Bioscience, Biochemistry and Bioinformatics*. 2(6): 441-444

Tira, H. S., Herreros, J. M., Tsolakis, A., Wyszynski M. L. (2014). Influence of the addition of LPG-reformate and H2 on an engine dually fuelled with LPG-diesel, RME and –GTL fuels. *Fuel*. 118:73-82.

Topare, N. S., Renge, V. C., Satish, V., Khedkar, Y. P., ShavonBhagat, S. L. (2011). Biodiesel from algae oil as an alternative fuel for diesel engine. *Journal of Chemical, Environment and Pharmaceutical Research*. 2: 2-3:116-120

Tuli, D. K. (2014).Non Edible Oils as Feed Stocks for Biodiesel. I*ndian Oil Corporation Limited R&D Centre. Sector 13, Farabad*, 121: 007

Ved K, and Padam K. (2013). Study of physical and chemical properties of biodiesel from sorghum oil. *Research Journal of Chemical Sciences*. 3(9): 64-68

Wang, X., Ge, Y., Yu, L., Feng, X. (2013). Comparison of combustion characteristics of brake thermal efficiency of a heavy-duty diesel engine fuelled with diesel and biodiesel at high altitude. *Fuel*. 107: 852-858

Whitley, K. (2010). Investigation of Super Turbocharger Performance Improvement Through Steady State Engine Simulation. Unpublished Master's Thesis, Department of Mechanical Engineering, Colourado State University, Fort Collins, Colourado, USA

Williams, H P (2008). Model Building in Mathematical Programming, Fourth Edition, John Willey and Sons Limited, the Atrium, South Gate, Chichester, West Sussex. PO19 8SQ, England. PP 3-10

Woo, C., Kook, S., Hawkes, E. R., Rogers, P. L., Marquis, C. (2015). Dependency of engine combustion on blending ratios of lipase-catalysed coconut oil biodiesel and petroleum diesel. *Fuel. http://dx. Doi. Org/10.1016/j. Fuel.2015.12.024*

Yoon, S. H., H. K. Suh, and C. S. Lee. (2009). Effect of Spray and EGR Rate on the Combustion and Emission Characteristics of Biodiesel Fuel in a Compression Ignition Engine. *Energy & Fuels*. 23, 1486-1493.

Zhang, X., Gao, G.,Li, L., Wu, Z., Hu, Z.,and Deng. J.(2008). Characteristics of Combustion and Emissions in a DI Engine Fueled with Biodiesel Blends from Soybean Oil. *SAE Technical Paper Series*. 2008-01-1832.

Zhang, Y. Hua, Z., Mohammed O., Alasdair C. (2013). CIA Combustion of gasoline and its mixture with ethanol in 2-stroke poppet valve DI gasoline engine. *Fuel*. 109:661-668

Zheng, J. (2009). Use of an Engine Cycle Simulation to Study a Biodiesel Fuelled Engine. Unpublished Master's Thesis, Department of Mechanical Engineering, Texas A&M University, TX, USA

Zheng, M., Han, X., Tan, Y., Kobler, M., Ko, S., Wang, M., Mulenga, M. C.,and Tjong, J. (2008). Low Temperature Combustion of Neat Biodiesel Fuel on a Common-rail Diesel Engine. *SAE Technical Paper Series*. 2008- 01-1396.

APPENDICES

APPENDIX A: GC-MS Results for Cotton, Jatropha and Neem Methyl Esters

Table A. 1: GC-MS Results for Cotton Methyl Ester

Peak Number	*Compound (Methyl Ester)*	*Area (%)*	*Peak #*	*Compound(Aldehyde)*	*Area (%)*
4	*Nonanoic Acid Methyl Ester* $C_{10}H_{18}O_3$	*0.20*	*2*	*Pentanal* $C_7H_{14}O$	*0.43*
6	*Octadecanoic Acid Methyl Ester* $C_{19}H_{36}O_2$	*3.49*	*3*	*Decadienal* $C_{10}H_{16}O$	*0.23*
7	*Pentanoic Acid Methyl Ester* $C_{17}H_{34}O_2$	*11.53*			*Total 0.66*
8	*Hexadecanoic Acid Methyl Ester* $C_{18}H_{36}O_2$	*0.54*	*Peak #*	*Compound (Alkane)*	*Area (%)*
9	*Octadecadienoic Acid Methyl Ester* $C_{19}H_{34}O_2$	*14.23*	*1*	*Heptanes* C_9H_{20}	*1.72*
10	*Octadecadienoic Acid Methyl Ester* $C_{19}H_{36}O_2$	*17.72*			*Total 1.72*
11	*Octadecadienoic Acid Methyl Ester* $C_{19}H_{38}O_2$	*7.32*	*Peak #*	*Compound (Acyl Chloride)*	*Area (%)*
12	*Oleic Acid Methyl Ester* $C_{18}H_3O_2$	*3.41*	*15*	*Octadecadenoyl Chloride* $C_{18}H_{31}CLO$	*2.98*
13	*Eicosadienoic Acid Methyl Ester* $C_{21}H_{38}O_2$	*1.81*	*18*	*Octadecadenoyl Chloride* $C_{18}H_{31}CLO$	*1.04*
14	*Octadecanoic Acid Methyl Ester* $C_{19}H_{38}O_2$	*1.49*			*Total 4.02*
16	*Methyl Ricinolate Methyl Ester* $C_{19}H_{36}O_3$	*1.85*	*Peak #*	*Compound (Alkanoate)*	*Area (%)*
17	*Eicosanoic Acid Methyl Ester* $C_{21}H_{42}O_2$	*3.47*	*5*	*Methyl Tetradecanoate* $C_{15}H_3O_2$	*3.84*
19	*Hexadecanoic Acid Methyl Ester* $C_{19}H_{38}O_4$	*7.07*			*Total 3.84*
20	*Octadecenoic Acid Methyl Ester* $C_{21}H_{14}O_4$	*15.62*			
	Total	*89.75*			*10.25*

Table A. 2: GC-MS Results of Jatropha Biodiesel

Peak Number	*Compound (Methyl Ester)*	*Area (%)*	*Peak #*	*Compound(Aldehyde)*	*Area (%)*
10	*Octadecanoic acid Methyl ester* $C_{19}H_{36}O_2$	*2.84*	*2*	*Pentanal* $C_7H_{14}O$	*0.34*
11	*Pentadecanoic acid Methyl ester* $C_{17}H_{34}O_2$	*14.25*	*3*	*Decadienal* $C_{10}H_{16}O$	*0.55*
12	*Hexadecanoic acid Methyl ester* $C_{16}H_{32}O_2$	*2.67*			*Total 0.89*
13	*Octadecanoic acid Methyl ester* $C_{19}H_{36}O_2$	*19.32*	*Peak #*	*Compound (Ketone)*	*Area (%)*
14	*Octadecanoic acid Methyl ester* $C_{19}H_{36}O_2$	*15.10*	*1*	*Hexanone* $C_8H_{16}O$	*1.37*
15	*Octadecanoic acid Methyl ester* $C_{19}H_{38}O_2$	*9.62*			*Total 1.37*
16	*Hexadecanoic acid Methyl ester* $C_{16}H_{30}O_2$	*15.10*	*4*	*Tridecane* $C_{13}H_{28}$	*0.30*
17	*Octadecanoic acid Methyl ester* $C_{18}H_{36}O_2$	*2.51*	*5*	*Tetradecane* $C_{14}H_{30}$	*0.45*
18	*Eicosanoic acid Methyl ester* $C_{21}H_{42}O_2$	*3.11*	*6*	*Hexadecane* $C_{16}H_{34}$	*0.42*
19	*Hexanoic acid Methyl ester* $C_{19}H_{38}O_4$	*1.35*	*7*	*Hexadecane* $C_{16}H_{34}$	*0.37*
20	*Docosanoic acid Methyl ester* $C_{23}H_{46}O_2$	*1.05*	*8*	*Heptadecane* $C_{19}H_{40}$	*0.43*
22	*Octadecanoic acid Methyl ester* $C_{21}H_{40}O_4$	*5.05*	*9*	*Hexadecane* $C_{16}H_{34}$	*0.32*
					Total 2.29
			Peak #	*Compound(Alkene)*	*Area (%)*
			23	*Squalene* $C_{30}H_{50}$	*0.66*
					Total 0.66
			Peak #	*Compound(Alcohol)*	*Area (%)*
			21	*Lupeol* $C_{30}H_{50}O$	*2.82*
					Total 2.82
	Total	*91.97*			*8.03*

Table A. 3: GC-MS Results of Neem Biodiesel

Peak Number	*Compound (Methyl Ester)*	*Area (%)*	*Peak #*	*Compound(Aldehyde)*	*Area (%)*
4	*Pentadecanoic acid Methyl ester* $C_{17}H_{34}O_2$	*10.64*	3	*Decadienal* $C_{10}H_{16}O$	*0.78*
5	*Hexadecanioc acid Methyl ester* $C_{16}H_{32}O_2$	*1.75*		*Total*	*0.78*
6	*Octadecanoic acid Methyl ester* $C_{19}H_{34}O_2$	*9.52*	*Peak #*	*Compound (Ketone)*	*Area (%)*
7	*Octadecanoic acid Methyl ester* $C_{19}H_{36}O_2$	*24.86*	*1*	*Ethanone* $C_6H_{10}O_2$	*11.27*
8	*Octadecanoic acid Methyl ester* $C_{19}H_{38}O_2$	*9.97*	*2*	*Pentanone* $C_6H_{12}O_2$	*2.84*
9	*Octadecanoic acid Methyl ester* $C_{18}H_{42}O_2$	*10.34*		*Total*	*14.11*
10	*Eicosanoic acid Methyl ester* $C_{21}H_{42}O_2$	*0.99*	*Peak #*	*Compound (Acyl chloride)*	*Area (%)*
11	*Hexadecanioc acid Methyl ester* $C_{19}H_{38}O_4$	*2.13*	*12*	*Octadecadienoyl chloride* $C_{18}H_{31}CLO$	*8.86*
	Total	*70.2*		*Total*	*8.86*
Peak #	*Compound (Alkane)*	*Area (%)*	*Peak #*	*Compound (Alkene)*	*Area (%)*
14	*Eicosane* $C_{26}H_{54}$	*3.28*	*13*	*Squalene* $C_{30}H_{50}$	*2.77*
		Total 3.28		*Total*	*2.77*

APPENDIX B: Physico Chemical Properties of Biodiesel

Table B. 1: Specific Gravity of Biodiesels

	Specific Gravity						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	0.8704	0.8727	0.8763	0.8773	0.8783	0.8823	0.9072
NEEM	0.8734	0.8763	0.8783	0.8813	0.8843	0.8863	0.9497
COTTON	0.8714	0.8743	0.8763	0.8773	0.8793	0.8823	0.9145
MIXED	0.8720	0.8742	0.8757	0.8770	0.8849	0.8720	0.8712
ASTM min	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000
ASTM max	0.9000	0.9000	0.9000	0.9000	0.9000	0.9000	0.9000
DIESEL	0.8690	0.8690	0.8690	0.8690	0.8690	0.8690	0.8690

Table B. 2: Viscosity of Biodiesels from Secondary Data

	Viscosity at 40^0C mm^2/s						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	4.92	4.37	5.22	5.60	5.56	5.88	6.00
NEEM	4.19	4.52	5.20	5.61	6.20	6.76	6.00
COTTON	4.14	4.62	5.03	5.08	6.00	6.30	6.50
MIXED	4.28	4.92	4.87	4.46	5.85	4.38	4.95
ASTM min	1.90	1.90	1.90	1.90	1.90	1.90	1.90
ASTM max	6.00	6.00	6.00	6.00	6.00	6.00	6.00
DIESEL	5.77	5.77	5.77	5.77	5.77	5.77	5.77

Table B. 3: Calorific Values of Biodiesels

	Calorific Value						
	B5	B10	B15	B20	B25	B30	B100
ASTM max	46	46	46	46	46	46	46
DIESEL	45.32	45.32	45.32	45.32	45.32	45.32	45.32
JATROPHA	42.84	43.72	42.99	44.21	45.41	42.1	44.23
NEEM	43.09	42.16	43.11	44.66	42.98	43.02	43.13
COTTON	44.44	43.59	44.61	43.19	42.11	44.77	43.41
MIXED	43.11	44.41	44.99	44.31	43.16	43.58	44.24
ASTM min	42	42	42	42	42	42	42

Table B. 4: Acid Values of Biodiesels

	Acid Value mgKOH/g						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	0.31	0.34	0.40	0.36	0.42	0.44	0.48
NEEM	0.16	0.14	0.18	0.12	0.20	0.20	0.24
COTTON	0.24	0.28	0.22	0.18	0.18	0.20	0.18
MIXED	0.22	0.23	0.21	0.20	0.19	0.20	0.23
ASTM max	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DIESEL	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Table B. 5: Flash Points of Biodiesels

	Flash Point ^{0}C						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	150	148	145	138	138	138	146
NEEM	152	149	148	143	143	143	175
COTTON	167	150	150	145	145	145	155
MIXED	165	155	150	145	150	155	165
ASTM min	130	130	130	130	130	130	130
ASTM max	170	170	170	170	170	170	170
DIESEL	95	95	95	95	95	95	95

Table B. 6: Pour Points of Biodiesels

	Pour Point ^{0}C						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	-9	-9	-12	-6	-15	-15	-3
NEEM	-9	-9	-6	-6	-6	-9	6
COTTON	-9	-9	-9	-6	-12	-6	3
MIXED	-12	-9	-6	-6	-6	-10	-9
ASTM min	-15	-15	-15	-15	-15	-15	-15
ASTM max	10	10	10	10	10	10	10
DIESEL	-6	-6	-6	-6	-6	-6	-6

Table B. 7: Cloud Points of Biodiesels

	Cloud Point ^{0}C						
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	-4	-2	-2	-2	-2	-2	9
NEEM	3	4	-4	8	10	3	9
COTTON	2	3	1	5	4	-2	18
MIXED	-5	-4	-6	-2	-3	-5	-3
ASTM min	-3	-3	-3	-3	-3	-3	-3
ASTM max	12	12	12	12	12	12	12
DIESEL	-6	-6	-6	-6	-6	-6	-6

Table B. 8: Cetane Number of Biodiesels

Cetane Number							
	B5	B10	B15	B20	B25	B30	B100
ASTM max	65	65	65	65	65	65	65
DIESEL	54	54	54	54	54	54	54
JATROPHA	58.474	57.9544	57.108	56.89	56.662	55.758	60.458
NEEM	57.828	57.118	56.662	55.984	55.31	54.862	48.852
COTTON	58.242	57.576	57.088	56.89	56.436	55.758	57.8
MIXED	58.104	57.598	57.256	56.96	55.176	51.231	54
ASTM min	48	48	48	48	48	48	48

Table B. 9: Copper Strip Corrosion of Biodiesels

Copper Strip							
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	1a	1a	1a	1a	1a	1a	1a
NEEM	1a	1a	1a	1a	1a	1a	1a
COTTON	1a	1a	1a	1a	1a	1a	1a
MIXED	1a	1a	1a	1a	1a	1a	2b
ASTM min	1a	1a	1a	1a	1a	1a	1a
ASTM max	3b	3b	3b	3b	3b	3b	3b
DIESEL	1a	1a	1a	1a	1a	1a	1a

Table B. 10: Total Sulphur Content of Biodiesels

Total Sulphur (%wt)							
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	0.192	0.183	0.170	0.155	0.141	0.129	0.048
NEEM	0.190	0.178	0.166	0.150	0.138	0.120	0.041
COTTON	0.192	0.181	0.168	0.153	0.139	0.126	0.049
MIXED	0.191	0.181	0.174	0.166	0.125	0.191	0.181
ASTM max	0.05	0.05	0.05	0.05	0.05	0.05	0.05
DIESEL	0.210	0.210	0.210	0.210	0.210	0.210	0.210

Table B. 11: Colour Indices of Biodiesels

Colour							
	B5	B10	B15	B20	B25	B30	B100
JATROPHA	2.0	2.0	<2.5	2.5	2.5	2.5	2.0
NEEM	2.0	2.0	<2.5	2.5	2.5	<3.0	<4.0
COTTON	2.5	2.5	<3.0	2.0	2.0	3.0	<3.0
MIXED	2.5	2.5	<3.0	2.5	2.5	2.5	2.5
ASTM min	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ASTM max	3.5	3.5	3.5	3.5	3.5	3.5	3.5
DIESEL	2.0	2.0	2.0	2.0	2.0	2.0	2.0

APPENDIX B: SECONDARY DATA OBTAINED FOR BIODIESEL PROPERTIES

Table B. 12: Properties of Yellow Grease Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	4.14	4.98	4.40	5.42	4.60	4.23	4.60	4.92	4.87	4.74	5.14	5.16	4.40	4.50	4.70	43.9	4.49	4.55	5.10	4.92	4.71	0.28
Density (g/cm^3)																						
Flash Point (^0C)			71		158	171	75	156	167	140	154			179			122				139.30	29.98
Acid value																						
HV (MJ/kg)	37.5	39.4	38.7	39.6	38.4			39.6	39.7		40.0	39.3	38.7		38.1	38.4	41.2		37.0	39.5	39.01	0.83
Cetane No	53.4		60.4		51.4	54.5		52.0	55.0	55.6	52.7		60.4			57.8	44.3		55.5		54.42	3.05
Pour Point (^0C)					-3		-4	-3			8										-0.50	4.25
Cloud Pnt (^0C)					2		-7	3		7	16				13			6			5.71	5.47
CFPP (^0C)	4	0	10		-4	1	-5			3	6	-6	10	-4		3		2			1.54	4.19
Copper strip																						
Sulphur (ppm)		6		0		7			3	15	0			3	2			6	1	0	3.91	3.34
Specific gravity	0.881	0.884	0.875	0.884	0.887	0.890	0.842	0.888	0.884		0.878		0.875	0.884	0.885	0.877	0.860	0.883	0.883	0.884	0.88	0.01
Sulph. Ash (%)																						
Carbon Res (%)																						
Iodine Value		92	62.0	94.9			83			78.8				116.0							87.78	13.18

Data Sources: [a] = Holden *et al.*(2006); [b]= Karavalakis *et al.*(2010); [c] = Ozsezen *et al.*(2008); [d] = Lapuerta *et al.*(2008); [e]= Enweremadu and Mbarawa (2009); [f] = Meng *et al.*(2008); [g] = Georgogianni *et al.*(2007); [h] = Kocak *et al.*(2007); [i] = Lin *et al.*(2009); [j] = McCormick *et al.*(2003); [k] = Graboski *et al.*(2003); [l] = Lapuerta *et al.*(2008)[c]; [m] = Ozsezen *et al.*(2009); [n] = Karabalaski *et al.*(2009)[a]; [o] = Curran *et al.*(2009); [p] = Zhang *et al.*(2008); [q] = Lin *et al.*(2007); [r] =Sanford *et al.*(2009); [s] = Okomoto *et al.*(2007); [t] = Armas *et al.*(2006)

Table B. 13: Properties of Palm Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	5.7	5.7	5.7	4.4	4.5	5.7	4.58	4.39	4.44	4.73	5.58	5.31	3.7	4.4	4.7	5.7	4.58	5.51	4.46	4.50	4.91	0.56
Density (g/cm^3)	0.88	0.88		0.855	0.877	0.88															0.87	0.008
Flash Point (^0C)	183	164		178		183		105	173			174	130	166	189	164			175		165.33	16.39
Acid value						0.2	0.01														0.11	0.10
HV (MJ/kg)	41.24		37.5	39.7	32.4	33.5	37.4	39.5	39.4	37.1	37.1		40.2		39.9	38.7				36.9	37.90	1.91
Cetane Number	62		62		70		62	64	69.5	62.0	62.0	58.3	58.0	64.0	62.0	62.0		61.4		64.5	62.91	2.32
Pour Point (^0C)			8				15	14	12	12	14	13					15	13		13	12.90	1.34
Cloud Point (^0C)			13	16			17		15	16	15	12		14	15	13	17	13	15		14.69	1.30
CFPP (^0C)							12		13	11		13	0				12	12			10.43	2.98
Copper strip corr.																						
Sulphur cont (ppm)									2		0	2	3	1			2		15	2	3.38	2.91
Specific gravity								0.881	0.871	0.872	0.871	0.875	0.876	0.873	0.878	0.880		0.875	0.876	0.874	0.88	0.00
Sulphated Ash (%)																						
Carbon Residue (%)																						
Iodine Value			37			65	54		54.0				45.0				54.0		52.7		51.67	6.10

Data Sources: [a] = Sivarinakrishnan and Ravikumar (2012); [b] = Boz *et al.* (2009); [c] = MLA. (2011); [d] = Topare *et al*. (2011); [e] = Izah and Ohimian (2012); [f] = Renita *et al*. (2013); [g] = Moset (2008); [h] = Lin *et al.* (2008)[b]; [i] = Moroz *et al.* (2009); [j] = Benjumia *et al.* (2009); [k] = Okomoto *et al.*(2007); [l] = Ohshio *et al.* (2008); [m] = Karabalaski *et al.*(2009)[b]; [n] =Lin *et al.* (2008)[a]; [o] = Lin *et al.* (2009); [p] = Srivastava ana Prasad (2010); [q] = Moser and Vaughn (2010); [r] = Hasegiwa *et al.*(2007); [s] = Jaroonjitsathian *et al.*(2009); [t] = Myo *et al.*(2007)

Table B. 14: Properties of Rapeseed Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	3.7	4.8	4.2	4.37	4.64	4.31	4.58	4.49	5.58	4.48		4.48	4.56	4.15	4.57	4.40	4.59	4.45	4.55	3.73	4.45	0.24
Density (g/cm^3)	0.91		0.882	0.882						0.883	0.915										0.89	0.014
Flash Point (^0C)	246	172.5	80		131	174	145		178		246	172	182	165	162	93	177	176			166.63	29.84
Acid value																						
HV (MJ/kg)	39.7		41.55		37.0	37	38.0	40.0		37.4	39.7	39.7	40	44.9	44.9	37.9	39.9		39.9	45.0	40.16	1.96
Cetane Number	37.6		54		56.1	52.8	52.5	52.5	58.0	54.7	37.6	52.6	49.5	51.0	49.6	52.0	54	51.0	53.9	55.0	51.36	3.54
Pour Point (^0C)	-32	-10		-12		-10		-12	-10			-12		-9	-7				-1		-11.50	4.40
Cloud Point (^0C)	-3.9	-1		-4.1		-5			-4			-5		-3	-2						-3.50	1.13
CFPP (^0C)					-22	-5	-14		-12			-12	-20	-9				-18		-9	-13.44	4.49
Copper strip corr																						
Sulphur (ppm)					6	2	3		2	5		2	2			3	1	2	2		2.73	1.11
Specific gravity					0.883	0.884	0.881	0.883	0.884			0.880	0.883	0.869	0.872	0.881	0.885	0.883	0.880	0.835	0.88	0.01
Sulphtd Ash (%)																						
Carbon Resd (%)		0.02								0.077											0.05	0.03
Iodine Value		110					113	110.0	114.0			113.0									112.00	1.60

Data Sources: [a] = Enciner *et al.* (2010); [b] = Saka *et al.* (2006); [c] = Sivarinakrishnan and Ravikumar (2012); [d] = Beczewski and Szezawinski (2011);[e] = Bielaczyc *et al.* (2009); [f]= Aoyagi *et al.* (2008); [g] = Karabalaski *et al.*(2009)[b]; [h] = Schonborn *et al.* (2009); [i] = Ohshio *et al.* (2008); [j] = Tira *et al. (*2014); [k] = Hellier *et al. (*2015); [l] = Moroz *et al.* (2009); [m] = Bannister *et al.* (2009); [n] = Rashid and Anwar (2008)[a]; [o] = Rashid and Anwar (2008)[b]; [p] = Soltic *et al.* (2009); [q] = Lin *et al.* (2009); [r] = Krahl *et al.* (2008); [s] =Peterson *et al.* (2006); [t] = Kousoulidou *et al.* (2009)

Table B. 15: Properties of Soy Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	4.44	4.5	3.97	4.12	4.24	4.5	4.7	4.55	5.10	4.4	4.38		4.06	4.02	4.07	4.40	4.50	4.12	4.12	4.06	4.33	0.23
Density (g/cm^3)	0.874	0.885	0.885									0.919									0.89	0.014
Flash Point (^0C)		178	139		180	178	341	167	168	187		254	157		142		178	161	134		183.14	33.22
Acid value			0.16	0.04																	0.10	0.06
HV (MJ/kg)		41.28		39.7	39.4		39.7	39.9		38.6	40.7	30.7	40.1	37.5		38.6	37.9			39.5	38.74	1.60
Cetane Number		45	60.1	48	50.6	45	51.6	59.0		52.0	52.0	37.9	51.6	57.5	47.4	51.5	45.0	53.0		45.8	50.18	4.37
Pour Point (^0C)			0	1	-6	-7	-7	-4	0				-7	-2	-3		-7		-3	-7	-4.00	2.62
Cloud Point (^0C)				1	-1	1	3	3	-1				3	-1	-1		1	-2	0	-1	0.38	1.49
CFPP (^0C)				-4	-3			-2	-3	-7	-9					-5			4	-4	-3.67	2.37
Copper strip corrosion																						
Sulphur content (ppm)					3			0	0	4	5			2	0	5		1	1		2.10	1.72
Specific gravity					0.883	0.885	0.887	0.888	0.885	0.882	0.883		0.887	0.884		0.882	0.885	0.882			0.88	0.00
Sulphated Ash (%)																						
Carbon Residue (%)																						
Iodine Value				134	127				127.7	122	117				127.4	118.0					124.73	4.91

Data Sources: [a] = Machando *et al.* (2009); [b] = Sivarinakrishnan and Ravikumar (2012); [c] = Boz *et al.* (2009); [d] =Moset (2008); [e] = Moroz *et al.* (2009); [f] = Barnwal and Sharma (2005); [g] = Schumacher *et al.* (1996); [h]= Graboski *et al.*(2003); [i] = Ohshio *et al.* (2008); [j] = Karabalaski *et al.*(2009)[e]; [k] = Karabalaski *et al.*(2009)[d]; [l] = Hellier *et al. (*2015); [m] = Ali *et al.* (1999); [n] = Yoon *et al.* (2009); [o] = McCormick *et al.*(2003); [p] = Karabalaski *et al.*(2009)[c]; [q] = Srivastava ana Prasad (2010); [r] = Ireland *et al.* (2009); [s] = Moser and Vaughn (2010); [t] = Schumacher *et al.* (1995);

Table B. 16: Properties of Canola biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	4.68	4.34	4.44	5.6	4.6	4.4	4.51	3.90	4.34	4.42	2.7	4.63	4.6	4.4	4.44	4.49	4.15	4.19	4.42	4.65	4.40	0.27
Density (g/cm^3)	0.875	0.883	0.881		0.883												0.882				0.88	0.00
Flash Point (^0C)		107	135.7		105		184	146	107			163		163			157				140.86	24.16
Acid value		0.14	0.72		0.11												0.19	0.01	0	0.02	0.17	0.16
HV (MJ/kg)				40.5	39.96	37.8		40.0			44.8	40.1				39.0	37.27	37.3		38.9	39.56	1.51
Cetane Number		61.5	62.8	62		53.6	54	52.9	61.5		56	53.9		51.5			55	48		56	56.05	3.63
Pour Point (^0C)		-8	-10	-15	-12			-6	-8	-9	-3	-4		-3			-9	-8	-9	-10	-8.14	2.43
Cloud Point (^0C)								-2		0		-3			-3		-7	-1	0	1	-1.88	1.88
CFPP (^0C)										-7		-4			-13	-8	-9	-6	-7	-8	-7.75	1.75
Copper strip corr					1a																	
Sulphur cont(ppm)						2				2				3	1						2.00	0.50
Specific gravity						0.884	0.884	0.882	0.884		0.890	0.881	0.88	0.883	0.882	0.883					0.88	0.00
Sulphated Ash (%)					0.01																0.01	0.00
Carbon Residue (%)																						
Iodine Value				110	118		109		109				107.5				108	110	110	110	110.17	1.74

Data Sources: [a] = Machando *et al.* (2009); [b],[c] = Boz *et al.* (2009); [d]= MLA. (2011); [e] = Karabas (2012); [f] = Zheng *et al.* (2009); [g] = Thanh *et al.* (2010); [h] = Kocak *et al.*(2007); [i] = Alptekin and Canakci (2009); [j] = Moser and Vaughn (2010); [k] = Patil *et al.* (2009)[g]; [l] = Graboski *et al.*(2003); [m] = Albuquerque *et al.* (2009); [n] = Imperial Oil (2009); [o] = Sanford *et al.*(2009); [p] = Ozsezen *et al.*(2009); [q]= Enweremadu *et al.*(2014); [r],[s],[t] = Moser (2008)

Table B. 17: Properties of Sun Flower biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	4.57	4.6	4.03	3.6	5.9	6	4.72	3.854	4.6	4.74	4.03	4.20	4.4		4.79	4.9	4.85	4.60	4.38	4.60	4.60	0.39
Density (g/cm^3)	0.875	0.86	0.884			0.68	0.86	0.886	0.872					0.917							0.854	0.04
Flash Point (^0C)		96	157	170			183	171	183		157	177		274	85	170	168	183	183	183	169.33	24.49
Acid value			0.14	o.27	0.1	0.36		0.28	0.15	0.04											0.18	0.09
HV (MJ/kg)		41.33		39.58				37.25	40.51	38.1			37.1	39.6	38.1	45.3	45.5	39.6	40.0	39.0	40.07	1.90
Cetane Number		49	60.9	49.2		48		52		48	60.9	50.0	51.3	37.1	49		55.0	49.0	54.5	49.0	50.86	3.93
Pour Point (^0C)			-1	-7			-5	-6		2	-1	-3			0	-4	-3				-2.80	2.24
Cloud Point (^0C)				-6			4	3		5					3	1	1	1		1	1.44	2.05
CFPP (^0C)								-7		-2					-3	-1	-1				-2.80	1.76
Copper strip corr				1a																		
Sulphur cont (ppm)				3.0			0.003												4		2.33	1.55
Specific gravity				0.884			0.892				0.884		0.886		0.887	0.880	0.884	0.866	0.886	0.860	0.88	0.01
Sulphated Ash (%)																						
Carbon Residue (%)				0.002		0.15															0.08	0.07
Iodine Value								126	52	85		132	125.2								104.04	28.43

Data Sources: [a] = Machando *et al.* (2009); [b] = Sivarinakrishnan and Ravikumar (2012); [c] = Boz *et al.* (2009); [d] = Mansoupour and Shariati (2012); [e] = Hossain and Boyce (2009); [f] = Thirumarimurugan *et al.*(2012); [g] = Ahmad *et al.* (2010); [h] = Enweremadu *et al.* (2014); [i] = Renita *et al.* (2013); [j] = Moser *et al.* (2008); [k] = Alptekin and Canakci (2009); [l] = Ramos *et al.* (2009); [m] = Lapuerta *et al.* (2008); [n] = Hellier *et al. (*2015); [o] = Avella *et al.* (1992); [p] = Rashid *et al.* (2008); [q] = Rashid *et al.* (2009); [r] = Barnwal *et al.* (2005); [s] = Lin *et al.* (2009); [t] = Srivastava *et al.* (2000)

Table B. 18: Properties of Jatropha Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	[o]	[p]	[q]	[r]	[s]	[t]	Mean	Dev
Viscosity (mm^2/S)	4.8	5.76	9.6	19.6*	20.6*	5.25	3.91	3.99	7.2	4.23	4.25	4.34	4.02	4.34	4.5	5.4	5.11	4.5	2.41	5.23	4.94	1.00
Density (g/cm^3)	0.876	0.862	0.869	0.869	0.869	0.871	0.917	0.872													0.88	0.01
Flash Point (^0C)	170	174	200	140	195	166	180	105	248	148		135	117	135	130	162	161	130			158.59	26.91
Acid value						0.5		0.38													0.44	0.06
HV (MJ/kg)		39.17	48.31	47.22	47.50	42.15	38.36	49.6	42.6	42.7			41.7		39.0	39.8	40		40.6		42.77	3.08
Cetane Number		53					45		57.1			58.4		58.4	58.4			54.9	60.6	57.8	55.96	3.33
Pour Point (^0C)							-3		4	4		3	-5	3			-8		-2		-0.50	4.00
Cloud Point (^0C)						-6			6	10	3						3				3.20	3.84
CFPP (^0C)											0										0.00	0.00
Copper strip corrosion																						
Sulphur content (ppm)							0.0002				1	1		1		0					0.60	0.48
Specific gravity	0.875		0.882	0.880	0.881				0.876	0.873	0.880	0.879	0.883	0.879	0.870	0.870		0.870	0.885	0.888	0.88	0.00
Sulphated Ash (%)	0.06																				0.06	0.00
Carbon Residue (%)	0.2																				0.20	0.00
Iodine Value	7.64*							46.9										39.0		39.5	41.80	3.40

The values marked (*) were not used in the calculation

Data Sources: [a] = Adebayo*et al.*(2011); [b] = Sivarinakrishnan and Ravikumar (2012); [c],[d],[e] = Belewu *et al.*(2010); [f] = Topare*et al.*(2011); [g] = Chalatlon*et al.*(2011); [h] = Renita *et al.*(2013); [i] = Choudhury and Bose (2008); [j] = Sahoo *et al.*(2009); [k] = Sanford *et al.*(2009); [l] = Bhatnagar *et al.*(2006); [m] = de Oliveira *et al.*(2009); [n] = Kaul *et al.*(2007); [o] = Suryawanshi and Deshpande (2006); [p] = Sundaresan *et al.*(2007); [q] = El Diwani *et al.*(2009); [r]= Suryawanshi, and Deshpande (2005); [s] = Patil *et al.* (2009)[g]; [t] = Schonborn *et al.*(2009)

Table B. 19: Properties of Tallow Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[j]	[k]	[l]	[m]	[n]	Mean	Dev
Viscosity (mm^2/S)	4.8	4.64		4.8	4.42	4.53	4.53	4.92		4.10	5.23	4.11		5.3	4.67	0.31
Density (g/cm^3)																
Flash Point (^0C)			96				170	154	96			96	96	157	123.57	31.51
Acid value		1.07														
HV (MJ/kg)	39.9	38.9		37.1	39.5			39.8			37.2	39.9			38.90	1.00
Cetane Number	73			57.5	57.2		62.4	59.6		58.0	54.9	57.8		60.4	60.09	3.45
Pour Point (^0C)	16		9		9			15	9			9	9		10.86	2.65
Cloud Point (^0C)	16		12			16	12	18	12			12	12		13.75	2.19
CFPP (^0C)						14		12			10			14	12.50	1.50
Copper strip corrosion																
Sulphur content (ppm)				18		7	3	0			48				15.20	14.24
Specific gravity				0.875	0.878	0.874	0.876	0.874		0.887	0.887	0.877		0.872	0.88	0.00
Sulphated Ash (%)																
Carbon Residue (%)																
Iodine Value	40	45.3			77										54.10	15.27

Data Sources: [a] = MLA. (2011); [b] = Mata *et al.* (2014); [c] = Srivastava *et al.* (2000); [d] = Zheng *et al.* (2008); [e] = Schonborn *et al.* (2009); [f] = Sanford *et al.* (2009); [g] = Imperial Oil (2009); [h] = Graboski *et al.* (2003); [i] = Barnwa *et al.* (2005); [j] = Demirbas (2009); [k] = Lapuerta *et al.* (2009); [l] = Ali *et al.* (1999); [m] = Fukuda *et al.* (2001); [n] = da Cunha *et al.* (2009)

Table B. 20: Properties of Corn Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	Mean	Dev
Viscosity (mm^2/S)	**4.33**	**4.38**	**4.36**	**2.55**	**3.62**	**4.18**	**4.4**		3.97	0.51
Density (g/cm^3)	**0.874**							**0.917**	0.90	0.022
Flash Point (^0C)			**167**		**154**	**192**	**170**	**277**	192.00	34.00
Acid value										
HV (MJ/kg)			**39.9**	**45.0**	**41.1**			**39.5**	41.47	2.36
Cetane Number			**55.4**	**58.7**		**60.9**	**53.5**	**37.6**	53.22	6.25
Pour Point (^0C)				**-4**		**-1**			-2.50	1.50
Cloud Point (^0C)		**-3**							-3.00	0.00
CFPP (^0C)		**-3**					**-12**		-7.50	4.50
Copper strip corrosion										
Sulphur content (ppm)		**5**	**3**						4.00	1.00
Specific gravity		**0.885**	**0.886**	**0.885**	**0.873**	**0.884**			0.88	0.00
Sulphated Ash (%)										
Carbon Residue (%)										
Iodine Value							**101.0**		101.00	0.00

Data Sources: [a]= Machado*et al.* (2012); [b]= Sanford *al.* (2009); [c]= Lin *et al.* (2009) ; [d]=Patil *et al.* (2009)[a]; [e]= Demirbas (2008); [f]= Alptekin and Canakci (2009) ; [g]= Ramos *et al.* (2009); [h] = Hellier *et al. (*2015)

Table B. 21: Properties of Algae Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	Mean	Dev
Viscosity (mm^2/S)	5.2	5.0	4.8	3.46	3.2	4.8	3.79		4.32	0.72
Density (g/cm^3)				0.94	0.992	0.971	0.91	0.912	0.95	0.029
Flash Point (^0C)	145	146	140	49	95	98	120	220	126.63	36.13
Acid value	0.49	0.5	0.46		0.32	0.47	0.45		0.45	0.04
HV (MJ/kg)	41.2	35.3	37.2		40	43	43	35.8	39.36	2.79
Cetane Number	53	51	49						51.00	1.33
Pour Point (^0C)				-10.5					-10.50	0.00
Cloud Point (^0C)				-11.5					-11.50	0.00
CFPP (^0C)					-10	-10			-10.00	0.00
Copper strip corrosion										
Sulphur content (ppm)										
Specific gravity	0.916	0.914	0.912						0.91	0.00
Sulphated Ash (%)										
Carbon Residue (%)										
Iodine Value	63	75	69				51		64.50	7.50

Data Sources: [a], [b], [c] = Ahmad *et al.* (2013); [d] = Topare*et al.* (2011); [e], [f]=Muthukumar*et al.* (2012); [g]= Renita *et al.* (2013); [h] = Hellier *et al. (*2015)

Table B. 22: Properties of Coconut Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	Mean	Dev
Viscosity (mm^2/S)	4.33	2.73	2.66	2.94	2.7	2.83	2.32	2.94	3.07	2.95	0.33
Density (g/cm^3)											
Flash Point (^0C)		115	107			110			120	113.00	4.50
Acid value											
HV (MJ/kg)				38.1	35.2			38.1		37.13	1.29
Cetane Number			70		57.0	51.0				59.33	7.11
Pour Point (^0C)					-5	-12				-8.50	3.50
Cloud Point (^0C)		0	-5			-3				-2.67	1.78
CFPP (^0C)		-4				-5				-4.50	0.50
Copper strip corrosion											
Sulphur content (ppm)		3	3		2					2.67	0.44
Specific gravity	0.913	0.870		0.875	0.874	0.873		0.875	0.872	0.88	0.01
Sulphated Ash (%)											
Carbon Residue (%)											
Iodine Value				30				30	7.0*	30.00	0.00

The values marked (*) were not used in the calculation

Data Sources: [a]= Sivarinakrishnan and Ravikumar (2012); [b]= Sanford *al.* (2009); [c]= Alleman and McCormic (2006); [d],[h]= Nakpong and Wootthikanokkhan (2010); [e]= Myo *et al.* (2007); [f]= Allen *al.* (1999); [g]= Kumar *et al.* (2010)[i]=Bachle *al.* (2009)

Table B. 23: Properties of Camelina Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	Mean	Dev
Viscosity (mm^2/S)	4.15		4.0	3.03	4.37	3.47	6.54	4.26	0.80
Density (g/cm^3)									
Flash Point (^0C)				136				136.00	0.00
Acid value						45.1		45.10	0.00
HV (MJ/kg)			45.0	45.6				45.30	0.30
Cetane Number	52.8		49.4	50.2		49.3		50.43	1.19
Pour Point (^0C)	-4	-4	-9	-10		-9		-7.20	2.56
Cloud Point (^0C)	3	3			2			2.67	0.44
CFPP (^0C)	-3	-3			-1		-5	-3.00	1.00
Copper strip corrosion									
Sulphur content (ppm)	3				1			2.00	1.00
Specific gravity			0.875	0.875	0.888	0.889	0.884	0.88	0.01
Sulphated Ash (%)									
Carbon Residue (%)									
Iodine Value	151.0						154.5	152.75	1.75

Data Sources: [a]= Moser and Vaugh (2010); [b],[g]= Frohlich and Rice (2005); [c]= Patil *et al.* (2008); [d]= Patil *et al.* (2009)[a] [e]= Sanford *et al.* (2009); [f]= Patil *et al.* (2009)[b]

Table B. 24: Properties of Safflower Biodiesel

Property	[a]	[b]	[c]	[d]	Mean	Dev
Viscosity (mm^2/S)	**4.29**	**4.03**	**4.11**		4.14	0.10
Density (g/cm^3)						
Flash Point (^0C)	**176**	**167**		**180**	174.33	4.89
Acid value						
HV (MJ/kg)	**45.2**	**41.3**		**40.1**	42.20	2.00
Cetane Number	**52.3**			**49.8**	51.05	1.25
Pour Point (^0C)	**-8**		**-8**	**-6**	-7.33	0.89
Cloud Point (^0C)	**-2**		**-5**		-3.50	1.50
CFPP (^0C)	**-6**				-6.00	0.00
Copper strip corrosion						
Sulphur content (ppm)						
Specific gravity	**0.880**	**0.866**	**0.890**		0.88	0.01
Sulphated Ash (%)						
Carbon Residue (%)						
Iodine Value			**141.0**		141.00	0.00

Data Sources: [a]= Rashid and Anwar (2008); [b]= Demirbas (2008); [c]=Imahara*et al.* (2008); [d]= Isigigur *et al.*(1994)

Table B. 25: Properties of Waste Cooking Oil Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	Mean	Dev
Viscosity (mm^2/S)	**5.03**	**4.86**	**5.55**	**4.35**	**4.35**	4.83	0.38
Density (g/cm^3)	**0.87**	**0.883**	**0.89**	**0.880**	**0.88**	0.88	0.005
Flash Point (^0C)	**164**					164.00	0.00
Acid value		**0.28**	**0.2**	**0.06**	**0.08**	0.16	0.09
LHV							
Cetane Number	**61**					61.00	0.00
Pour Point (^0C)	**-16**				**-10**	-13.00	3.00
Cloud Point (^0C)	**-1**					-1.00	0.00
CFPP (^0C)		**-5.3**				-5.30	0.00
Copper strip corrosion							
Sulphur content (ppm)	**2**					2.00	0.00
Specific gravity							
Sulphated Ash (%)		**0.007**				0.01	0.00
Carbon Residue (%)							
Iodine Value		**105**				105.00	0.00

Data Sources: [a]= Chhetri *et al.* (1998); [b]= Rice *et al.*(2008); [c], [d], [e]= Azocar*et al.*

Table B. 26: Properties of Castor Biodiesel

Property	[a]	[b]	[c]	[d]	Mean	Dev
Viscosity (mm^2/S)	**10.75**	**10.23**	**11.02**	**13.75**	11.44	1.16
Density (g/cm^3)	**0.871**	**0.874**	**0.868**	**0.928**	0.89	0.02
Flash Point (^0C)	**160**	**167.5**	**158.5**	**120**	151.50	15.75
Acid value	**0.35**	**0.55**	**0.15**		0.35	0.13
HV (MJ/kg)	**30.40**	**31.30**	**29.5**		30.40	0.60
Cetane Number						
Pour Point (^0C)						
Cloud Point (^0C)	**-13**	**-12**	**-14**		-13.00	0.67
CFPP (^0C)						
Copper strip corrosion				**1**	1.00	0.00
Sulphur content (ppm)						
Specific gravity						
Sulphated Ash (%)						
Carbon Residue (%)						
Iodine Value						

Data Sources: [a], [b], [c] = Topare*et al.* (2011); [d] = Tuli (2014)

Table B. 27: Properties of Cotton Biodiesel

Property	[a]	[b]	[c]	[d]	[e]	[F]	Mean	Dev
Viscosity (mm^2/S)	4.45	4.45	4.45	4.51	4.51	4.51	4.48	0.03
Density (g/cm^3)	0.881	0.882	0.883	0.886	0.887	0.888	0.88	0.003
Flash Point (^0C)	168	170	172	166	168	170	169.00	1.67
Acid value	0.15	0.17	0.19	0.15	0.16	0.17	0.17	0.01
HV (MJ/kg)								
Cetane Number								
Pour Point (^0C)								
Cloud Point (^0C)								
CFPP (^0C)								
Copper strip corrosion								
Sulphur content (ppm)								
Specific gravity								
Sulphated Ash (%)								
Carbon Residue (%)								
Iodine Value								

Data Sources: [a], [b], [c], [d], [e], [f] = Fernandes *et al. (*2012)

Table B. 28: Properties of Other Biodiesels from Various Feedstocks

Property	[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[i]	[J]	[k]	[l]	[m]	[n]	[o]	Mean	Dev
Viscosity (mm^2/S)	**5.0**	**4.9**	**9.6**	**5.29**	**3.24**	**3.95**	**4.11**	**5.8**	**6.1**	**4.9**	**3.6**	**4.2**	**5.6**	**4.0**		5.02	1.04
Density (g/cm^3)	**0.881**	**0.883**	**0.9**	**0.877**	**0.871**			**0.885**	**0.920**	**0.883**	**0.875**	**0.878**	**0.889**	**0.881**	**0.903**		
Flash Point (^0C)		**176**	**114**	**183**	**155**			**167.3**	**159**	**176**	**127**				**271**	169.81	28.17
Acid value					**0.31**	**0.63**	**0.56**		**3.5**			**0.26**					
HV (MJ/kg)		**41.71**	**35.9**			**39.49**	**39.62**			**41.71**	**41.15**				**39.8**	39.91	1.38
Cetane Number		**54**	**54.3**					**60.4**	**54**	**54**	**63**				**41.8**	54.50	4.11
Pour Point (^0C)					**6**				**-4**							1.00	5.00
Cloud Point (^0C)					**8**											8.00	0.00
CFPP (^0C)																	
Copper strip corrosion																	
Sulphur content (ppm)								**9**								9.00	0.00
Specific gravity					**0.875**											0.88	0.00
Sulphated Ash (%)								**0.014**									
Carbon Residue (%)									**0.025**				**0.039**	**0.036**			
Iodine Value					**101**	**77.9**	**76.7**					**139.5**				98.78	21.48

Data Sources: [a], [h], [m], [n] = Tuli (2014); [b], [c], [j], [k] = Sivarinakrishnan and Ravikumar (2012); [d][g]= Boz *et al. (*2009); [e], [f] = Ved *et al. (*2013); [i] =Hari Prasad *et al. (*2011); [l] = Lomonaco *et al. (*2012); [o] = Hellier *et al. (*2015)

Other Feedstocks referred here are: [a]Neem Seed, [b]Peanut, [c]Karanja, [d]Rice bran, [e], [f]Sorghum, [g]Lard, [h]Poultry fat, [i]Mustard, [J]Peanut, [k]Babarsu,[l]Fish oil, [m]Kusum, [n]Beheda and [o]Groundnut Biodiesel

Table B. 29: Mean Values and Deviations of Biodiesel Properties 1

Biodiesel	Yellow Grease		Palm		Rapeseed		Soy		Canola		Sun flower		Jatropha		Tallow		Corn		Algae	
Property	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev	Mean	Dev
Viscosity (mm^2/S)	4.71	0.28	4.91	0.56	4.45	0.24	4.33	0.23	4.40	0.27	4.60	0.39	4.94	1.00	4.67	0.31	3.97	0.51	4.32	0.72
Density (g/cm^3)			0.87	0.008	0.89	0.014	0.89	0.014	0.88	0.00	0.854	0.04	0.88	0.01			0.90	0.022	0.95	0.029
Flash Point (^0C)	139.30	29.98	165.33	16.39	166.63	29.84	183.14	33.22	140.86	24.16	169.33	24.49	158.59	26.91	123.57	31.51	192.00	34.00	126.63	36.13
Acid value			0.11	0.10			0.10	0.06	0.17	0.16	0.18	0.09	0.44	0.06					0.45	0.04
HV (MJ/kg)	39.01	0.83	37.90	1.91	40.16	1.96	38.74	1.60	39.56	1.51	40.07	1.90	42.77	3.08	38.90	1.00	41.47	2.36	39.36	2.79
Cetane Number	54.42	3.05	62.91	2.32	51.36	3.54	50.18	4.37	56.05	3.63	50.86	3.93	55.96	3.33	60.09	3.45	53.22	6.25	51.00	1.33
Pour Point (^0C)	-0.50	4.25	12.90	1.34	-11.50	4.40	-4.00	2.62	-8.14	2.43	-2.80	2.24	-0.50	4.00	10.86	2.65	-2.50	1.50	-10.50	0.00
Cloud Point (^0C)	5.71	5.47	14.69	1.30	-3.50	1.13	0.38	1.49	-1.88	1.88	1.44	2.05	3.20	3.84	13.75	2.19	-3.00	0.00	-11.50	0.00
CFPP (^0C)	1.54	4.19	10.43	2.98	-13.44	4.49	-3.67	2.37	-7.75	1.75	-2.80	1.76	0.00	0.00	12.50	1.50	-7.50	4.50	-10.00	0.00
Copper strip corr.																				
Sulphur cont (ppm)	3.91	3.34	3.38	2.91	2.73	1.11	2.10	1.72	2.00	0.50	2.33	1.55	0.60	0.48	15.20	14.24	4.00	1.00		
Specific gravity	0.88	0.01	0.88	0.00	0.88	0.01	0.88	0.00	0.88	0.00	0.88	0.01	0.88	0.00	0.88	0.00	0.88	0.00	0.91	0.00
Sulphated Ash (%)									0.01	0.00			0.06	0.00						
Carbon Residue (%)					0.05	0.03					0.08	0.07	0.20	0.00						
Iodine Value	87.78	13.18	51.67	6.10	112.00	1.60	124.73	4.91	110.17	1.74	104.04	28.43	41.80	3.40	54.10	15.27	101.00	0.00	64.50	7.50
NUMBER OF REFERENCES		20		20		20		20		20		20		20		14		8		8

Table B. 30: Mean Values and Deviations of Biodiesel Properties 2

Biodiesel	Coconut		Camelina		Safflower		WCO		Castor		Cotton		Others	
Property	**Mean**	**Dev**	**Mean**	**Dev**	**Mean**	**Dev**	**Mean**	**Dev**	**Mean**	**Dev**	**Mean**	**Dev**	**Mean**	**Dev**
Viscosity (mm^2/S)	2.95	0.33	4.26	0.80	4.14	0.10	4.83	0.38	11.44	1.16	4.48	0.03	5.02	1.04
Density (g/cm^3)							0.88	0.005	0.89	0.02	0.88	0.003		
Flash Point (^0C)	113.00	4.50	136.00	0.00	174.3	4.89	164.00	0.00	151.50	15.75	169.0	1.67	169.81	28.17
Acid value			45.10	0.00			0.16	0.09	0.35	0.13	0.17	0.01		
HV (MJ/kg)	37.13	1.29	45.30	0.30	42.20	2.00			30.40	0.60			39.91	1.38
Cetane Number	59.33	7.11	50.43	1.19	51.05	1.25	61.00	0.00					54.50	4.11
Pour Point (^0C)	-8.50	3.50	-7.20	2.56	-7.33	0.89	-13.00	3.00					1.00	5.00
Cloud Point (^0C)	-2.67	1.78	2.67	0.44	-3.50	1.50	-1.00	0.00	-13.00	0.67			8.00	0.00
CFPP (^0C)	-4.50	0.50	-3.00	1.00	-6.00	0.00	-5.30	0.00						
Copper strip corr.									1.00	0.00				
Sulphur cont (ppm)	2.67	0.44	2.00	1.00			2.00	0.00					9.00	0.00
Specific gravity	0.88	0.01	0.88	0.01	0.88	0.01							0.88	0.00
Sulphated Ash (%)							0.01	0.00						
Carbon Residue (%)														
Iodine Value	30.00	0.00	152.75	1.75	141.0	0.00	105.00	0.00					98.78	21.48
NUMBER OF REFERENCES		9		7		4		5		4		6		15

Table B. 31: Mean Physico-Chemical Properties of Biodiesel from Various Feedstocks

Property	Yellow Grease	Palm	Rapeseed	Soy	Canola	Sun flower	Jatropha	Tallow	Corn	Algae	Coconut	Camelina	Safflower	WCO	Castor	Cotton	Others
Viscosity (mm^2/S)	4.71	4.91	4.45	4.33	4.40	4.60	4.94	4.67	3.97	4.32	2.95	4.26	4.14	4.83	11.44	4.48	5.02
Density (g/cm^3)		0.87	0.89	0.89	0.88	0.854	0.88		0.90	0.95				0.88	0.89	0.88	
Flash Point (^0C)	139.30	165.33	166.63	183.14	140.86	169.33	158.59	123.57	192.0	126.6	113.00	136.00	174.3	164.00	151.50	169.0	169.81
Acid value		0.11		0.10	0.17	0.18	0.44			0.45		45.10		0.16	0.35	0.17	
HV (MJ/kg)	39.01	37.90	40.16	38.74	39.56	40.07	42.77	38.90	41.47	39.36	37.13	45.30	42.20		30.40		39.91
Cetane Number	54.42	62.91	51.36	50.18	56.05	50.86	55.96	60.09	53.22	51.00	59.33	50.43	51.05	61.00			54.50
Pour Point (^0C)	-0.50	12.90	-11.50	-4.00	-8.14	-2.80	-0.50	10.86	-2.50	-10.50	-8.50	-7.20	-7.33	-13.00			1.00
Cloud Point (^0C)	5.71	14.69	-3.50	0.38	-1.88	1.44	3.20	13.75	-3.00	-11.50	-2.67	2.67	-3.50	-1.00	-13.00		8.00
CFPP (^0C)	1.54	10.43	-13.44	-3.67	-7.75	-2.80	0.00	12.50	-7.50	-10.00	-4.50	-3.00	-6.00	-5.30			
Copper strip corr.															1.00		
Sulphur cont (ppm)	3.91	3.38	2.73	2.10	2.00	2.33	0.60	15.20	4.00		2.67	2.00		2.00			9.00
Specific gravity	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.91	0.88	0.88	0.88				0.88
Sulphated Ash (%)					0.01		0.06							0.01			
Carbon Residue (%)			0.05			0.08	0.20										
Iodine Value	87.78	51.67	112.00	124.73	110.17	104.04	41.80	54.10	101.00	64.50	30.00	152.75	141.0	105.00			98.78

APPENDIX C: ENGINE PERFORMANCE

Table C. 1: Engine Performance of Cotton Biodiesel and Blends at 1000 rpm

Properties	COTTON SEED BIODIESEL AND ITS BINARY BLENDS at 1000 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	167.1571	179.2932	165.8105	164.0842	146.7566	180.7528	186.0901
Torque	25.58359	29.9035	27.1143	28.53454	24.36455	28.33334	24.8001
Specific Fuel Cons. kg/kW-h	0.30	0.51	0.53	0.32	0.58	0.33	0.43
Brake Power	2.6795	3.1319	2.8398	2.9885	2.5518	2.9674	2.5974
Brake Mean effective Pressure (MN/M2)	5494.23	6421.96	5822.96	6127.97	5232.44	6084.76	5325.97
Brake Thermal Efficiency (%)	0.42	0.47	0.36	0.46	0.24	0.38	0.43

Table C. 2: Engine Performance of Cotton Biodiesel and Blends at 1500 rpm

Properties	COTTON SEED BIODIESEL AND ITS BINARY BLENDS at 1500 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	167.1571	182.6231	191.3273	194.6681	172.1884	195.4544	196.0901
Torque	32.48755	23.02715	33.52906	32.17194	26.68428	28.7673	25.2401
Specific Fuel Cons. kg/kW-h	0.34	0.57	0.56	0.43	0.62	0.47	0.36
Brake Power	3.4025	2.4117	3.5116	3.3695	2.7947	3.0129	2.6435
Brake Mean effective Pressure (MN/M2)	6976.90	4945.22	7200.57	6909.12	5730.61	6177.95	5420.47
Brake Thermal Efficiency (%)	0.39	0.39	0.33	0.43	0.32	0.49	0.49

Table C. 3: Engine Performance of Cotton Biodiesel and Blends at 2000 rpm

Properties	COTTON SEED BIODIESEL AND ITS BINARY BLENDS at 2000 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	194.1725	196.0689	191.8672	218.5941	216.2048	214.0949	206.0901
Torque	29.99424	30.45976	29.7023	31.99836	29.83643	21.47278	26.2001
Specific Fuel Cons. kg/kW-h	0.57	0.52	0.40	0.39	0.59	0.55	0.44
Brake Power	3.1414	3.1902	3.1108	3.3513	3.1249	2.2489	2.7440
Brake Mean effective Pressure (MN/M2)	6441.45	6541.42	6378.75	10454433	6407.56	4611.41	5626.63
Brake Thermal Efficiency (%)	0.41	0.47	0.42	0.49	0.49	0.38	0.48

Table C. 4: Engine Performance of Cotton Biodiesel and Blends at 2500 rpm

Properties	COTTON SEED BIODIESEL AND ITS BINARY BLENDS at 2500 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	205.0723	202.9773	189.7209	240.2627	237.8403	248.166	216.9001
Torque	31.38292	30.92134	29.80882	33.22923	33.4975	39.95566	28.9001
Specific Fuel Cons. kg/kW-h	0.75	0.82	0.52	0.58	0.76	0.64	0.42
Brake Power	3.2868	3.2385	3.1220	3.4802	3.5083	4.1847	3.0268
Brake Mean effective Pressure (MN/M2)	6739.67	6640.55	6401.63	7136.18	7193.79	8580.72	6206.47
Brake Thermal Efficiency (%)	0.41	0.39	0.46	0.56	0.38	0.51	0.57

Table C. 5: Engine Performance of Jatropha Biodiesel and Blends at 1000 rpm

Properties	JATROPHA SEED BIODIESEL AND ITS BINARY BLENDS at 1000 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	154.0787	165.5196	156.8206	114.999	94.82483	100.8143	220.001
Torque	27.51276	33.54484	29.93111	22.28012	12.43757	18.34342	20.4004
Specific Fuel Cons. kg/kW-h	0.36	0.56	0.37	0.27	0.21	0.53	0.50
Brake Power	2.8815	3.5133	3.1348	2.3335	1.3026	1.9212	2.1366
Brake Mean effective Pressure (MN/M2)	5908.53	7203.96	6427.89	4784.79	2671.04	3939.36	4381.11
Brake Thermal Efficiency (%)	0.48	0.48	0.46	0.53	0.59	0.34	0.40

Table C. 6: Engine Performance of Jatropha Biodiesel and Blends at 1500 rpm

Properties	JATROPHA SEED BIODIESEL AND ITS BINARY BLENDS at 1500 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	159.0962	192.8975	177.5026	117.6612	116.0131	84.97439	246.002
Torque	33.0951	28.74758	36.83507	27.98441	21.89709	14.05507	28.4004
Specific Fuel Cons. kg/kW-h	0.37	0.54	0.38	0.28	0.23	0.15	0.41
Brake Power	3.4662	3.0108	3.8579	2.9309	2.2934	1.4720	2.9745
Brake Mean effective Pressure (MN/M2)	7107.37	6173.72	7910.56	6009.82	4702.53	3018.41	6099.16
Brake Thermal Efficiency (%)	0.49	0.51	0.54	0.57	0.59	0.41	0.54

Table C. 7: Engine Performance of Jatropha Biodiesel and Blends at 2000 rpm

Properties	JATROPHA SEED BIODIESEL AND ITS BINARY BLENDS at 2000 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	193.6359	208.7869	229.098	125.9442	130.0581	113.8151	237.001
Torque	30.0258	28.79492	31.21722	8.402593	12.10618	13.50275	23.6004
Specific Fuel Cons. kg/kW-h	0.42	0.35	0.68	0.34	0.31	0.15	0.54
Brake Power	3.1447	3.0158	3.2695	0.8800	1.2679	1.4142	2.4717
Brake Mean effective Pressure (MN/M2)	6448.22	6183.88	6704.09	1804.51	2599.88	2899.80	5068.33
Brake Thermal Efficiency (%)	0.49	0.50	0.45	0.52	0.58	0.47	0.43

Table C. 8: Engine Performance of Jatropha Biodiesel and Blends at 2500 rpm

Properties	JATROPHA SEED BIODIESEL AND ITS BINARY BLENDS at 2500 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	232.3412	223.6907	250.5819	133.368	131.0279	78.2393	248.4001
Torque	33.82889	34.49562	32.51517	34.77738	12.19692	14.31939	28.4004
Specific Fuel Cons. kg/kW-h	0.64	0.41	0.58	0.35	0.28	0.51	0.50
Brake Power	3.5430	3.6128	3.4054	3.6424	1.2774	1.4997	2.9745
Brake Mean effective Pressure (MN/M2)	7264.96	7408.14	6982.83	7468.65	2619.36	3075.18	6099.16
Brake Thermal Efficiency (%)	0.51	0.52	0.54	0.55	0.59	0.53	0.56

Table C. 9: Engine Performance of Neem Biodiesel and Blends at 1000 rpm

Properties	NEEM SEED BIODIESEL AND ITS BINARY BLENDS at 1000 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	167.1571	179.2932	165.022	188.7748	184.1962	172.6927	189.6927
Torque	25.58359	29.9035	27.78891	28.87382	31.07125	29.48532	24.24002
Specific Fuel Cons. kg/kW-h	0.30	0.51	0.48	0.50	0.54	0.59	0.39
Brake Power	2.6795	3.1319	2.9104	3.0241	3.2542	3.0881	2.5387
Brake Mean effective Pressure (MN/M2)	5494.23	6421.96	5967.84	6200.83	6672.74	6332.15	5205.69
Brake Thermal Efficiency (%)	0.36	0.47	0.46	0.46	0.54	0.49	0.32

Table C. 10: Engine Performance of Neem Biodiesel and Blends at 1500 rpm

Properties	NEEM SEED BIODIESEL AND ITS BINARY BLENDS at 1500 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	193.0846	182.6231	167.7097	188.0341	189.7339	168.3887	190.001
Torque	29.88772	23.02715	29.22494	30.28223	21.76077	29.87194	25.24002
Specific Fuel Cons. kg/kW-h	0.37	0.24	0.29	0.30	0.30	0.30	0.43
Brake Power	3.1302	2.4117	3.0608	3.1716	2.2791	3.1286	2.6435
Brake Mean effective Pressure (MN/M2)	6418.57	4945.22	6276.23	6503.29	4673.26	6415.18	5420.45
Brake Thermal Efficiency (%)	0.29	0.43	0.49	0.48	0.40	0.48	0.52

Table C. 11: Engine Performance of Neem Biodiesel and Blends at 2000 rpm

Properties	NEEM SEED BIODIESEL AND ITS BINARY BLENDS at 2000 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	194.1725	174.6261	196.3247	203.6658	198.8899	192.2264	200.6927
Torque	29.77331	18.67963	30.19938	30.54261	29.67468	29.97451	26.21002
Specific Fuel Cons. kg/kW-h	0.57	0.55	0.51	0.52	0.50	0.57	0.60
Brake Power	3.1183	1.9564	3.1629	3.1988	3.1079	3.1393	2.7451
Brake Mean effective Pressure (MN/M2)	6394.00	4011.56	6485.50	6559.21	6372.82	6437.21	5628.76
Brake Thermal Efficiency (%)	0.40	0.43	0.49	0.48	0.50	0.48	0.48

Table C. 12: Engine Performance of Neem Biodiesel and Blends at 2500 rpm

Properties	NEEM SEED BIODIESEL AND ITS BINARY BLENDS at 2500 RPM						
Blends	B5	B10	B15	B20	B25	B30	B100
Exhaust Temp./^{0}C	203.4513	201.3556	243.1017	209.2928	200.6394	176.0054	216.6927
Torque	31.3553	30.75564	31.56834	30.96868	32.33369	33.43044	30.26002
Specific Fuel Cons. kg/kW-h	0.42	0.80	0.91	0.35	0.52	0.56	0.55
Brake Power	3.2839	3.2211	3.3063	3.2435	3.3864	3.5013	3.1692
Brake Mean effective Pressure (MN/M2)	6733.74	6604.96	6779.49	6650.71	6943.86	7179.39	6498.52
Brake Thermal Efficiency (%)	0.52	0.40	0.38	0.55	0.56	0.40	0.52

Table C. 13: Engine Performance of Multi Biodiesel and Blends at 1000 rpm

Properties	COTTON, JATROPHA & NEEM MULTI- BLENDS at 1000 RPM					
Blends	B222	B333	B444	B555	B101010	B000
Exhaust Temp./^{0}C	194.8048	180.8365	167.64	158.0359	188.2423	195.5226
Torque	12.76984	28.71996	24.53331	18.35131	26.87759	23.1249
Specific Fuel Cons. kg/kW-h	0.50	0.38	0.55	0.56	0.44	0.49
Brake Power	1.3374	3.0079	2.5695	1.9220	2.8150	2.4219
Brake Mean effective Pressure (MN/M2)	2742.40	6167.79	5268.68	3941.05	5772.13	4966.21
Brake Thermal Efficiency (%)	0.21	0.24	0.32	0.32	0.40	0.41

Table C. 14: Engine Performance of Multi Biodiesel and Blends at 1500 rpm

Properties	COTTON, JATROPHA & NEEM MULTI- BLENDS at 1500 RPM					
Blends	B222	B333	B444	B555	B101010	B000
Exhaust Temp./^{0}C	190.1263	177.3425	178.1852	186.3505	193.0082	185.1968
Torque	30.12442	31.98258	28.52271	20.44704	29.39852	29.75358
Specific Fuel Cons. kg/kW-h	0.55	0.39	0.45	0.54	0.49	0.39
Brake Power	3.1550	3.3496	2.9873	2.1415	3.0790	3.1162
Brake Mean effective Pressure (MN/M2)	6469.40	6868.45	6125.43	4391.13	6313.51	6389.76
Brake Thermal Efficiency (%)	0.35	0.42	0.42	0.36	0.49	0.48

Table C. 15: Engine Performance of Multi Biodiesel and Blends at 2000 rpm

Properties	COTTON, JATROPHA & NEEM MULTI- BLENDS at 2000 RPM					
Blends	B222	B333	B444	B555	B101010	B000
Exhaust Temp./^{0}C	205.1279	191.0809	197.3684	194.5723	200.7688	198.6008
Torque	30.62151	30.62151	29.92322	27.74552	30.64124	29.85616
Specific Fuel Cons. kg/kW-h	0.51	0.54	0.45	0.57	0.58	0.55
Brake Power	3.2071	3.2071	3.1340	2.9059	3.2092	3.1269
Brake Mean effective Pressure (MN/M2)	6576.16	6576.16	6426.19	5958.52	6580.39	6411.79
Brake Thermal Efficiency (%)	0.48	0.48	0.45	0.48	0.51	0.48

Table C. 16: Engine Performance of Multi Biodiesel and Blends at 2500 rpm

Properties	COTTON, JATROPHA & NEEM MULTI- BLENDS at 2500 RPM					
Blends	B222	B333	B444	B555	B101010	B000
Exhaust Temp./^{0}C	216.7887	201.772	214.0352	191.3188	208.2273	196.7324
Torque	29.07502	30.84638	30.76353	33.48567	32.02992	23.1249
Specific Fuel Cons. kg/kW-h	0.54	0.70	0.78	0.56	0.78	0.86
Brake Power	3.0451	3.2306	3.2220	3.5071	3.3546	2.4219
Brake Mean effective Pressure (MN/M2)	6244.04	6624.45	6606.66	7191.25	6878.62	4966.21
Brake Thermal Efficiency (%)	0.52	0.40	0.38	0.55	0.40	0.52

APPENDIX D: ENGINE EXHAUST EMISSIONS

Table D. 1: Emissions of Multi-Blends Blends of Biodiesel (2:2:2)

B2:2:2 at 1500 rpm		B2:2:2 at 2000 rpm		B2:2:2 at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas	130	Gas	124	Gas	96
Room	44	Room	44	Room	44
Air Gas %		Air Gas %		Air Gas %	
O_2	15.5	O_2	15.5	O_2	15.5
CO_2	5.4	CO_2	5.4	CO_2	5.4
Exhaust Air	3.87	Exhaust Air	3.87	Exhaust Air	3.87
Losses	12.6	Losses	11.8	Losses	7.6
Efficiency	87.4	Efficiency	88.2	Efficiency	92.4
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.973	CO	1.094	CO	0.883
CO (0 % O_2)	3.770	CO (0 % O_2)	4.234	CO (0 % O_2)	3.418
NO_X	0.300	NO_X	0.310	NO_X	0.317
NO_X(0 % O_2)	1.161	NO_X(0 % O_2)	1.200	NO_X(0 % O_2)	1.227
S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 2: Emissions of Multi-Blends Blends of Biodiesel (3:3:3)

B3:3:3at 1500 rpm		B3:3:3at 2000 rpm		B3:3:3at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas	86	Gas	86	Gas	79
Room	30	Room	30	Room	30
%		%		%	
O_2	16.1	O_2	16.6	O_2	15.6
CO_2	4.8	CO_2	4.3	CO_2	5.3
Exhaust Air	4.35	Exhaust Air	4.86	Exhaust Air	3.94
Losses	9.2	Losses	10.2	Losses	7.3
Efficiency	90.8	Efficiency	89.8	Efficiency	92.7
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.540	CO	0.670	CO	0.629
CO (0 % O_2)	2.351	CO (0 % O_2)	3.257	CO (0 % O_2)	2.480
NO_X	0.281	NO_X	0.303	NO_X	0.412
NO_X(0 % O_2)	1.224	NO_X(0 % O_2)	1.473	NO_X(0 % O_2)	1.625
S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 3: Emissions of Multi-Blends Blends of Biodiesel (4:4:4)

B4:4:4 at 1500 rpm		B4:4:4 at 2000 rpm		B4:4:4 at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	77	Gas	79	Gas	70
Room	30	Room	30	Room	30
%		%		%	
O_2	16.5	O_2	17.2	O_2	15.7
CO_2	4.4	CO_2	3.7	CO_2	5.2
Exhaust Air	4.75	Exhaust Air	5.65	Exhaust Air	4.02
Losses	8.4	Losses	10.3	Losses	6.1
Efficiency	91.6	Efficiency	89.7	Efficiency	93.9
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.564	CO	0.503	CO	0.613
CO (0 % O_2)	2.679	CO (0 % O_2)	2.841	CO (0 % O_2)	2.464
NO_X	0.223	NO_X	0.278	NO_X	0.329
NO_X(0 % O_2)	1.059	NO_X(0 % O_2)	1.570	NO_X(0 % O_2)	1.322
S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 4: Emissions of Multi-Blends Blends of Biodiesel (5:5:5)

B5:5:5 at 1500 rpm		B5:5:5 at 2000 rpm		B5:5:5 at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	65	Gas	80	Gas	69
Room	30	Room	30	Room	30
%		%		%	
O_2	15.4	O_2	16.7	O_2	18.5
CO_2	5.5	CO_2	4.2	CO_2	2.4
Exhaust Air	3.80	Exhaust Air	4.98	Exhaust Air	8.71
Losses	5.1	Losses	9.3	Losses	12.5
Efficiency	94.9	Efficiency	90.7	Efficiency	87.5
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	1.241	CO	0.604	CO	0.100
CO (0 % O_2)	4.716	CO (0 % O_2)	3.006	CO (0 % O_2)	0.871
NO_X	0.344	NO_X	0.291	NO_X	0.295
NO_X(0 % O_2)	1.307	NO_X(0 % O_2)	1.448	NO_X(0 % O_2)	2.569
S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 5: Emissions of Multi-Blends Blends of Biodiesel (10:10:10)

B10:10:10 at 1500 rpm		B10:10:10 at 2000 rpm		B10:10:10 at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	130	Gas	122	Gas	88
Room	44	Room	44	Room	44
%		%		%	
O_2	15.6	O_2	15.5	O_2	15.1
CO_2	5.3	CO_2	5.4	CO_2	5.8
Exhaust Air	3.94	Exhaust Air	3.87	Exhaust Air	3.60
Losses	12.9	Losses	11.5	Losses	6.0
Efficiency	87.1	Efficiency	88.5	Efficiency	94.0
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.800	CO	0.111	CO	0.724
CO (0 % O_2)	3.155	CO (0 % O_2)	4.319	CO (0 % O_2)	2.609
NO_X	0.295	NO_X	0.327	NO_X	0.354
NO_X(0 % O_2)	1.163	NO_X(0 % O_2)	1.266	NO_X(0 % O_2)	1.276
S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 6: Emissions of Pure Diesel with no Biodiesel (0:0:0)

B0:0:0 at 1500 rpm		B0:0:0 at 2000 rpm		B0:0:0 at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	126	Gas	121	Gas	86
Room	44	Room	44	Room	44
%		%		%	
O_2	15.4	O_2	15.2	O_2	14.8
CO_2	5.5	CO_2	5.7	CO_2	6.1
Exhaust Air	3.80	Exhaust Air	3.67	Exhaust Air	3.43
Losses	11.8	Losses	10.7	Losses	5.5
Efficiency	88.2	Efficiency	89.3	Efficiency	94.5
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.863	CO	1.025	CO	0.808
CO (0 % O_2)	3.279	CO (0 % O_2)	3.758	CO (0 % O_2)	2.768
NO_X	0.278	NO_X	0.317	NO_X	0.358
NO_X(0 % O_2)	1.056	NO_X(0 % O_2)	1.162	NO_X(0 % O_2)	1.227
S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 7: Emissions of 5 % Jatropha Biodiesel Blend with Diesel

$B5_J$at 1000 rpm		$B5_J$at 1500 rpm		$B5_J$at 2000 rpm		$B5_J$at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	128	Gas	101	Gas	80	Gas	55
Room	41	Room	41	Room	41	Room	41
%		%		%		%	
O_2	15.5	O_2	16.5	O_2	15.8	O_2	16.2
CO_2	3.2	CO_2	2.6	CO_2	3.1	CO_2	2.8
Exhaust Air	3.87	Exhaust Air	4.75	Exhaust Air	4.1	Exhaust Air	4.45
Losses	10.6	Losses	8.8	Losses	5.0	Losses	1.9
Efficiency	89.4	Efficiency	91.2	Efficiency	95	Efficiency	98.1
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.341	CO	0.543	CO	0.444	CO	0.271
CO (0 % O_2)	1.320	CO (0 % O_2)	2.579	CO (0 % O_2)	1.820	CO (0 % O_2)	1.205
NO_X	0.400	NO_X	0.187	NO_X	0.290	NO_X	0.220
NO_X(0 % O_2)	1.548	NO_X(0 % O_2)	0.888	NO_X(0 % O_2)	1.188	NO_X(0 % O_2)	0.978
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.00
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.00

Table D. 8: Emissions of 10 % Jatropha Biodiesel Blend with Diesel

$B10_J$at 1000 rpm		$B10_J$at 1500 rpm		$B10_J$at 2000 rpm		$B10_J$at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	121	Gas	104	Gas	82	Gas	56
Room	41	Room	41	Room	41	Room	41
%		%		%		%	
O_2	14.3	O_2	15.6	O_2	15.1	O_2	16.4
CO_2	3.9	CO_2	3.2	CO_2	3.5	CO_2	2.7
Exhaust Air	3.17	Exhaust Air	3.94	Exhaust Air	3.6	Exhaust Air	4.64
Losses	8.2	Losses	7.8	Losses	4.7	Losses	2.2
Efficiency	91.8	Efficiency	92.2	Efficiency	95.3	Efficiency	97.8
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.433	CO	0.549	CO	0.424	CO	0.251
CO (0 % O_2)	1.371	CO (0 % O_2)	2.165	CO (0 % O_2)	1.528	CO (0 % O_2)	1.166
NO_X	0.489	NO_X	0.335	NO_X	0.306	NO_X	0.168
NO_X(0 % O_2)	1.548	NO_X(0 % O_2)	1.321	NO_X(0 % O_2)	1.103	NO_X(0 % O_2)	0.780
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 9: Emissions of 15 % Jatropha Biodiesel Blend with Diesel

$B15_J$at 1000 rpm		$B15_J$at 1500 rpm		$B15_J$at 2000 rpm		$B15_J$at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	136	Gas	114	Gas	85	Gas	57
Room	41	Room	41	Room	41	Room	41
%		%		%		%	
O_2	14.8	O_2	15.2	O_2	16.3	O_2	17.4
CO_2	3.6	CO_2	3.4	CO_2	2.8	CO_2	2.1
Exhaust Air	3.43	Exhaust Air	3.67	Exhaust Air	4.54	Exhaust Air	5.97
Losses	10.4	Losses	8.5	Losses	6.2	Losses	2.9
Efficiency	89.6	Efficiency	91.5	Efficiency	93.8	Efficiency	97.1
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.313	CO	0.489	CO	0.233	CO	0.063
CO (0 % O_2)	1.072	CO (0 % O_2)	1.793	CO (0 % O_2)	1.081	CO (0 % O_2)	0.376
NO_X	0.409	NO_X	0.388	NO_X	0.242	NO_X	0.133
NO_X(0 % O_2)	1.401	NO_X(0 % O_2)	1.423	NO_X(0 % O_2)	1.100	NO_X(0 % O_2)	0.794
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 10: Emissions of 20 % Jatropha Biodiesel Blend with Diesel

$B20_J$at 1000 rpm		$B20_J$at 1500 rpm		$B20_J$at 2000 rpm		$B20_J$at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas		Gas	63	Gas	58	Gas	54
Room		Room	31	Room	31	Room	31
%		%		%		%	
O_2		O_2	18.4	O_2	18.0	O_2	18.5
CO_2		CO_2	1.5	CO_2	1.7	CO_2	1.4
Exhaust Air		Exhaust Air	8.36	Exhaust Air	7.21	Exhaust Air	8.71
Losses		Losses	8.0	Losses	5.9	Losses	6.0
Efficiency		Efficiency	92.0	Efficiency	94.1	Efficiency	94.0
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.250	CO	0.119	CO	0.021
CO (0 % O_2)		CO (0 % O_2)	2.090	CO (0 % O_2)	0.858	CO (0 % O_2)	0.183
NO_X		NO_X	0.125	NO_X	0.123	NO_X	0.074
NO_X(0 % O_2)		NO_X(0 % O_2)	1.045	NO_X(0 % O_2)	0.886	NO_X(0 % O_2)	0.644
S O_2		S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)		S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 11: Emissions of 25 % Jatropha Biodiesel Blend with Diesel

$B25_J$at 1000 rpm		$B25_J$at 1500 rpm		$B25_J$at 2000 rpm		$B25_J$at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas		Gas	57	Gas	52	Gas	47
Room		Room	31	Room	31	Room	31
%		%		%		%	
O_2		O_2	18.9	O_2	18.8	O_2	19.0
CO_2		CO_2	1.2	CO_2	1.3	CO_2	1.1
Exhaust Air		Exhaust Air	10.5	Exhaust Air	9.95	Exhaust Air	11.0
Losses		Losses	8.1	Losses	6.2	Losses	5.2
Efficiency		Efficiency	91.9	Efficiency	93.8	Efficiency	94.8
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.305	CO	0.266	CO	0.179
CO (0 % O_2)		CO (0 % O_2)	3.187	CO (0 % O_2)	2.647	CO (0 % O_2)	1.969
NO_X		NO_X	0.072	NO_X	0.080	NO_X	0.062
NO_X(0 % O_2)		NO_X(0 % O_2)	0.752	NO_X(0 % O_2)	0.796	NO_X(0 % O_2)	0.682
S O_2		S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)		S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 12: Emissions of 30 % Jatropha Biodiesel Blend with Diesel

$B30_J$at 1000 rpm		$B30_J$at 1500 rpm		$B30_J$at 2000 rpm		$B30_J$at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	85	Gas	85	Gas	91	Gas	89
Room		Room	31	Room	31	Room	31
%		%		%		%	
O_2		O_2	16.2	O_2	15.9	O_2	15.1
CO_2		CO_2	4.7	CO_2	5	CO_2	5.8
Exhaust Air		Exhaust Air	4.45	Exhaust Air	4.18	Exhaust Air	3.60
Losses		Losses	9.0	Losses	9.5	Losses	8.0
Efficiency		Efficiency	91.0	Efficiency	90.5	Efficiency	92.0
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.505	CO	0.930	CO	0.633
CO (0 % O_2)		CO (0 % O_2)	2.246	CO (0 % O_2)	3.887	CO (0 % O_2)	2.281
NO_X		NO_X	0.291	NO_X	0.346	NO_X	0.392
NO_X(0 % O_2)		NO_X(0 % O_2)	1.294	NO_X(0 % O_2)	1.446	NO_X(0 % O_2)	1.413
S O_2		S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)		S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 13: Emissions of 100 % Jatropha Biodiesel Blend with Diesel

$B100_J$ at 1000 rpm		$B100_J$ at 1500 rpm		$B100_J$ at 2000 rpm		$B100_J$ at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas		Gas		Gas		Gas	
Room		Room		Room		Room	
%		%		%		%	
O_2		O_2		O_2		O_2	
CO_2		CO_2		CO_2		CO_2	
Exhaust Air		Exhaust Air		Exhaust Air		Exhaust Air	
Losses		Losses		Losses		Losses	
Efficiency		Efficiency		Efficiency		Efficiency	
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO		CO		CO	
CO (0 % O_2)		CO (0 % O_2)		CO (0 % O_2)		CO (0 % O_2)	
NO_X		NO_X		NO_X		NO_X	
NO_X(0 % O_2)		NO_X(0 % O_2)		NO_X(0 % O_2)		NO_X(0 % O_2)	
S O_2		S O_2		S O_2		S O_2	
S O_2 (0 % O_2)		S O_2 (0 % O_2)		S O_2 (0 % O_2)		S O_2 (0 % O_2)	

Table D. 14: Emissions of 5 % Neem Biodiesel Blend with Diesel

$B5_N$ at 1000 rpm		$B5_N$ at 1500 rpm		$B5_N$ at 2000 rpm		$B5_N$ at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	81	Gas	81	Gas	79	Gas	64
Room	39	Room	39	Room	39	Room	39
%		%		%		%	
O_2	16.8	O_2	16.8	O_2	16.3	O_2	15.5
CO_2	4.1	CO_2	81	CO_2	4.6	CO_2	5.4
Exhaust Air		Exhaust Air	5.1	Exhaust Air	4.54	Exhaust Air	3.87
Losses		Losses	8.0	Losses	6.8	Losses	3.7
Efficiency		Efficiency	92.0	Efficiency	93.2	Efficiency	96.3
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.401	CO	0.673	CO	0.573
CO (0 % O_2)		CO (0 % O_2)	2.044	CO (0 % O_2)	3.058	CO (0 % O_2)	2.218
NO_X		NO_X	0.308	NO_X	0.332	NO_X	0.407
NO_X(0 % O_2)		NO_X(0 % O_2)	1.570	NO_X(0 % O_2)	1.508	NO_X(0 % O_2)	1.575
S O_2		S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)		S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 15: Emissions of 10 % Neem Biodiesel Blend with Diesel

$B10_N$ at 1000 rpm		$B10_N$ at 1500 rpm		$B10_N$ at 2000 rpm		$B10_N$ at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas		Gas	81	Gas	82	Gas	64
Room		Room	39	Room	39	Room	39
%		%		%		%	
O_2		O_2	16.4	O_2	16.0	O_2	16.1
CO_2		CO_2	4.5	CO_2	4.9	CO_2	4.8
Exhaust Air		Exhaust Air	4.64	Exhaust Air	4.27	Exhaust Air	4.35
Losses		Losses	7.3	Losses	6.9	Losses	4.1
Efficiency		Efficiency	92.7	Efficiency	93.1	Efficiency	95.9
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.476	CO	0.841	CO	0.398
CO (0 % O_2)		CO (0 % O_2)	2.211	CO (0 % O_2)	3.587	CO (0 % O_2)	1.733
NO_X		NO_X	0.312	NO_X	0.354	NO_X	0.358
NO_X(0 % O_2)		NO_X(0 % O_2)	1.449	NO_X(0 % O_2)	1.510	NO_X(0 % O_2)	1.559
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 16: Emissions of 15 % Neem Biodiesel Blend with Diesel

$B15_N$ at 1000 rpm		$B15_N$ at 1500 rpm		$B15_N$ at 2000 rpm		$B15_N$ at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas		Gas	105	Gas	75	Gas	55
Room		Room	39	Room	39	Room	39
%		%		%		%	
O_2		O_2	15.5	O_2	15.8	O_2	16.6
CO_2		CO_2	5.4	CO_2	5.1	CO_2	4.3
Exhaust Air		Exhaust Air	3.87	Exhaust Air	4.1	Exhaust Air	4.85
Losses		Losses	9.7	Losses	5.6	Losses	2.9
Efficiency		Efficiency	90.3	Efficiency	94.4	Efficiency	97.1
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.503	CO	0.495	CO	0.420
CO (0 % O_2)		CO (0 % O_2)	1.597	CO (0 % O_2)	2.029	CO (0 % O_2)	2.041
NO_X		NO_X	0.434	NO_X	0.399	NO_X	0.271
NO_X(0 % O_2)		NO_X(0 % O_2)	1.680	NO_X(0 % O_2)	1.635	NO_X(0 % O_2)	1.317
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 17: Emissions of 20 % Neem Biodiesel Blend with Diesel

$B20_N$ at 1000 rpm		$B20_N$ at 1500 rpm		$B20_N$ at 2000 rpm		$B20_N$ at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas	82	Gas	96	Gas	101	Gas	98
Room	47	Room	47	Room	47	Room	47
%		%		%		%	
O_2	17.2	O_2	16.3	O_2	15.3	O_2	15.3
CO_2	3.7	CO_2	4.6	CO_2	5.6	CO_2	5.6
Exhaust Air	5.65	Exhaust Air	4.54	Exhaust Air	3.73	Exhaust Air	3.73
Losses	7.4	Losses	8.4	Losses	7.7	Losses	7.2
Efficiency	92.6	Efficiency	91.6	Efficiency	92.3	Efficiency	92.8
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO		CO		CO	
CO (0 % O_2)		CO (0 % O_2)		CO (0 % O_2)		CO (0 % O_2)	
NO_X	0.230	NO_X	0.308	NO_X	0.368	NO_X	0.358
NO_X(0 % O_2)	1.299	NO_X(0 % O_2)	1.399	NO_X(0 % O_2)	1.373	NO_X(0 % O_2)	1.336
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 18: Emissions of 25 % Neem Biodiesel Blend with Diesel

$B25_N$ at 1000 rpm		$B25_N$ at 1500 rpm		$B25_N$ at 2000 rpm		$B25_N$ at 2500 rpm	
Temperature ^0C		Temperature ^0C		Temperature ^0C		Temperature ^0C	
Gas		Gas	68	Gas	73	Gas	65
Room		Room	29	Room	29	Room	29
%		%		%		%	
O_2		O_2	17.4	O_2	17.5	O_2	16.4
CO_2		CO_2	2.1	CO_2	2.0	CO_2	2.7
Exhaust Air		Exhaust Air	5.97	Exhaust Air	6.15	Exhaust Air	4.64
Losses		Losses	7.1	Losses	8.2	Losses	5.2
Efficiency		Efficiency	92.9	Efficiency	91.8	Efficiency	94.8
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.333	CO	0.483	CO	0.461
CO (0 % O_2)		CO (0 % O_2)	1.988	CO (0 % O_2)	2.969	CO (0 % O_2)	2.141
NO_X		NO_X	0.189	NO_X	0.238	NO_X	0.316
NO_X(0 % O_2)		NO_X(0 % O_2)	1.129	NO_X(0 % O_2)	1.463	NO_X(0 % O_2)	1.468
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 19: Emissions of 30 % Neem Biodiesel Blend with Diesel

B30 $_N$at 1000 rpm		B30 $_N$at 1500 rpm		B30 $_N$at 2000 rpm		B30 $_N$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas		Gas	62	Gas	69	Gas	55
Room		Room	29	Room	29	Room	29
%		%		%		%	
O_2		O_2	17.8	O_2	16.6	O_2	15.6
CO_2		CO_2	1.9	CO_2	2.6	CO_2	3.2
Exhaust Air		Exhaust Air	6.74	Exhaust Air	4.86	Exhaust Air	3.94
Losses		Losses	6.8	Losses	6.0	Losses	3.2
Efficiency		Efficiency	93.2	Efficiency	94.0	Efficiency	96.8
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.294	CO	0.754	CO	0.604
CO (0 % O_2)		CO (0 % O_2)	1.982	CO (0 % O_2)	3.665	CO (0 % O_2)	2.382
NO_X		NO_X	0.164	NO_X	0.240	NO_X	0.314
NO_X(0 % O_2)		NO_X(0 % O_2)	1.106	NO_X(0 % O_2)	1.167	NO_X(0 % O_2)	1.238
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 20: Emissions of 100 % Neem Biodiesel Blend with Diesel

B100 $_N$at 1000 rpm		B100 $_N$at 1500 rpm		B100 $_N$at 2000 rpm		B100 $_N$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas		Gas	89	Gas	81	Gas	72
Room		Room	31	Room	31	Room	31
%		%		%		%	
O_2		O_2	17.3	O_2	17.2	O_2	17.3
CO_2		CO_2	2.2	CO_2	2.2	CO_2	2.2
Exhaust Air		Exhaust Air	5.81	Exhaust Air	5.65	Exhaust Air	6.4
Losses		Losses	10.3	Losses	8.7	Losses	7.3
Efficiency		Efficiency	89.7	Efficiency	91.3	Efficiency	92.7
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.095	CO	0.106	CO	0.079
CO (0 % O_2)		CO (0 % O_2)	0.552	CO (0 % O_2)	0.599	CO (0 % O_2)	0.459
NO_X		NO_X	0.091	NO_X	0.253	NO_X	0.244
NO_X(0 % O_2)		NO_X(0 % O_2)	0.109	NO_X(0 % O_2)	1.429	NO_X(0 % O_2)	1.417
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 21: Emissions of 5 % Cotton Biodiesel Blend with Diesel

B5 $_C$ at 1000 rpm		B5 $_C$at 1500 rpm		B5 $_C$at 2000 rpm		B5 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas		Gas	63	Gas	76	Gas	69
Room		Room	29	Room	29	Room	29
%		%		%		%	
O_2		O_2	17.8	O_2	17.3	O_2	15.7
CO_2		CO_2	1.9	CO_2	2.2	CO_2	3.1
Exhaust Air		Exhaust Air	6.74	Exhaust Air	5.81	Exhaust Air	4.02
Losses		Losses	7.0	Losses	8.4	Losses	5.1
Efficiency		Efficiency	93	Efficiency	91.6	Efficiency	94.9
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.366	CO	0.611	CO	0.696
CO (0 % O_2)		CO (0 % O_2)	2.468	CO (0 % O_2)	3.547	CO (0 % O_2)	2.797
NO_X		NO_X	0.142	NO_X	0.222	NO_X	0.296
NO_X(0 % O_2)		NO_X(0 % O_2)	0.957	NO_X(0 % O_2)	1.289	NO_X(0 % O_2)	1.190
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 22: Emissions of 10 % Cotton Biodiesel Blend with Diesel

B10 $_C$ at 1000 rpm		B10 $_C$at 1500 rpm		B10 $_C$at 2000 rpm		B10 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas		Gas	64	Gas	70	Gas	65
Room		Room	29	Room	29	Room	29
%		%		%		%	
O_2		O_2	17.6	O_2	18.1	O_2	16.6
CO_2		CO_2	2.0	CO_2	1.7	CO_2	2.6
Exhaust Air		Exhaust Air	6.33	Exhaust Air	7.46	Exhaust Air	4.86
Losses		Losses	6.7	Losses	9.2	Losses	5.4
Efficiency		Efficiency	93.3	Efficiency	90.8	Efficiency	94.6
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.366	CO	0.329	CO	0.489
CO (0 % O_2)		CO (0 % O_2)	2.318	CO (0 % O_2)	2.456	CO (0 % O_2)	2.377
NO_X		NO_X	0.156	NO_X	0.220	NO_X	0.290
NO_X(0 % O_2)		NO_X(0 % O_2)	0.988	NO_X(0 % O_2)	1.642	NO_X(0 % O_2)	1.410
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 23: Emissions of 15 % Cotton Biodiesel Blend with Diesel

B15 $_C$at 1000 rpm		B15 $_C$at 1500 rpm		B15 $_C$at 2000 rpm		B15 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas		Gas	73	Gas	59	Gas	66
Room		Room	29	Room	29	Room	29
%		%		%		%	
O_2		O_2	17.1	O_2	20.9	O_2	19.3
CO_2		CO_2	2.3	CO_2	0.0	CO_2	1.0
Exhaust Air		Exhaust Air	5.50	Exhaust Air	5.50	Exhaust Air	13.1
Losses		Losses	7.4	Losses	7.4	Losses	14.3
Efficiency		Efficiency	92.6	Efficiency	92.6	Efficiency	85.7
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.568	CO	0.009	CO	0.139
CO (0 % O_2)		CO (0 % O_2)	3.124	CO (0 % O_2)	0.068	CO (0 % O_2)	1.816
NO_X		NO_X	0.195	NO_X	0.043	NO_X	0.197
NO_X(0 % O_2)		NO_X(0 % O_2)	1.073	NO_X(0 % O_2)	0.165	NO_X(0 % O_2)	2.573
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.009
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.118

Table D. 24: Emissions of 20 % Cotton Biodiesel Blend with Diesel

B20 $_C$at 1000 rpm		B20 $_C$at 1500 rpm		B20 $_C$at 2000 rpm		B20 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas	61	Gas	54	Gas	45	Gas	42
Room	29	Room	29	Room	29	Room	29
%		%		%		%	
O_2	17.6	O_2	16.9	O_2	17.6	O_2	17.8
CO_2	2.0	CO_2	2.4	CO_2	2.0	CO_2	1.8
Exhaust Air	6.33	Exhaust Air	5.22	Exhaust Air	6.33	Exhaust Air	6.00
Losses	6.2	Losses	4.0	Losses	3.1	Losses	2.5
Efficiency	93.8	Efficiency	96.0	Efficiency	96.9	Efficiency	97.5
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.346	CO	0.019	CO	0.155	CO	0.125
CO (0 % O_2)	2.191	CO (0 % O_2)	0.099	CO (0 % O_2)	0.982	CO (0 % O_2)	0.782
NO_X	0.144	NO_X	0.197	NO_X	0.199	NO_X	0.129
NO_X(0 % O_2)	0.912	NO_X(0 % O_2)	1.029	NO_X(0 % O_2)	1.260	NO_X(0 % O_2)	0.860
S O_2	0.000	S O_2	0.049	S O_2	0.017	S O_2	0.011
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.256	S O_2 (0 % O_2)	0.108	S O_2 (0 % O_2)	0. 058

Table D. 25: Emissions of 25 % Cotton Biodiesel Blend with Diesel

B25 $_C$at 1000 rpm		B25 $_C$at 1500 rpm		B25 $_C$at 2000 rpm		B25 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas	126	Gas	102	Gas	78	Gas	54
Room	32	Room	32	Room	32	Room	32
%		%		%		%	
O_2	14.4	O_2	15.1	O_2	15.0	O_2	16.3
CO_2	3.9	CO_2	3.5	CO_2	3.5	CO_2	2.8
Exhaust Air	3.22	Exhaust Air	3.60	Exhaust Air	3.54	Exhaust Air	4.54
Losses	9.7	Losses	8.0	Losses	5.2	Losses	3.1
Efficiency	90.3	Efficiency	92.0	Efficiency	94.8	Efficiency	96.9
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.364	CO	0.480	CO	0.521	CO	0.323
CO (0 % O_2)	1.170	CO (0 % O_2)	1.730	CO (0 % O_2)	1.846	CO (0 % O_2)	1.468
NO_X	0.429	NO_X	0.353	NO_X	0.298	NO_X	0.166
NO_X(0 % O_2)	1.379	NO_X(0 % O_2)	1.272	NO_X(0 % O_2)	1.056	NO_X(0 % O_2)	0.754
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 26: Emissions of 30 % Cotton Biodiesel Blend with Diesel

B30 $_C$at 1000 rpm		B30 $_C$at 1500 rpm		B30 $_C$at 2000 rpm		B30 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas	125	Gas	109	Gas	80	Gas	56
Room	32	Room	32	Room	32	Room	32
%		%		%		%	
O_2	14.6	O_2	15.3	O_2	15.4	O_2	17.3
CO_2	3.8	CO_2	3.3	CO_2	3.3	CO_2	2.2
Exhaust Air	3.32	Exhaust Air	3.73	Exhaust Air	3.80	Exhaust Air	5.81
Losses	9.9	Losses	9.1	Losses	5.8	Losses	4.3
Efficiency	90.1	Efficiency	90.9	Efficiency	94.2	Efficiency	95.7
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO	0.296	CO	0.451	CO	0.258	CO	0.190
CO (0 % O_2)	0.982	CO (0 % O_2)	1.683	CO (0 % O_2)	0.980	CO (0 % O_2)	1.103
NO_X	0.388	NO_X	0.345	NO_X	0.261	NO_X	0.127
NO_X(0 % O_2)	1.287	NO_X(0 % O_2)	1.288	NO_X(0 % O_2)	0.992	NO_X(0 % O_2)	0.737
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

Table D. 27: Emissions of 100 % Cotton Biodiesel Blend with Diesel

B100 $_C$at 1000 rpm		B100 $_C$at 1500 rpm		B100 $_C$at 2000 rpm		B100 $_C$at 2500 rpm	
Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C		Temperature ^{0}C	
Gas		Gas	79	Gas	71	Gas	68
Room		Room	31	Room	31	Room	31
%		%		%		%	
O_2		O_2	17.8	O_2	17.7	O_2	17.9
CO_2		CO_2	1.9	CO_2	1.9	CO_2	1.8
Exhaust Air		Exhaust Air	6.74	Exhaust Air	6.53	Exhaust Air	6.97
Losses		Losses	9.8	Losses	7.9	Losses	7.8
Efficiency		Efficiency	90.2	Efficiency	92.1	Efficiency	92.2
Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3		Flue Gases g/M^3	
CO		CO	0.120	CO	0.073	CO	0.036
CO (0 % O_2)		CO (0 % O_2)	0.809	CO (0 % O_2)	0.477	CO (0 % O_2)	0.251
NO_X		NO_X	0.084	NO_X	0.166	NO_X	0.154
NO_X(0 % O_2)		NO_X(0 % O_2)	0.566	NO_X(0 % O_2)	1.084	NO_X(0 % O_2)	1.073
S O_2	0.000	S O_2	0.000	S O_2	0.000	S O_2	0.000
S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000	S O_2 (0 % O_2)	0.000

APPENDIX E: SIMULATED RESULTS OF ENGINE PERFORMANCE

Table E. 1: Simulated and Experimented Results of Engine Performance

BIODIESEL	Engine Speeds /RPM	SFC of Engine kg/kW-h	SFC Simulated kg/kW-h	BMEP Engine (MN/M2)	BMEP Simulated (MN/M2)	BTE Engine (%)	BTE Simulated (%)
COTTON	1000	0.429115	0.435	5325.973	5625.973	0.568669	0.5866876
	1500	0.362299	0.376931	5420.465	5720.465	0.685494	0.7154939
	2000	0.441295	0.471295	5626.631	5926.631	0.58419	0.6041898
	2500	0.424461	0.444613	6206.47	6306.47	0.6699484	0.66994838
JATROPHA	1000	0.499121	0.489121	4381.11	4481.11	0.401118	0.4311178
	1500	0.413359	0.433588	6099.16	6011.16	0.6742739	0.71273908
	2000	0.53521	0.552099	5068.33	5468.33	0.432747	0.4627473
	2500	0.501936	0.543571	6099.159	6599.159	0.555284	0.5852844
NEEM	1000	0.394349	0.423486	5205.692	5305.692	0.612308	0.6523075
	1500	0.429817	0.458165	5420.448	5020.448	0.584956	0.6049565
	2000	0.603869	0.686896	5628.761	5728.761	0.432356	0.4623561
	2500	0.547954	0.579542	6498.52	6898.52	0.5501004	0.59010036

Table E. 2: Simulated Results of Engine Performance of Different Feedstocks

Biodiesel	SFC (kg/kW-h)	BMEP (MN/M^2)	BTE (%)
Yellow Grease	0.4491	5125	0.5468
Palm	0.3729	5220	0.6493
Rapeseed	0.4741	5266	0.5141
Soy	0.4461	6106	0.6991
Canola	0.4912	4581	0.4611
Sun flower	0.4358	6199	0.6892
Tallow	0.5935	6158	0.5655
Corn	0.3943	5420	0.6223
Algae	0.4981	5448	0.5495
Coconut	0.6016	5228	0.4323
Camelina	0.5179	5312	0.565
Safflower	0.3348	5686	0.6442
WCO	0.4816	6101	0.4827
Castor	0.6138	4538	0.5855