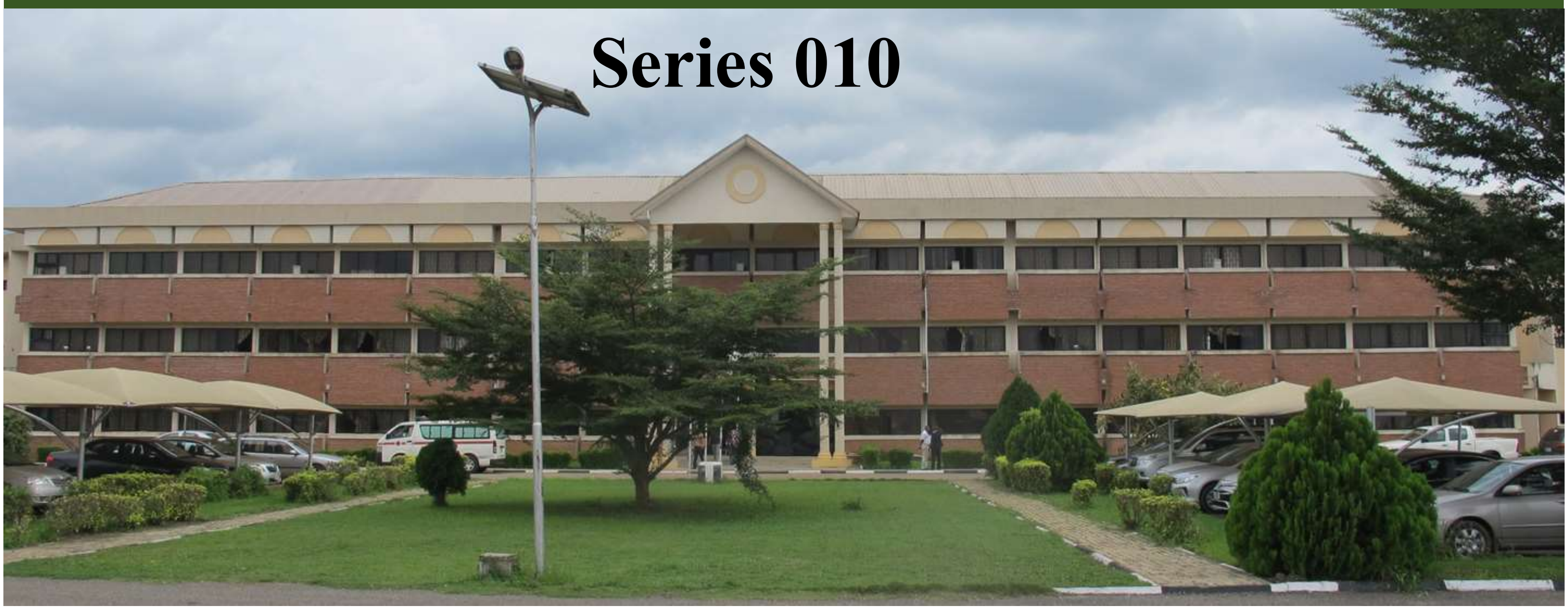
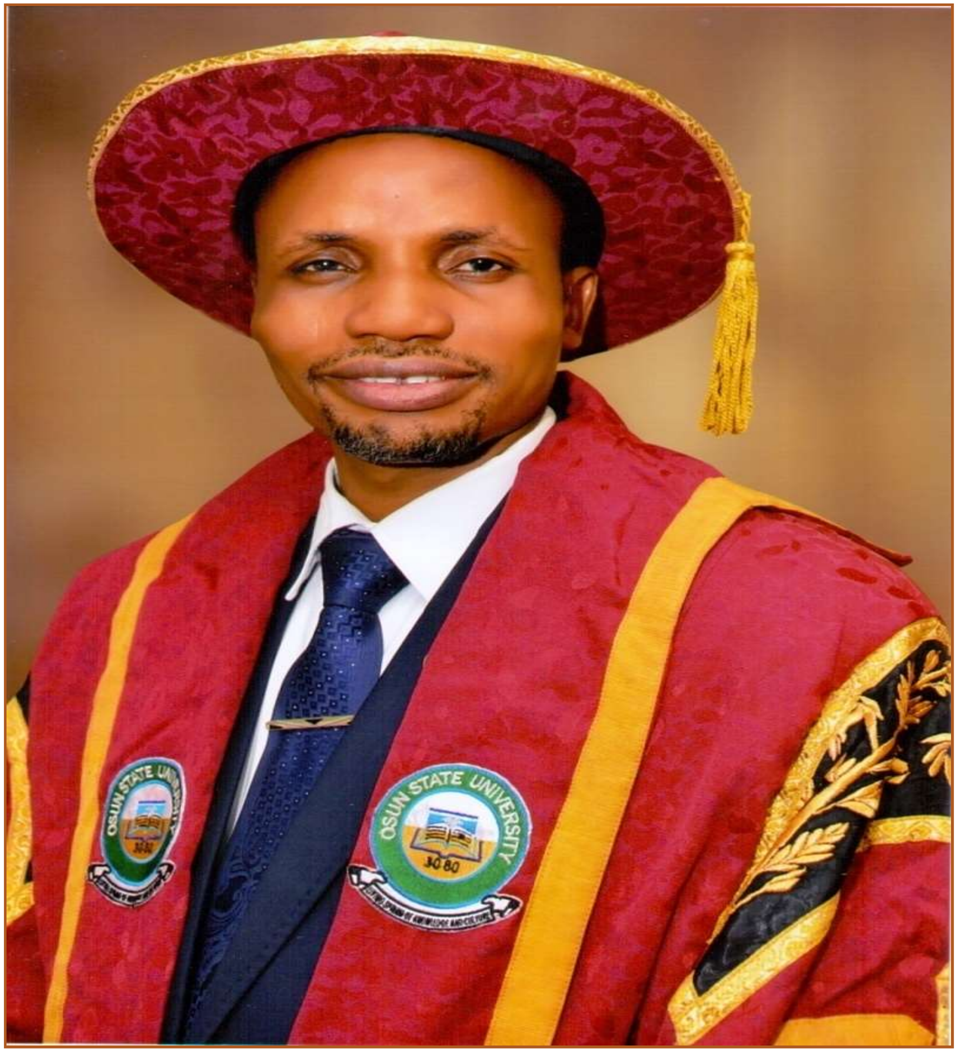
OSUN STATE UNIVERSITY

INAUGURAL LECTURE

Series 010



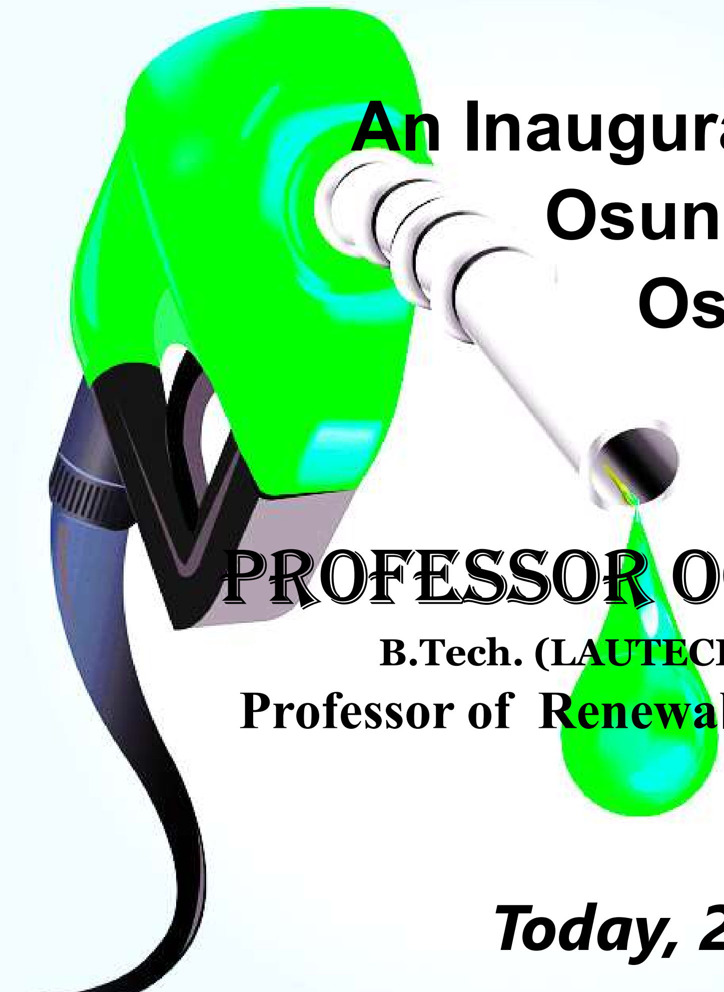


Professor Oguntola Jelil Alamu

B.Tech. (LAUTECH), M.Sc. (Ibadan), Ph.D (LAUTECH)

Professor of Renewable Energy (Mechanical Engineering)

SOURCING RENEWABLE FUEL FOR DIESEL ENGINES



An Inaugural Lecture Delivered at
Osun State University
Osogbo, Nigeria

BY

PROFESSOR OGUNTOLA JELIL ALAMU

B.Tech. (LAUTECH), M.Sc. (Ibadan), Ph.D (LAUTECH)

Professor of Renewable Energy (Mechanical Engineering)

Today, 21st December, 2016

- The Vice-Chancellor,
- Ag. Registrar and other Principal Officers of the University,
- Provosts of Colleges,
- Deans of Faculties,
- Directors of Centres and Units,
- Professors and other members of Senate,
- Members of Academic Staff,
- Members of Administrative and Technical Staff of the University,
- My Lords Spiritual and Temporal,
- Members of my Family,
- Distinguished Invited Guests,
- Gentlemen of the Print and Electronic Media,
- Great Students of Osun State University,
- Ladies and Gentlemen.

Preamble

To the glory of God, I feel greatly honoured to be given the opportunity to stand here today to give an account of my research experience, the contributions I have been able to make to advance the frontiers of knowledge as well as my current research efforts. I sincerely appreciate the Vice-Chancellor for this wonderful opportunity. I give gratitude to God for the pioneering grace he keeps bestowing on me in my career.

1) He made it possible for me to be the pioneer (first) staff and de facto Head of Mechanical Engineering Department of the Olabisi Onabanjo University at its Ibogun Campus.
2) By His grace, I was the Head of Mechanical Engineering Department that produced the first set of B.Eng. graduating students and ;
3) the first set of postgraduate students at the Federal University of Agriculture, Abeokuta.

4) The Almighty God allowed me to bag the first PhD degree to be awarded in the Department of Mechanical Engineering of Ladoke Akintola University of Technology (LAUTECH), Ogbomoso.

5) He gave me the grace to be the first staff in the College of Science, Engineering and Technology of Osun State University to be promoted to the rank of Professor.

6) Besides, the Almighty God gave me an epoch-making grace to set the pace as the first alumnus of LAUTECH to become a Professor.

7) He ensured the fulfilment of a rare and unique destiny as the first alumnus of LAUTECH to head a University by my divine appointment as acting Vice-Chancellor of Osun State University in 2015.

BIODIESEL

8) Earlier as Director of Academic Planning, I processed and secured approval of the National Universities Commission for commencement of Postgraduate programmes and as acting Vice-Chancellor, I admitted and matriculated the first set of Postgraduate students of Osun State University.

9) The Almighty God equally ensured that I also make history as the first alumnus of LAUTECH, anywhere in the world, to deliver an Inaugural lecture.

10) This inaugural lecture is the first to be delivered from the Department of Mechanical Engineering as well as the Faculty of Engineering of this unique institution.

It is therefore not a mere coincidence that I have recorded ten **(10)** major pioneering feats as I deliver the **10th** Inaugural Lecture in the history of this great University at God's appointed time; today **21 December,** 2016 when it was exactly **10** years that Osun State University was licensed by the National Universities Commission.

The uniqueness of the date of this Inaugural Lecture is further evident from the fact that

- Mr. Vice-Chancellor and the Chairman of this lecture, Professor Labode Popoola bagged his Ph.D on ***21 December, 1990***.
- Ladies and gentlemen, it may interest you to note that I became an academic staff on ***21 December, 1998!*** - the day I assumed duty as Graduate Assistant at LAUTECH.

This climax is divine; delivering my Inaugural Lecture precisely **18 years** of assumption of duty as an academic staff is a victorious fulfillment of an uncommon and unenviable destiny (*Alhamdulilah*).

The Almighty God couldn't have been more faithful to an orphan like me! I therefore dedicate this Inaugural lecture to my late parent. *"As you both rest in Aljanat fridaous, here is your son in the midst of erudite scholars and eminent personalities, celebrating many firsts."*

Mr. Vice-Chancellor sir, eminent scholars and distinguished audience, energy is an essential factor in the socio-economic development of any nation. Its impact traverses such spheres of human endeavour as agriculture, health, education and transportation amongst others.

Petroleum-based fuels are the major fuel source used in the transportation sector of most of the developing nations. Unfortunately, its combustion generates emissions which are carcinogenic.

These emissions constitute a nuisance to the environment and adversely affect human health. They also lead to climate change due largely to the depletion of the ozone layer. This fact, coupled with global instability in the pump price of petroleum fuel, has redirected research interest to renewable energy resources.

The quest for greener fuels sources thus became a topical issue that has been attracting wide societal and political interests, especially for its reduced greenhouse emissions, biodegradability and sustainability (Marchetti, 2009; Follegati-Romero et al., 2010; Frac et al., 2010; Baroutian et al., 2011; Bolaji et al., 2012; Ezeonu et al., 2012; Hayyan et al., 2013; Sakthivel et al., 2013a,b; Samuel et al., 2013; Elkady et al., 2015).

Modern biofuels are therefore considered promising long-term renewable energy sources with the potential to address both environmental impacts and security concerns posed by current dependence on fossil fuels.

Diesel engines are very common around the world. They are used in the automotive and marine industries as well as for power generation, construction equipment and agriculture. The reliance of these engines on diesel fuel has made countries and communities more dependent on the local and global availability of diesel fuel.

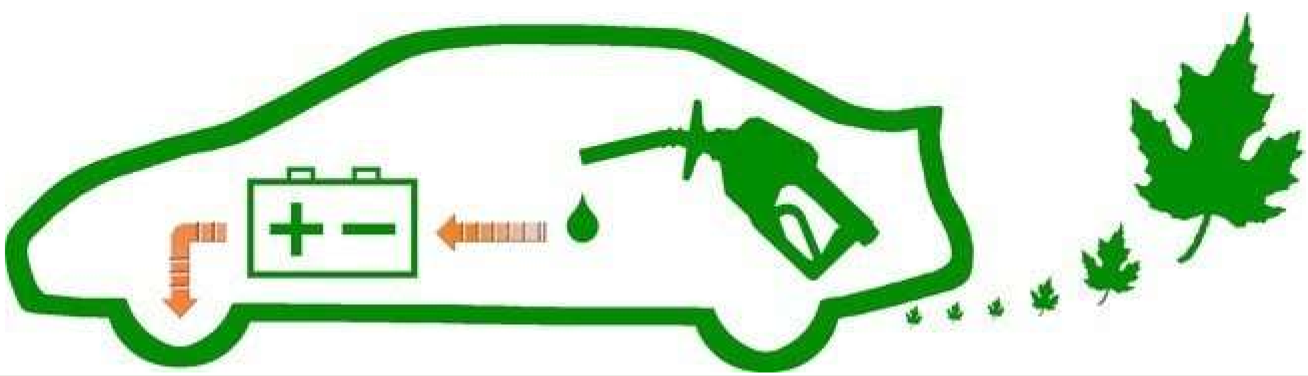
Biodiesel, a renewable liquid biofuel, produced from renewable lipid sources such as vegetable oils and animal fats, offers one of the most promising solutions to the ever-increasing demand of diesel. Energy crops represent the largest potential source of bioenergy feedstocks.

Biodiesel can be produced from different types of plants, thereby giving opportunities for developing countries to contribute to future energy solutions (Alsoudy et al., 2012, Kannan and Anand, 2012).

It is providing a fuel of similar or superior properties to conventional fossil diesel from renewable resources and has been an important research subject in recent times (Moser, 2009; Karabesko et al., 2009; Balat and Balat, 2010; Zhu et al., 2010; Kannan et al., 2011; Mendow et al., 2011; Anastopolous et al., 2011; Hossain et al., 2012; Andualem and Gessesse, 2012; Ingle et al., 2012; Abduh et al., 2013; Ali, 2013; Soni and Agarwa, 2013; Mythili et al., 2014, Sakthivel et al., 2014; Kumar et al., 2015).

As a developing country, Nigeria is not left out in this global area of research (Alamu, 2007a,b; Alamu, 2008a,b; Enweremadu and Alamu, 2010; Ejikeme et al., 2011;

Olutoye and Hammed, 2011; Dairo et al., 2011; Abila, 2012; Aransiola et al., 2012; Agbede et al., 2012; Dairo et al., 2012a,b; Ezeonu et al., 2012; Jimoh et al., 2012; Oniya and Bamgboye, 2012; Samuel and Dairo, 2012; Umaru and Aberuagba, 2012; Adebowale et al., 2013; Agarry et al., 2013; Aworanti et al., 2013; Bamgboye and Oniya, 2013; Dairo et al., 2013; Igbokwe and Obiukwu, 2013; Ishola et al., 2013; Izah and Ohimain, 2013; Onanuga and Coker, 2013; Giwa and Ogunbona, 2014; Ohimain and Chibuezelzah, 2014; Umaru et al., 2014; Zubairu and Ibrahim, 2014; Tadama et al., 2016; Igbokwe and Nwafor, 2016; Giwa et al., 2016).



From the foregoing, ‘sourcing renewable fuel for diesel engines’ needs no further definition of terms. This phrase is the outcome of my search for a succinct description of some of my independent as well as collaborative research efforts on biodiesel from palm kernel oil and a few under-utilized / non-edible oil in Nigeria (Alamu, 2007a,b; Alamu et al., 2007a,b,c,d; Alamu, 2008; Alamu et al., 2008; Alamu et al., 2009a,c; Enweremadu and Alamu, 2010; Alamu, 2011; Dairo et al., 2011; Alamu, 2012; Alamu and Adebisi, 2012; Dairo et al., 2012a,b, 2013; Alamu et al., 2014).

This is synonymous with the description of efforts of researchers on ***Canola*** in Canada, China, India, France, Austria and Germany (as reported in Marchetti, 2009; Owolabi et al., 2012); **Corn** in USA, Mexico, Russia and the United Kingdom (Nisa and Hamzah, 2012; Anastopoulus et al., 2013; Alhassan et al., 2014); ***Soybean*** in USA, Argentina, Brazil, India and China (Kim et al., 2010; Gomes et al., 2011; Pisarello et al., 2014); ***Sunflower*** in Russia, Argentina, France, Italy and Germany (Porte et al., 2010; Sankaranarayanan, 2012; Saba et al., 2016); ***Coconut*** in Malaysia, Vietnam, Mozambique, Bangladesh and Ghana (Sulaiman et al., 2010;

BioDiesel

Hossain et al., 2012); ***Jatropha curcas*** in India, Yemen and Nigeria (Ejilah et al., 2010; Baggash and Abdulrahman, 2010; Highina et al., 2011 & 2012; Umaru and Aberuagba, 2012) and ***Palm oil*** in Malaysia, Indonesia, China, Mexico, Colombia, Nigeria, Cote d'Ivoire and Ghana (Suppalakpanya et al., 2010; Suppalakpanya et al., 2011; Baroutian et al., 2012; Deshpande and Kulkarni, 2012; Shahla et al., 2012a,b; Lee and Ofori-Boateng, 2013a,b; Bakar et al., 2014; Noipin and Kumar, 2014a,b; Wong et al., 2015).

It is my pleasure therefore to address this audience on the topic **"*Sourcing renewable fuel for diesel engines*"**.

1. NARROWING THE FOCUS FROM THERMO-FLUID TO RENEWABLE ENERGY

My major research focus is on Thermo-fluids and Energy studies. These are core areas of Mechanical Engineering research, where I have been able to make a few contributions to knowledge. I conducted research in the areas of heat transfer, engineering economy in pipe flow, simulation of hot rolling of steel, and more prominently in biodiesel potentials of Nigerian palm kernel oil (PKO). In addition, I have been able to advance the frontiers of knowledge on characterization of a few non-edible oil crops as biofuel.

1.1 Thermodynamics and Fluid Mechanics: The Humble Beginning

About eighteen (18) years ago, as a Graduate Assistant at the Ladoke Akintola University of Technology, Ogbomoso, I had a tasking, yet fulfilling training experience as a university teacher and researcher under the indefatigable Professor Emmanuel Babajide Lucas. It appeared frustrating initially carrying chalk and duster, trailing behind *"Baba Lucas"* to lecture theatre and standing in the midst of students, with apprehension, waiting to be called upon to demonstrate a concept of Mechanical Engineering discipline to the students without prior notice or preparation on the subject.

A rather more tasking experience was his idea of asking Graduate Assistants and other new lecturers in the Department to submit research write-up on any engineering problem to him every Tuesday!

1.1.1 Heat Transfer in Materials

Mr. Vice-Chancellor sir, distinguished audience, it was in meeting up with the *"Tuesday"* marching order that I remembered a curious observation I used to make about the clay pot while I was growing up as a kid in ***Ogunajo*** village in Iwoland. There used to be a continuous boiling of water or soup over a period of time after my mother's clay pot had been removed from the local stove. I also remembered the challenges usually faced by local *garri* fryers while using the "fire-clay" stove. The thinner the wall of clay, the more exposed the *garri* fryers were to health hazards associated with excessive heat. I decided to explore the basic principles of Thermodynamics, materials science and economics, to proffer possible solution to a major challenge.

Clay is cheap and characterized by the ability not only to withstand heat but also resistant to chemical attack, abrasion, impact and shock caused by thermal stresses. The thermal conductivity of clay is generally low at the operational temperature of 200^{o}C. The subsequent retention of heat by the pot for considerable period of time affords thermal conditioning of food item. This property prevents food items such as stew from early loss of taste.

In order that the heat loss through the clay pot is reduced, increase in the thickness of the clay can be considered a practical solution. However, increase in the thickness of the clay layer leads to an increased operational cost of the clay pot. A minimum thickness must therefore exist which ensures the required reduction of heat loss to the surrounding and minimizes heating and insulation cost.

a) Insulation Thickness

Since local fire clay pots are modeled in hemispherical configuration, the heat transfer phenomenon associated with the clay pot was therefore analyzed using the thick spherical shell design approach. Mathematical relationships were developed connecting heat transfer in spherical shells with cost analysis of heating and procurement of pot material. The thickness at which the total cost function goes through a minimum was taken as optimum.

The work, which was presented at the 3rd Annual Engineering Conference, Federal University of Technology, Minna, Nigeria (Alamu and Durowoju, 2001) was a numerical analysis and software (written in C++) for determination of economic thickness of local fire-clay cooking pot for functional performance in heat retention at minimum expense on heating and material. Further research on the same subject was recently conducted by other authors (Olatona and Alamu, 2013).

A similar concept had earlier been adopted in solving the problem of clay stove used by local *garri* fryers. Computational solution was also proffered. The output of the computer program developed gave an economic thickness of fire-clay stove to be 0.21m, which was in agreement with results from the calculus approach commonly used to solve similar problems. Results obtained were also found to be in conformity with the Occupational Health and Industrial Safety Regulations Standard.

In spite of this, during an initial review, Professor Lucas tore the manuscript into pieces with his pen, with obvious corrections on every page!

As a Graduate Assistant, I was so excited when the paper was eventually accepted for presentation at a national conference organized by the Department of Mechanical Engineering, University of Uyo, Nigeria (Alamu and Durowoju, 2000). I was glad that in my own little way, I was contributing to local content development in my country.

b) Influence of Thermal Conductivity

Further in this line of research, considering the fact that variation in the refractory properties of different types of clay suggests different design values of fireclay thickness for thermal applications, the influence of thermal conductivity of fireclay on optimum thickness of insulation for a local bread-baking oven was studied. This was accomplished through computer codes developed in FORTRAN. The program was validated through case studies with thermal conductivity of the range 0.03-1.63 W/mK.

Results obtained revealed a general increase in the economic thickness of fireclay with thermal conductivity, especially at low values. The results were further processed leading to a quantitative relationship of the form $k = mX_{opt} + C$ (m= insulation gradient, c = constant). The work was also published locally in Nigeria (Akintaro and Alamu, 2004), after initial rigorous review by my senior colleagues and "*Baba Lucas*".

c) Temperature Distribution Model

My research experience in Heat Transfer was enhanced through my postgraduate programme at the University of Ibadan under distinguished teachers like Professor Peter Olaitan Aiyedun – the former Dean of College of Engineering, Federal University of Agriculture, Abeokuta; Professor Olufemi Bamiro – the former Vice-Chancellor of the University of Ibadan and Professor Babatunde Alabi, the former Vice-Chancellor of the Federal University of Petroleum Resources, Effurun. My first conference paper published outside the shore of this country, Switzerland to be specific, was a collaborative work with Professor P.O. Aiyedun on Thermodynamics of Materials (Alamu *et al.*, 2006; 2009b).

We integrated the Reverse Sandwich Model (RSM) into the Hot Rolling Bland and Ford’s Theory (HRBF) for use in estimating load and torque in steel rolling. From this research, we were able to develop a new model capable of predicting temperature distribution during hot rolling at low strain rates. The model also afforded us the opportunity of predicting the effects of other rolling parameters on temperature distribution during hot rolling of AISI316 stainless steel (Alamu, *et al*., 2006; 2009b; Aiyedun *et al*., 2010; Okediran and Alamu, 2014).

1.1.2 Fluid Flow in Pipes

Mr. Vice-Chancellor sir, the motivation for my research in the area of Fluid Mechanics was through the qualitative mentoring I enjoyed from my teacher Professor Jeremiah Oludele Ojediran, the former Deputy Vice-Chancellor of Ladoke Akintola University of Technology, Ogbomoso and the current Vice-Chancellor of Bells University of Technology, Ota. His undergraduate project at the University of Ibadan, which was supervised by Dr. G.A. Alade in 1979 his Master's thesis at Cranfield Institute of Technology at Silsoe Bedford in the United Kingdom in 1984 and his PhD thesis, supervised by Professor A.Y. Sangodoyin in 1997 were all released to me to explore his research experience in water resources.

Aided by my little computational skills, these materials provided the necessary springboard needed for the fulfilling research experience I had in fluid flow.

a) Optimization of Pipe Diameter for Fluid Flow

As a major mode of bulk conveyance of products, pipelines provide significant savings. This justifies their applications in oil and gas conveyances, industrial and domestic water distribution systems as well as urban drainage and sewage schemes. Besides, modern day irrigation practice uses pipe systems for water conveyance and application. Increase in pipe diameter, for a given set of flow condition, results in an increase in fixed charges for the piping system and a decrease in pumping or blowing cost. Therefore, an optimum pipe diameter must exist.

In collaboration with two other colleagues, the possible effect of fluid density on optimum design of pipes for engineering applications was explored. Equations governing fluid flow in pipelines, developed by researchers, notably, Osborne Reynolds, Darcy-Weisbach, Fanning and Scobey, were integrated into pipeline costing to generate expressions in terms of internal pipe diameter. These were then minimized using computer–aided iterative technique. The computer program, developed in C++ was validated using available case studies. Cases representative of fluids with different densities were also used with a view to evolving a possible relationship between optimum economic pipe diameter for turbulent flow and fluid density.

Results obtained showed that less dense fluids require larger optimum pipe diameter. The work was accepted for publication by a Nigerian university-based Journal (Alamu *et al*., 2003). The breakthrough recorded in this attempt prompted further exploits into the cases of laminar flow problems in pipes (Alamu and Taiwo, 2004) and the development of empirical relationship between optimum pipe diameter and fluid viscosity for streamline flows (Alamu *et al*., 2004). My joy knew no bounds when the latter was also published in a university-based Journal in Nigeria. Specifically, Professor J.O. Ojediran invited me along with a research colleague, Adigun Olusegun Johnwest, to his house and celebrated these publications for me with bottles of "Coke", his favourite "drink"!

b) Fluid Flow Problem in Water-cooled Condenser

Fluid flow problem in a water-cooled condenser was also studied. A steam condenser is a closed vessel, which receives the exhaust steam from the turbine or engine cylinder; it condenses the steam and delivers the condensate to the feed pump. Cooling water from a cooling tower or other sources passes through the condenser tubes and the steam condenses in the outside of the tubes. This equipment is designed primarily to maintain a low pressure so as to increase the expansion ratio of steam thus increase the efficiency of the steam power plant. To achieve this, it is essential that the temperature difference between the inlet vapour and outlet condensate should be as large as possible.

The logarithmic temperature difference depends on the temperature of the water. Increase in the quantity of water will cause a reduction in heat transfer area. This leads to a reduction in investment and fixed charges. However, increase in the quantity of water will lead to a higher cost of water and pumping. An optimum flow rate corresponding to the least total operational cost, therefore, exists. This was determined by Alamu *et al*. (2002). Further research on the same subject was recently conducted in collaboration with other authors (Alamu et al., 2015).

1.2 The Divine Turn to Energy Studies

Mr. Vice-Chancellor sir, eminent scholars and distinguished audience, the passion I developed over the first five years as a young academic in the application of computational skills to some concepts of Heat Transfer and Fluid flow led to the invitation by one of my mentors, a Humboldt scholar, the former Head of Department of Agricultural Engineering and immediate past Director of Academic Planning of Ladoke Akintola University of Technology, Ogbomoso, Professor Simeon O. Jekayinfa. This erudite scholar picked interest in the computer programs in my publications and invited me to a collaborative work on Energy.

The work, which was co-authored with two other researchers and subsequently published by the University of Ibadan, was on simulation of energy requirement for in-store drying of cereal grains in Nigeria (Jekayinfa *et al.*, 2003). Meteorological data were collected from Ilorin and Ikeja, Nigeria, on the monthly mean maximum and minimum dry-bulb temperatures, as well as the average dry-bulb temperature during the coolest 15, 25 and 50 percent of the time, and during the warmest 50 percent of the time. The absolute humidity of the ambient air during these times were estimated from data collected on relative humidity and dew point.

All these data were used in calculating energy requirements for the drying of grain. Also calculated were the power required to pump air through the grain and the periods required for drying. Results from the simulation were in agreement with experimental results.

To further encourage me, Engr. S.O. Jekayinfa enlisted me in the computer program aspect of his PhD thesis on Energy. He subsequently introduced me to energy potentials of some agricultural-based materials. This was the beginning of my voyage to the world of renewable energy. The end to my search for research focus came when on my way to the University of Uyo for a conference organized by the Department of Mechanical Engineering of the institution, in November, 2005, I lost vital PhD research resources on Thermodynamics of materials to the "men of the underworld" along Onitsha-Owerri road. On my safe return, Professor S.O. Jekayinfa and Professor J.O. Ojediran persuaded Professor E.B. Lucas to consider acceding to my wish to continue the pursuit of my PhD on Energy.

I was so delighted when "Baba Lucas", on the telephone, called to sympathize with me over the "Owerri episode" and granted my wish to focus on energy from agricultural sources in my doctoral research.

This was how my doctoral research supervision was transferred from Professor E.B. Lucas to a German-trained Professor of Thermo-fluid and Energy, Professor Muftau Adekojo Waheed (the former Director of Academic Planning and immediate past Deputy Vice-Chancellor [Academic] at the Federal University of Agriculture, Abeokuta). The doctoral thesis, entitled "*Optimal Operating Conditions for the Production of Biodiesel from Palm Kernel Oil*" was examined by a renowned energy expert and former Energy Advisor to the Government of Botswana, Professor Richard 'Layi Fagbenle.

To the glory of the Almighty God, prior final oral examination, the thesis had four manuscripts already accepted for publication by four top-rated high-impact international journals in Fuel and Energy. Two of the articles were published by Elsevier (Alamu et al., 2007b&c), while the other two were published by International Commission of Agricultural Engineering (Alamu, et al., 2007a&d). Another article from the thesis was later published by Taylor and Francis (Alamu et al., 2009c). What a divine turn!

Mr. Vice-Chancellor sir, I seek your kind permission to delve briefly into the world of energy studies with a narrow focus on alternative fuel for diesel engine from agricultural feedstock.

2. THE NEED TO SEEK ALTERNATIVES TO CONVENTIONAL FOSSIL FUEL

Man has always been in need of energy, and continues to use energy at an increasing rate for his sustenance and well-being. Energy can be described as the ability or capability to do work and the use of energy can be seen in every facet of human life, ranging from agriculture, transportation and communication to the production of goods and services. Energy is a resource essential to mankind for various activities and it is an indication of development and prosperity of any nation.

Energy resources have been categorized broadly into conventional and non-conventional energy resources. Conventional energy resources are those energy resources that are finite and non-renewable. Thus they are considered as exhaustible over a long period of time, such include fossil fuels, and coal. Non-conventional energy resources, that is, sun, wind, geothermal and biofuel, are considered renewable and they are sustainable over a relatively longer period of time.

The Energy Commission of Nigeria (ECN) recently observed that Nigeria's fossil fuel-led economy is under severe pressure. In decades to come, the sun will slowly but certainly set on crude oil production. Nigeria currently imports about 80% of its petroleum requirements and has been hit hard by rapidly increasing cost and uncertainty as reported by Alamu et al. (2007a). Interestingly, Nigeria is endowed with significant renewable energy resources including large and small hydroelectric power resources, solar energy, biomass, underutilized and non-edible oil crops, wind and potentials for hydrogen utilization as well as development of geothermal and ocean energy (Akintola and Alamu, 2010; Sulaiman et al., 2016).

From the U.S. Energy Information Administration (USEIA) data reported by Alamu and Adebisi (2014), Nigeria is the largest oil producer in Africa and was the world's fourth (4th) leading exporter of liquefied natural gas (LNG) in 2012. Most of this oil is found in small fields in the coastal areas of the Niger Delta. By the beginning of 2014, available statistical data ranked Nigeria as the 11th largest oil producer in the world with whooping 37.2 billion barrels proven oil reserves. Proved reserves are those quantities of petroleum which, by analysis of geological and engineering data, can be estimated with a high degree of confidence to be commercially recoverable from a given date forward, from known reservoirs and under current economic conditions.

Annual oil production rate for Nigeria was estimated at 2.52 million barrels per day, while domestic consumption stood at 300,000 barrels per day. In addition to its oil wealth, Nigeria has an estimated 182 trillion cubic feet (tcf) of proven natural gas reserves, the 9th largest reserves in the world.

This amazing oil wealth notwithstanding, Nigeria's oil production is hampered by instability, supply disruptions and decreased exploration activity due largely to rising security problems coupled with regulatory uncertainty, while the natural gas sector is restricted by the lack of infrastructure to monetize gas that is currently flared (burned off). Besides, the ECN recently expressed fears over future depletion of this non-renewable resource. Crude oil production in Nigeria began to decline significantly after 2005 as violence from militant groups surged, forcing many companies to withdraw staff and shut down production. Oil production recovered somewhat after 2009/2010 but kept fluctuating till date because of ongoing supply disruptions (Alamu and Adebisi, 2014).

On a global scene, ten (10) major oil fields from the twenty (20) largest world oil producers experienced decline in oil reserves from 2005 up to 2007 (and beyond in some cases). These countries include Saudi Arabia, Iran, Russia, United States, China, Mexico, Brazil, Angola, Indonesia and the United Kingdom (Alamu *et al.*, 2007b). Ten (10) largest losses in world oil reserves between 2000-2007 were recorded in Mexico, China, Norway, Australia, United Kingdom, Saudi Arabia, Columbia, Yemen, Malaysia and Romania. These losses ranged from 0.8-16.0 billion barrels (Alamu, 2009c).

From available records (Table 1), a total of 29 major world oil producing countries experienced declining oil reserves between 2005 and 2007 (Alamu, 2007b). As at the beginning of 2014, countries like Mexico, Norway, Vietnam, Indonesia, Sudan and Italy were still experiencing declining reserves (Alamu and Adebisi, 2014).

Since the instability in the Middle East, international oil prices have been on the increase, the global petroleum market has become volatile and world crude oil supply became grossly characterized by instability.

Few months ago, there was a global drop in oil prices. These fluctuations in the world oil price pose a serious threat to the nation's economic and energy security. Hence the urgent need to seek alternatives.

At present, the fuel used in the transport sector is derived from crude oil after necessary distillation and purification. The major constituents of distilled crude oil are gasoline commonly called petrol, and diesel. While both petrol and diesel are used in internal combustion engines, the former is used in spark ignition (SI) engine vehicles and the latter is used in compression ignition (CI) engine vehicles. These fuels take a long span of time in their formation and are considered a non-renewable source of energy.

Diesel fuel is very important for any economy because it has a wide area of usage. Among these are long haul truck transportation, railroad, agricultural and construction equipment.

With increasing demand for the use of fossil fuels, stronger threat to clean environment is being posed as burning of fossil fuels is associated with emissions like CO_2, CO, SO_2, NO_2 and particulate matter which are currently the dominant global source of emissions (Aworanti et al., 2012). Out of the various modes of transportation, road accounts for 80% of emissions followed by rail and air which are responsible for 13% and 6% emission, respectively (Singh et al., 2011). Combustion of diesel fuel along with lubricating oil results in emission of pollutants such as particulate matter, hydrocarbons, carbon dioxide, carbon monoxide, soot (carbon) and adsorbed heavier hydrocarbon compounds.

Diesel exhaust is considered to be a complex mixture that is carcinogenic to animals and humans. Benzene, toluene, ethylbenzene, and a host of others are well documented carcinogenic compounds and are also emitted from the exhaust of a diesel run CI engine (Singh et al., 2011).

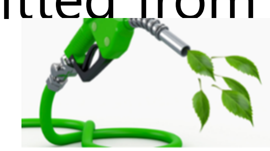


Table 1: World oil producers with experience of declining/fluctuating oil reserves

Country	Oil (billion barrels)		
	Year-end 2005	January 1, 2007	Year-end 2013
Saudi Arabia	264.211	262.300	268.350
Iran	137.490	136.270	157.300
Russia	74.436	60.000	80.000
Kazakhstan	39.620	30.000	30.002
United States	29.922	21.757	26.544
China	16.038	16.000	25.585
Mexico	13.670	12.352	10.264
Norway	9.691	7.849	6.900
Angola	9.035	8.000	10.470
Sudan	6.405	5.000	2.800
India	5.919	5.625	9.043
Oman	5.572	5.500	5.500
Ecuador	5.060	4.517	8.240
Indonesia	4.301	4.300	3.990-4.118
Malaysia	4.200	3.000	5.800
Australia	4.045	1.592	4.158
United Kingdom	3.998	3.875	6.900
Egypt	3.720	3.700	4.500
Vietnam	3.119	0.600	4.400
Syria	3.000	2.500	2.500
Gabon	2.205	2.000	3.700
Congo (Brazzaville)	1.784	1.600	1.940
Equatorial Guinea	1.765	1.100	1.705
Brunei	1.120	1.100	1.200
Peru	1.097	0.930	1.240
Trinidad and Tobago	0.809	0.728	0.830
Italy	0.731	0.600	0.400
Tunisia	0.681	0.400	0.425
Thailand	0.527	0.290	0.442

Source: (EIA data reported in Alamu, 2007b; updated in Alamu and Adebisi, 2014)

Petroleum-based energy sources pose severe threats to man's environment through these hazardous emissions. Industrial and economic development through conventional energy technologies have brought about significant environmental degradation and climate change with severe impact on human and aquatic life. In Nigeria, typical of some other oil-producing countries, water, air, and soil have suffered serious damage from oil spills, especially in the Niger Delta - Nigeria's centre of crude oil extraction. As previously reported (Alamu *et al*. 2007a, Zubairu and Ibrahim, 2014), severe environmental impacts have been ignored in the country's haste to develop the oil industry. This has generated militancy from the local people making successful oil prospecting a nearly impossible task for the multinational companies in Nigeria.

3. POWERING DIESEL ENGINES WITH NEAT VEGETABLE OIL

The depletion of world petroleum reserves, the harmful exhaust emissions from engines, instability in the prices of petroleum products and uncertainties of their supply have created renewed interest among researchers to search for suitable alternative fuels. Possible substitutes to fossil fuels are oils extracted from animal or vegetable sources. The use of vegetable oil in a CI engine was first demonstrated by a German inventor, Rudolph Diesel who used peanut oil in his engine as widely reported in literatures (Alamu, 2007; Alamu et al., 2010; Hossain et al., 2012; Owolabi et al., 2012; Mythili et al., 2014).

Developed in the 1890s, the diesel engine has become the engine of choice for power, reliability, and high fuel economy worldwide.

Fig.1: (a) Modern diesel engine (b) exploded cylinder view (c) basic components

Diesel engine was developed out of a desire to improve upon inefficient, cumbersome and sometimes dangerous steam engines of the late 1800s. It works on the principle of compression ignition, in which fuel is injected into the engine's cylinder after air has been compressed to a high pressure and temperature. As the fuel enters the cylinder it self-ignites and burns rapidly, forcing the piston back down and converting the chemical energy in the fuel into mechanical energy.

Rudolph Diesel understood thermodynamics and the theoretical and practical constraints on fuel efficiency. He knew that as much as 90% of the energy available in the fuel is wasted in a steam engine. His work in engine design was therefore driven by the goal of much higher efficiency ratios.

After experimenting with a Carnot Cycle engine, he developed his own approach. In his engine, fuel was injected at the end of compression and the fuel was ignited by the high temperature resulting from compression. Rudolf Diesel, for which the engine is named, obtained patents for his design in Germany and other countries, including the U.S. (U.S. Patent 542,846 and U.S. Patent 608,845) (Aworanti et al., 2012; Alamu and Adebisi, 2014; Mythili et al., 2014).

Biodiesel

The early diesel engines had complex injection systems and were designed to run on a variety of fuels. The first public demonstration of vegetable oil based diesel fuel was at the 1900 World's Fair, when the French government commissioned the Otto company to build a diesel engine to run on peanut oil (Hossain et al., 2012; Owolabi et al., 2012). Rudolph Diesel later did extensive work on vegetable oil fuels and became a leading proponent of such a concept, believing that farmers could benefit from providing their own fuel.

Diesel was a visionary who believed his highly efficient engine could help disassemble the monopolized energy and power industries.

He envisioned that pure vegetable oils could power early diesel engines for agriculture in remote areas of the world, where petroleum was not available at the time. Unfortunately for Diesel, due to the low cost of mineral oils at the time, the diesel engine was modified to run on petroleum oil. Biodiesel technology was overlooked while the demand for crude oil increased significantly as the automotive and industrial age ensued.

Fig.2: Modern diesel engine applications

It had been reported (Owolabi et al., 2012; Alamu and Adebisi, 2014) that Rudolf Diesel was well aware that renewable fuel would not be of major relevance during his lifetime when he said, "*The use of vegetable oils for engine fuel may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time.*" Not everyone shared his vision at that time as it took almost a century before his vision became a widespread reality. Sadly, this genius mysteriously disappeared and died in 1913. Shortly after Diesel's death, petroleum became widely available in a variety of forms, including the class of fuel we know today as "diesel fuel". With petroleum being available and cheap, the diesel engine design was changed to match the properties of petroleum diesel fuel.

As a result, vegetable oil-based fuels gained little attention, except in times of high oil prices and shortages.

The Second World War and the oil crises of the 1970s saw brief interest in using vegetable oils to fuel diesel engines. Unfortunately, the newer diesel engine designs could not run on traditional vegetable oils due to the much higher viscosity of vegetable oil compared to petroleum diesel fuel - leading to injector coking to such an extent that fuel atomization does not occur properly or is even prevented, decrease in power output and thermal efficiency of the engines; another consequence was carbon deposits and oil ring sticking - thickening or gelling of the lubricating oil as a result of contamination by vegetable oils.

There was therefore the need to lower the viscosity of vegetable oils. Many methods have been proposed to perform this task, including pyrolysis, blending with solvents, and emulsifying the fuel with water or alcohols. It was a Belgian inventor in 1937 who first proposed using transesterification to convert vegetable oils into fatty acid alkyl esters and use them as a diesel fuel replacement (Jimoh et al., 2012). The process of transesterification converts vegetable oil into three smaller molecules which are much less viscous and easy to burn in a diesel engine.

The transesterification reaction is the basis for the production of modern biodiesel, which is the trade name for fatty acid methyl esters.

4. BIODIESEL PRODUCTION FOR DIESEL ENGINES

In the early 1980s, concerns over the environment, energy security, and agricultural overproduction once again brought the use of vegetable oils to the forefront, this time with transesterification as the preferred method of producing such fuel replacements. Biodiesel, simply defined as the mono-alkyl esters of fatty acids, is an environmentally attractive alternative to conventional petroleum diesel fuel. It is derived from different sources, including vegetable oils, animal fats, used frying oils as well as soapstocks. It has many important technical advantages over conventional diesel, such as inherent lubricity, low toxicity, derivation from a renewable and domestic feedstock, safe handling due to superior flash point, biodegradability, negligible sulfur content, and lower exhaust emissions. Typical biodiesel produces about 65% less net carbon monoxide, 78% less carbon dioxide, 90% less sulphur dioxide and 50% less unburnt hydrocarbon emission.

(Alamu et al., 2008; Karabesko et al., 2009; Alamsya et al., 2010; Suppalakpanya et al., 2011; Hossain et al., 2012; Agarry et al., 2013; Umaru et al., 2014; Viele et al., 2014; Zubairu and Ibrahim, 2014). It is characterized by higher cetane rating, which can improve performance and clean up emissions.

Biodiesel production enjoys a positive social impact by enhancing rural revitalization. Increasing the use of biofuel could also lead to improved economic development and poverty alleviation, especially in rural areas, since it attracts investment in new jobs and business opportunities for small- and medium-sized enterprises in the fields of production, transportation, trade and use. Biodiesel can be used in its pure form (B100) or may be blended with petroleum diesel in modern diesel engines.

Biodiesel fuel blends reduce particulate matter, hydrocarbon, carbon monoxide and sulphur oxides. However, NO*x* emissions are slightly increased depending on biodiesel concentration in the fuel. The use of biodiesel will complement the necessary balance among agriculture, engineering and technology, economic development and environmental protection (Alamu et al., 2007c; Moser, 2009; Mumtaz et al., 2012; Igbokwe and Nwafor, 2016).

Important disadvantages of biodiesel however include high feedstock cost (feedstock cost comprises a substantial portion of overall biodiesel cost), inferior storage and oxidative stability, lower volumetric energy content and inferior low-temperature operability amongst others (Moser, 2009).

4.1 Transesterification Process

The transesterification process of producing biodiesel involves a combination of alcohol, oil and catalyst in an agitated reactor/plant. Smaller plants often use batch mode reactors, but larger plants use continuous flow processes involving continuous stirred-tank reactors or plug flow reactors (Alamsyah et al., 2010; Baroutian et al., 2012; Santori et al., 2012).

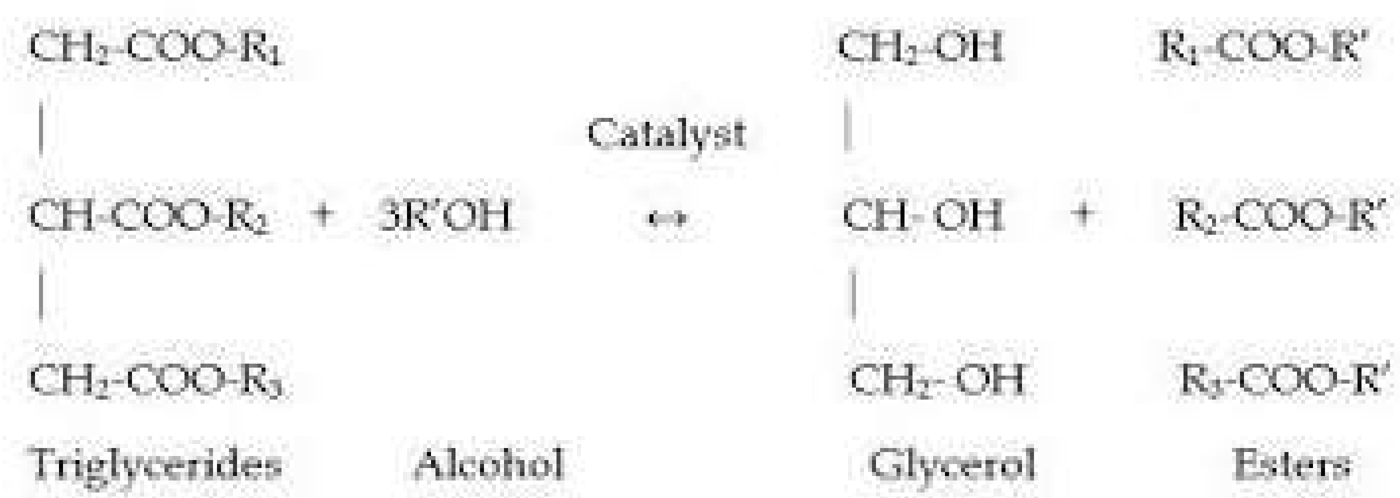


Fig.3: Transesterification reaction

By the stoichiometry of the transesterification reaction, 1 mol of the vegetable oil is required to react with 3 moles of alcohol to produce 3 moles of the biodiesel and 1 mole of glycerol. It is required that reaction temperature must be below the boiling point of alcohol used. Reaction time for biodiesel production ranges from less than 30 min. to more than 2 hours, while most researchers have used 0.1 to 1.2 % concentration of catalyst (wt% oil) as reported in Alamu (2007a,b).

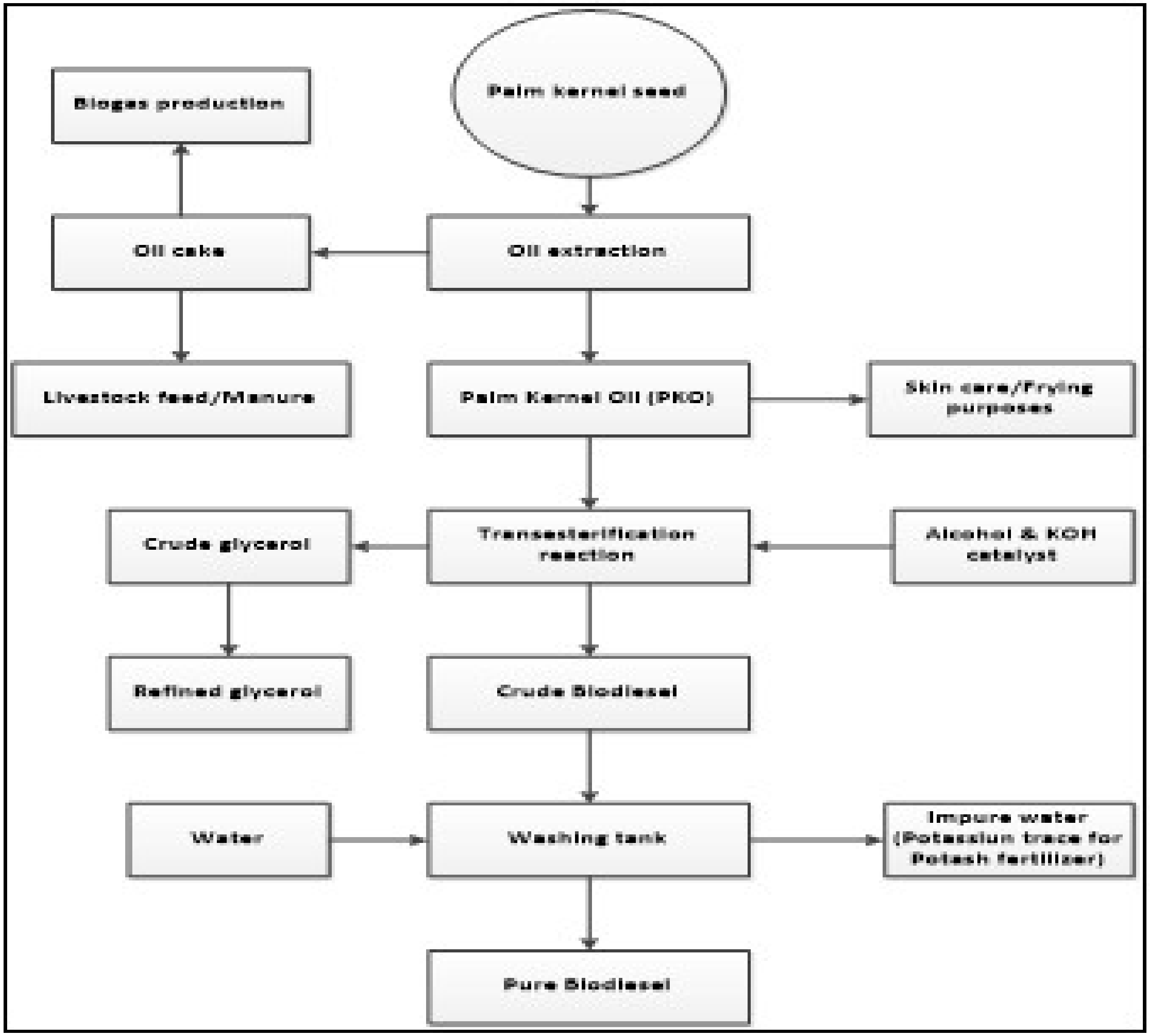


Fig.4: Process flow chart for biodiesel production from palm-kernel Oil

4.1.1 Alcohols used in the Production of Biodiesel

Methanol is the most common alcohol used in the production of biodiesel (Eze and Ejilah, 2010; Enweremadu and Alamu, 2010; Anand et al., 2010a,b; Baroutian et al., 2012; Samuel et al., 2013; Igbokwe and Obiukwu, 2013; Pisarello et al., 2014; Thliveros et al., 2014). Other alcohols such as ethanol (Alamu et al., 2007c,2008; Alamsya et al., 2010; Kuwornoo and Ahiekpor, 2010; Mendow et al., 2011; Stamenkovic et al., 2011; Abduh et al., 2013; Noipin and Kumar, 2014a; Ngamprasertsith et al., 2014), propanol, iso-propanol, and butanol (Alsoudy et al., 2012) have also been used. Ethanol is of particular interest primarily because it is less expensive than methanol in some regions of the world, and biodiesel prepared from bio-ethanol is completely bio-based (Karabesko et al., 2009; Moser, 2009; Brunschwig et al., 2012; Adeleke et al., 2012,2013a).

4.1.2 Catalysts for Biodiesel Production

A wide range of catalysts may be used for biodiesel production, such as homogenous and heterogeneous acids and bases, sugars, lipases, ion exchange resins, zeolites, and other heterogeneous materials. Biodiesel is produced commercially using homogenous alkali catalysts such as sodium (or potassium) hydroxide or methoxide because the transesterification reaction is generally faster, less expensive, involves lower temperatures and pressures, and is less corrosive to industrial equipment than acid-catalyzed methods. Therefore, less capital and operating costs are incurred for biodiesel production facilities.

However, the homogenous acid-catalyzed reaction holds an important advantage over the base-catalyzed method in that the performance of acid catalysts is not adversely influenced by the presence of FFA (Moser, 2009; Zabeti et al., 2009; Chen et al., 2011; Ehsana and Chowdhurya, 2015). The use of heterogenous catalysts has also been reported (Olutoye and Hameed, 2011; Singh et al., 2011, Ling et al., 2014; Wong et al., 2014; Khanahmadi et al., 2016).

In the last few years, studies of the enzymatic catalysed production of biodiesel have shown significant progress (Sivasamy et al., 2009; Amos et al., 2016). As reported by Agarry et al. (2013), the main problem of enzyme catalyzed process is the high cost of the lipases (enzyme) used as catalyst.

4.2 Biodiesel Feedstock

In general, there are four major biodiesel feedstock categories: oilseeds, animal fats, algae and various low-value materials such as used cooking oils, greases, and soapstocks.

4.2.1 Oilseeds

The use of oils from coconut, soybean, sunflower, safflower, peanut, linseed, rapeseed/canola, corn, cottonseed, peanut and palm oil amongst others has been attempted for production of biodiesel (Suppalakpanya, 2009; Kim et al., 2010; Raman et al., 2010; Gomes et al., 2011; Aworanti et al., 2012; Baroutian et al., 2012; Deshpande and Kulkarmi, 2012; Hossain et al., 2012; Roekngam, 2012; Sankaranarayanan, 2012; Lee and Ofori-Boateng, 2013a,b; Lima et al., 2013; Bakar et al., 2014; Noipin and Kumar. 2014a; Porte et al., 2014; Rajaeifar, et al., 2014; Santos et al., 2014; Viele et al., 2014; Saba et al., 2016).

These amongst others were the traditional oilseed feedstocks for biodiesel production. Castor oil (Dairo et al., 2011,2012a,b; Olawuni and Adejumobi, 2014), groundnut oil (Eijilah and Asere, 2008; Ibeto et al., 2011; Oniya and Bamgboye, 2014), palm kernel oil (Alamu, 2007a,b; Musa, 2009; Kuwornoo and Ahiekpor, 2010), shea-butter (Eze and Ejilah, 2010; Enweremadu et al., 2011a,b), desert date seed oil (Akaagerger et al., 2016), grape seed, maize, camelina, pumpkin seed, beechnut, lupin, pea, poppyseed, hemp, chestnut, olive and a few less common oils such as babassu, and crude raisin seed oil and non-vegetable sources such as industrial tallow and fish oils have also been studied by different researchers (Moser, 2011; Eze, 2012; Iko and Eze, 2012; Jimoh et al., 2012; Sakthivel et al., 2013a,b; Majeed et al., 2014; Sharma et al., 2014b; Hemanandh and Narayanan, 2015)

Fig.5: Oil palm (a) plantation (b) fruit-bearing plant (c) fruit

Alternative feedstocks normally arise out of necessity from regions of the world where the above materials are not locally available or as part of a concerted effort to reduce dependence on imported petroleum. For instance, non-edible *Jatropha curcas* oil has recently attracted considerable interest as a feedstock for biodiesel production in India and other climatically similar regions of the world (Baggash and Abdulrahman, 2010; Ejilah et al., 2010; Highina et al., 2011; Olutoye and Hammed, 2011; Abdel-fatah et al., 2012; Aransiola et al., 2012; Umaru and Aberuagba, 2012; Abduh et al., 2013; Kumar et al., 2015).

Fig.6: Jatropha curcas (a) plant (b) fruit (c) seed

The continued drive for energy sustainability and independence globally, governmental mandates for alternative fuel usage and increased global production capacity necessitated the need for alternative sources of biodiesel fuel. For instance, production capacity in the 27 European Union countries in 2008 was estimated by the European Biodiesel Board to be 4.8 billion gallons per year versus 1.4 billion gallons per year in 2006 (Moser, 2009).

Moser (2009) presented a number of desirable characteristics of alternative oilseed feedstocks for biodiesel production to include adaptability to local growing conditions, regional availability, high oil content, favorable fatty acid composition, compatibility with existing farm infrastructure, low agricultural inputs, definable growth season, uniform seed maturation rates, potential markets for agricultural by-products, and the ability to grow in agriculturally undesirable lands and/or in the off-season from conventional commodity crops.

According to Hanks (2012), biodiesel fuels prepared from feedstock that meet at least a majority of the above criteria will hold the most promise as alternatives to conventional diesel.

Other alternative non-edible feedstock include *M. ferruginea* (Brebra seed), *Pongamia pinnata* (Karanja or Honge), *Madhuca indica, Melia azedarach, Moringa oleifera, Nicotiana tabacum, Balanites aegyptiaca, Terminalia catappa* (Indian Almond nut), *Hevea brasiliensis, Asclepias syiaca, Zanthoxylum bungeanum, Rice bran, Raphanus sativus, Brassica carinatac, Calophyllum inophyllum, Cynara cardunculus, Camelina sativa, Carthamus tinctorius, Sesamum indicum, Vernicia fordii, Sclerocarya birrea and Cucurbita pepo, Mangifera indica* (Mango), *Chrysophyllum albidum* (African star apple), *Schleichera oleosa* L oil, *Adansonia digitata L* (Baobab Seed Kernel) Oil (Moser, 2009; Alang et al., 2011; Singh et al., 2011; Agbede et al., 2012; Andualem and Gessesse, 2012; Barku et al., 2012; Betiku et al., 2014; Mumtaz et al., 2012; Silitonga et al., 2015).

4.2.2 Animal fats

Animal fats may include materials from a variety of domesticated animals, such as cows, chickens, pigs, and other animals such as fish and insects. Animal fats are normally characterized by a greater percentage of saturated fatty acids in comparison to oils obtained from plants. Animal fats are generally considered as waste products, so they are normally less expensive than commodity vegetable oils, which makes them attractive as feedstocks for biodiesel production. Biodiesel has been prepared from animal fats such as salmon, melon bug, sorghum bug, pork lard, fish oil, beef tallow and chicken fat (Sakthivel and Nagarajan, 2011; Fadhil et al., 2012; Fadhil and Ali, 2013a,b; Ejikeme et al., 2013; Sharma et al., 2014a; Sakthivel et al., 2014; Didar, 2015).

4.2.3 Other waste oils

Waste oils may include a variety of low- value materials such as used cooking or frying oils, vegetable oil soapstocks, acid oils, tall oil, and other waste materials. Used or waste frying or cooking oil is primarily obtained from the restaurant industry and is less expensive than commodity vegetable oils. These materials have successfully been used to produce biodiesel as reported by Anand et al. (2010a,b), Moghaddam et al. (2010), Enweremadu and Rutto (2010), Anastopoulus et al. (2011), Alsoudy et al. (2012), Abd Rabu et al. (2013), Aworanti et al. (2013), Gnanaprakasam et al. (2013), Naima and Liazid (2013), Samuel et al. (2013), Majeed et al. (2014), Sarantopoulos et al. (2014) and Ehsana and Chowdhurya (2015) amongst others.

4.3 Case for Palm Kernel Oil as Biodiesel Feedstock

Common vegetable oils in Nigeria include palm oil, palm kernel oil (PKO), peanuts, cottonseed and soybean. Nigeria is the largest producer of oil palm in Africa and the fifth largest in the world with 850 metric tonnes of palm oil over the past three years and forecast for the next two years have shown that the Nigerian oil palm sector is stagnated unlike Malaysia, Indonesia, Thailand and Columbia as reported by Izah and Ohimain (2013). PKO production in Nigeria rose from 272,000 tons in 2004 and 2005 to 275,000 tons in 2006. Industrial underutilization of this commodity had also been reported (Alamu et al., 2007d) as only 86,000 out of 275,000 tons produced in 2006 was utilized for industrial consumption.

Its industrial use has however been limited to soap, detergent, baker's fat and margarine. Soap manufacturers in the country are, even, increasingly turning to imported tallow. Successful reports on transesterification of some Nigerian lauric oils in the preparation of biodiesel is an indication of better industrial utilization of PKO in Nigeria, as considerable research efforts are now focusing on this alternative diesel fuel worldwide (Alamu, 2007a,b; Musa, 2009; Kuwornoo and Ahiekpor, 2010; Nisa and Hamzah, 2012; Igbokwe and Obiukwu, 2013; Onanuga and Coker, 2013; Izah and Ohimain, 2013; Ohimain and ChibuezeIzah, 2014; Bejan et al., 2014; Viele et al., 2014; Igbokwe and Nwafor, 2016).

Fig.7: (a) Oil Palm seed, (b) Palm kernel and (c) Palm kernel oil

It has been reported that oil palm is a major staple item in Nigeria and its use for biodiesel production could trigger food versus fuel conflicts. To stem the tide of food/fuel use controversy over some under-utilized but edible oil crop such as palm kernel oil, a number of recommendations have been reported in the literature, one of which is aggressive oil crop plantation, specifically for biofuel use (Ezeonu et al., 2012; Izah and Ohimain, 2013). This will go a long way in the successful implementation of Nigerian Biofuel Policy.

Fig.8: Oil palm plantation can be specifically established for fuel use

4.3.1 Nigerian Biofuel Policy

The Nigerian government released the Nigerian Biofuel Policy and incentives in 2007, which mandated the Nigerian National Petroleum Corporation (NNPC) to receive and blend 20% of biodiesel into the petro-diesel fuel sold in Nigeria (B20). As reported by Izah and Ohimain (2013), the policy created an immediate demand of 480 million litres of biodiesel per year, which could increase to 900 million litres in 2020. The policy mandated the NNPC to purchase all biodiesel produced in Nigeria. The aim of the policy is to link the agricultural sector with the petroleum sector in order to boost the agricultural and rural sectors. Incentives included in the policy for emerging biofuel companies include waivers (VAT, withholding and import duty), loans and insurance coverage.

4.4 Influence of Biodiesel Composition on Fuel Properties

The fatty ester composition, along with the presence of contaminants and minor components, dictates the fuel properties of biodiesel. Such properties include low-temperature operability, oxidative and storage stability, kinematic viscosity, exhaust emissions, cetane number, and energy content (Moser, 2009). The fatty acid profile of palm kernel oil, the principal feedstock used by Alamu (2007a) in his biodiesel research is presented in Table 2.

Table 2: Fatty acid profile of PKO

Type of fatty acid	Percentage
Lauric (C12:0)	48.2
Myristic (C14:0)	16.2
Palmitic (C16:0)	8.4
Capric (C10:0)	3.4
Caprylic (C8:0)	3.3
Stearic (C18:0)	2.5
Oleic (C18:1)	15.3
Linoleic (C18:2)	2.3
Others (unknown)	0.4

4.5 Factors affecting Biodiesel Production

Production of biodiesel through transesterification is influenced by factors such as molar ratio of alcohol, catalyst concentration, reaction temperature, reaction time, agitation speed, water and FFA content. This has been widely reported for different feedstocks (Alamu, 2007a; Anand et al., 2010a,b; Kuwornoo and Ahiekpor, 2010; Ayuk et al., 2011; Mathiyazhagan and Ganapathi, 2011; Enweremadu et al., 2011a; Dairo et al., 2011,2012a,b; Alsoudy et al., 2012; Abd Rabu et al., 2013; Aworanti et al., 2013; Noipin and Kumar, 2014b; Wong et al., 2015; Betiku et al., 2015; Verma et al., 2016).

5. CONTRIBUTIONS TO KNOWLEDGE ON BIODIESEL

Mr. Vice-Chancellor sir, in my exploits on Thermo-fluid and Energy studies. I have made a few contributions to knowledge in the area of engineering economy in heat transfer, pipe flow and simulation of hot rolling of materials, as earlier highlighted. My prominent focus on energy studies is in biodiesel potentials of Nigerian palm kernel oil (PKO) and characterization of a few non-edible oil crops as biofuel. To the glory of God, I have been able to advance the frontiers of knowledge in a little but impactful manner on biodiesel research, evident from modest scholarly publications, one of which has already earned enviable global ranking from Sciencedirect - Elsevier.

5.1 Alkali-catalysed Production of Biodiesel

(a) KOH Catalysed Biodiesel Production

Laboratory scale quantities of PKO biodiesel were produced through transesterification process using 100g PKO, 20.0% ethanol (wt% PKO), 1.0% potassium hydroxide (KOH) catalyst at $60^{o}C$ reaction temperature and 90 min. reaction time. Instrumentation and experimental procedures adopted has been reported in Alamu (2007a). The procedure, which involves transesterification, separation and washing was replicated severally and average biodiesel yield as well as glycerol yields were measured.

(b) NaOH Catalysed Biodiesel Production

Palm kernel oil biodiesel was also produced at the laboratory scale through transesterification of PKO with ethanol using sodium hydroxide (NaOH) catalyst. The transesterification process, using 100g PKO, 20.0% ethanol (wt% PKO), 1.0% NaOH, 60^{o}C reaction temperature and 90 min. reaction time, yielded average 95.8% PKO biodiesel for several replications (Alamu et al., 2008). Effect of NaOH concentration on yield of palm kernel oil biodiesel was later established by Alamu and Adebisi (2012).

5.2 Characterization of PKO Biodiesel as Fuel and Comparison with Petroleum Diesel and Biodiesel from other Oil Crops

Fuels are generally characterized through tests for properties such as specific gravity, viscosity, pour point and cloud point. Others include flash point, heat of combustion, boiling point and cetane number, to mention a few. Specific gravity has been described as one of the basic and most important properties of fuels because some important performance indicators are correlated with it. It has also been reported to be connected with fuel storage and transportation. Viscosity, the measurement of the internal flow resistance of a liquid, constitutes an intrinsic property of vegetable oils.

It is of remarkable influence in the mechanism of atomization of the fuel spray. Pour point is the temperature at which wax becomes visible when the fuel is cooled. It has been described as an important parameter for low temperature operation of a fuel. Pour point is the temperature at which the amount of wax out of solution is sufficient to gel the fuel. Thus, it is the lowest temperature at which the fuel can flow. Cloud point is another important parameter for low temperature operation of a fuel. It is the temperature at which solidification of heavier components of the fuel resulting in a cloud of crystals within the body of the fuel first appeared.

In assessing the suitability of the biodiesel produced as alternative diesel fuel, the PKO biodiesel and the commercial grade fossil diesel, were analyzed for basic fuel properties such as specific gravity at reference 60^{O}F, viscosity at 40^{O}C, pour point, cloud point and flash point following ASTM standard test procedures. Specific gravity and viscosity measurements were made using the Thermal-Hydrometer apparatus and Viscometer, following ASTM standards D1298 and D445 respectively.

The biodiesel was analyzed for cloud point and pour point using Baskeyl cloud and pour point apparatus following ASTM standards D25100-8 and D97 respectively, while flash point was determined using Pensky-Martens flash point closed-cup apparatus. Boiling point and heat of combustion of the biodiesel were also determined. Detailed procedures and sources of instrumentation for these tests have been reported (Alamu, 2007a,b,2008b, Alamu et al., 2009c). Results obtained are presented in Table 3 (Alamu et al., 2007d).

Table 3. Measured PKO biodiesel and fossil diesel fuel properties

Fuel Characteristics (Properties)	Values (PKO biodiesel)	(Petroleum diesel)
Pour point (^0C)	2	-16
Cloud point (^0C)	6	-12
Flash Point (^0C)	167	74
Boiling Point (^0C)	320	191
Gross heat of combustion (MJ/kg)	40.56	45.43
Net heat of combustion (MJ/kg)	37.25	42.91
Specific gravity (at 15.56^0C)	0.883	0.853
Viscosity (at 40^0C) (mm^2/s)	4.839	2.847

5.2.1 Specific Gravity for PKO Biodiesel Fuel

In agreement with earlier observations made by several authors as reported by Alamu et al. (2007a, b, c & d) the specific gravity recorded for the PKO biodiesel was higher than the values obtained for the fossil diesel. Compared to other ethanol-based biodiesel from other oil crops such as rapeseed methyl ester (RME), rapeseed ethyl ester (REE), canola methyl ester (CME), canola ethyl ester (CEE), beef tallow methyl ester (TME), beef tallow ethyl ester (TEE), soybean methyl ester (SME), soybean ethyl ester (SEE), and midwest biofuel methyl soyate (MWF), specific gravity of PKO biodiesel obtained for palm kernel oil ethyl ester (PKOEE) is in good agreement; minimum and maximum deviation being 0.227% and 0.79%. This comparison is illustrated in Figure 9.

Besides, the specific gravity obtained for the PKO biodiesel was found to be within the limit specified for biodiesel fuel in Europe (EN14214: 0.86-0.90), Austria (ONC1191: 0.85-0.89), Czech Republic (CSN656507: 0.87-0.89), Germany (DINV51606: 0.875-0.90), Sweden (SS155436: 0.87-0.90) and Italy (UNI10635: 0.86-0.90) (Alamu et al., 2007d). The level of agreement recorded in specific gravity for the PKO biodiesel is an important pointer to suitability of the biodiesel as diesel fuel substitute as important fuel performance indicators such as cetane number, heating values, fuel storage and transportation are correlated with specific gravity (Alamu et al., 2007d).

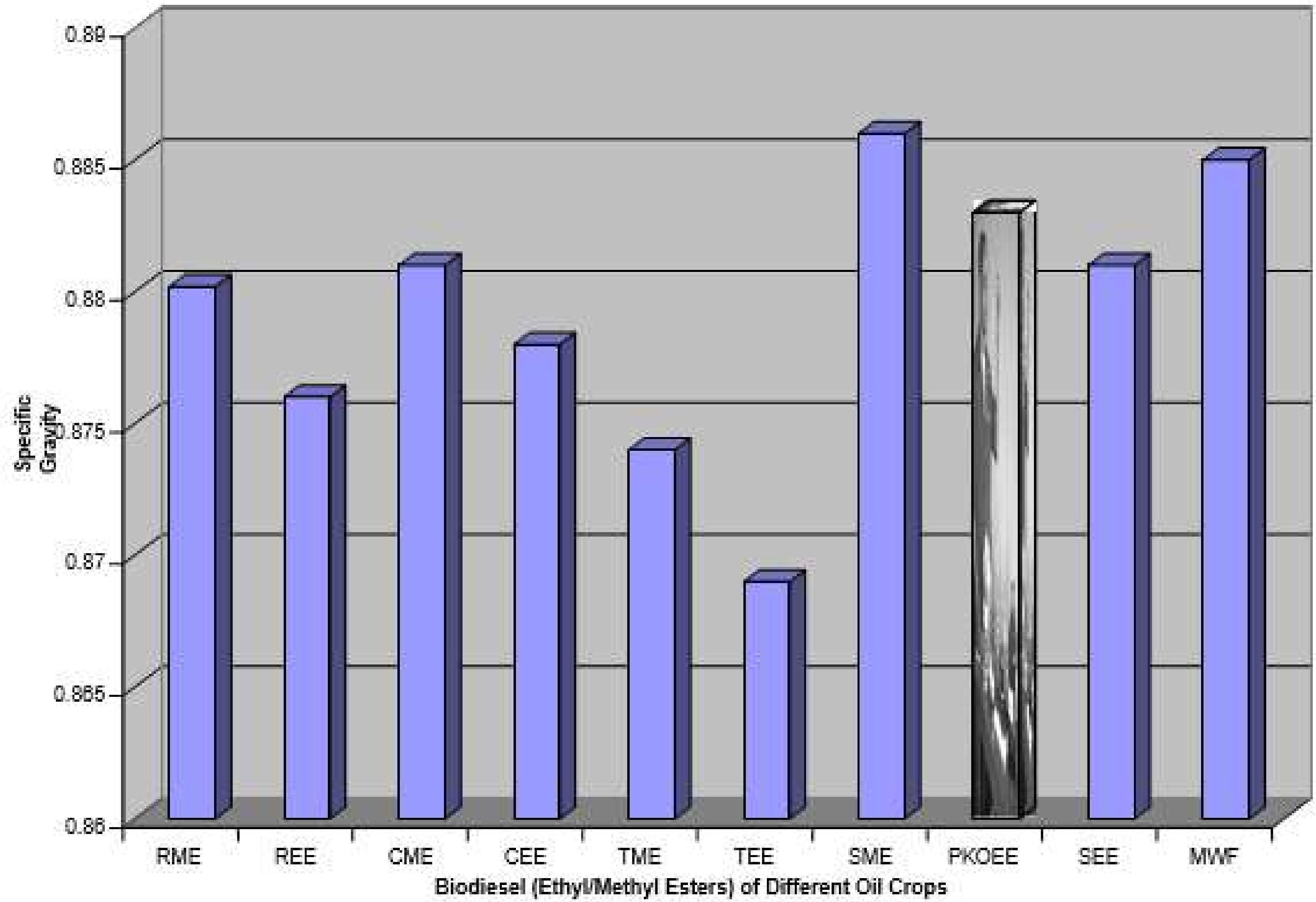


Fig.9: Comparison of Specific Gravity of PKO Biodiesel with other Biodiesel Fuel at 15.56°C

Specific Gravity-Temperature Correlation for PKO Biodiesel

Alamu (2011) obtained linear relationship between specific gravity and temperature for the PKO biodiesel. For the purpose of comparison, a similar correlation was obtained for commercial grade petroleum diesel. These are respectively presented as equations (1) and (2) from Fig.10.

$$SG_{EEPKO} = -0.0007T + 0.8939 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$SG_{Pet.Diesel} = -0.0006T + 0.8633 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

(where *SG* denotes the specific gravity, *T* is the temperature in °C, and *m* and *b* are correlation constants; Regression coefficient R^2 are respectively 0.9994 and 0.9993 for equations (1) and (2) as reported in Alamu (2011)).

Subsequently, comparison and improvement of predictive models on density of biodiesel and its mixtures were reported by Garcia et al. (2013). Further on this, Talavera-Prieto et al. (2015) later worked on correlation and prediction of biodiesel density for extended ranges of temperature and pressure.

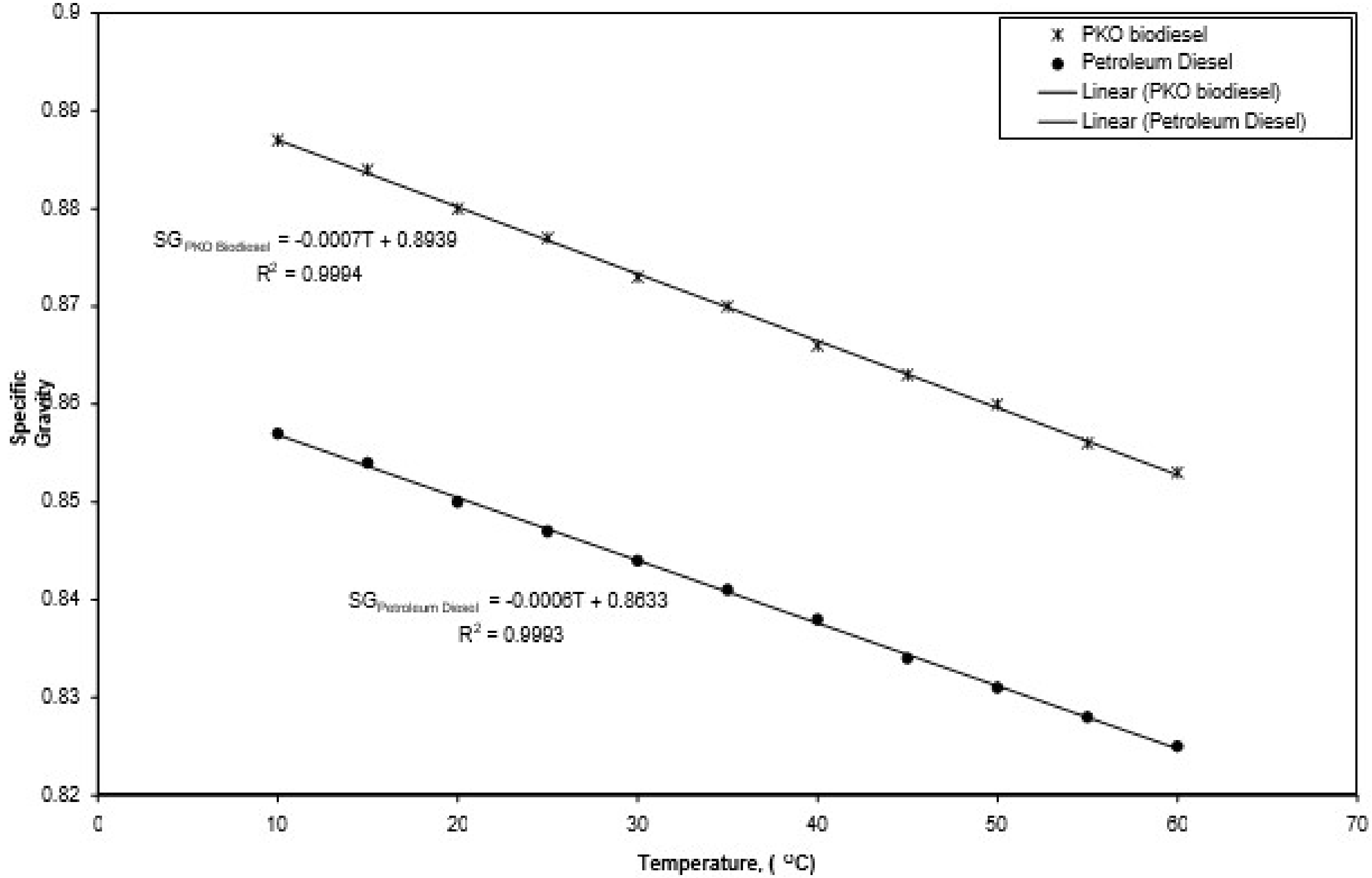


Fig. 10: Variation of Specific Gravity with Temperature for PKO biodiesel and Petroleum Diesel

5.2.2 Viscosity of PKO Biodiesel Fuel

Esterification of PKO produced a marked decrease in values of viscosity from the reported range 30-50 mm^2/s for vegetable oils at $40^{O}C$ to 4.839mm^2/s for PKO biodiesel at the same temperature. With this value of viscosity, it implies that a reduction of about 85% viscosity has been achieved in the PKO fuel. This appreciable reduction in viscosity, no doubt, will enhance the fluidity of this alternative fuel in diesel engine.

However, from Table 3, PKO biodiesel has higher viscosity than conventional diesel fuel in agreement with reports from several researchers who conducted similar investigation on the same feedstock after results from Alamu (2007a,b) and Alamu et al. (2007a,b,c,d) appeared in print (Kuwornoo and Ahiekpor, 2010;

Nisa and Hamzah, 2012; Igbokwe and Obiukwu, 2013; Bejan et al., 2014; Igbokwe and Nwafor, 2016; Viele et al., 2014). The PKO biodiesel viscosity of 4.839 mm^2/s obtained is almost twice the viscosity of the fossil diesel as found also in alcohol esters of rapeseed, canola, beef tallow and soybean (Kim et al., 2010; Gomes et al., 2011; Aworanti et al., 2012; Pisarello et al., 2014; Rajaeifa et al., 2014). The value also falls within the specified limits by ASTM D6751, ASTM D975 and BIS (India) standards. The reported technical implication of higher viscosity of biodiesel is that it decreases the leakages of fuel in a plunger pair (Alamu et al., 2007d)

Viscosity-Temperature Correlation for PKO Biodiesel

As evident from Fig.11, viscosity of the PKO biodiesel, as well as that of the conventional petroleum diesel falls as temperature increases. Alamu (2007a,b) established a correlation between viscosity of PKO biodiesel and temperature (as shown in the regression equation (3) with R^2 = 0.9974)

$$\mu_{PKObiodiesel} = 6.4592\, e^{-0.0075T} \quad \text{..................} \quad (3)$$

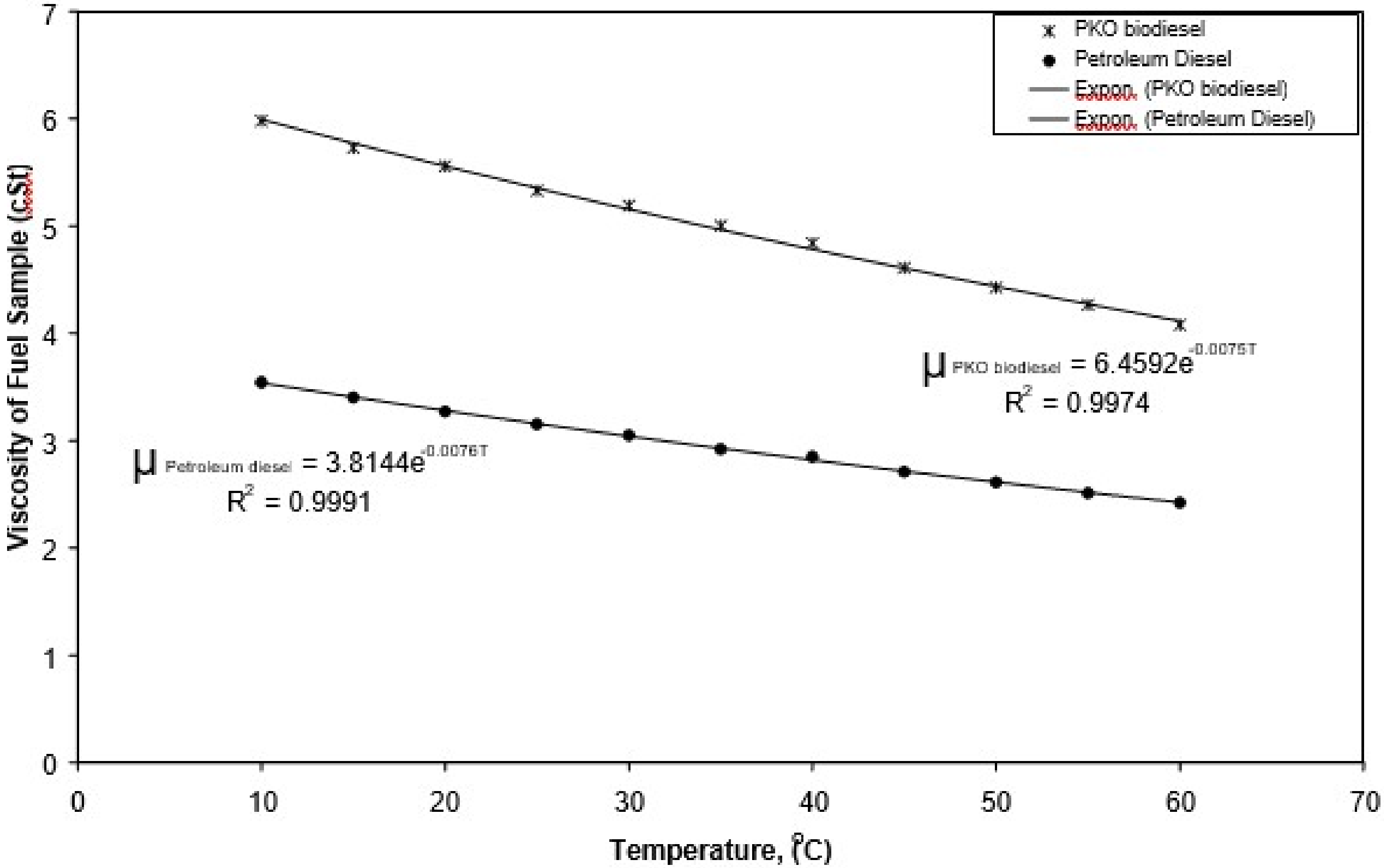


Fig. 11: Variation of Viscosity with Temperature for PKO biodiesel and Petroleum Diesel

The regression equation obtained for PKO biodiesel agree very closely in form with Andrade equation, which has been described in the literature as one of the best-known equations that correlate liquid viscosity and temperature. The Viscosity-Temperature correlation obtained for PKO biodiesel has also been found to be in good agreement with proposition of Eyring as earlier reported by Alamu (2007a,b). With this expression, viscosities of the PKO biodiesel can be computed at different temperatures.

5.2.3 Pour Point, Cloud Point and other Properties of PKO Biodiesel Fuel

Higher pour point, cloud point, flash point and boiling point obtained for PKO biodiesel (compared to conventional petroleum based diesel) as well as lower gross and net heat of combustion obtained for fossil diesel were found to be consistent with earlier findings on such biodiesel fuel from rapeseed, canola, beef tallow, soybean and midwest biofuel methyl soyate as compiled by Alamu et al. (2007d).

5.3 Studies on Parameters affecting Biodiesel Fuel yield

5.3.1 Effect of Catalyst Concentration on Fuel yield

Concentrations of catalysts have been widely reported as an important process parameter upon which biodiesel yield depends (Dairo et al., 2011; Chen et al., 2011; Mathiyazhagan and Ganapathi, 2011; Anastopoulus et al., 2013; Lima et al., 2013; Wong et al., 2014). Further to the laboratory production of PKO biodiesel fuel, the effect of KOH concentration on PKO biodiesel yield was studied, with a view to identifying the catalyst concentration corresponding to optimal process yield. Replicated transesterification experimental runs were carried out for each of the KOH concentrations 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75% and 2.0% under identical typical transesterification reaction conditions of 60^{o}C temperature, 120 minutes duration and 20% ethanol.

From the results obtained, a plot of PKO biodiesel yield against KOH concentration showed a peak PKO biodiesel yield at 95.8% with a corresponding KOH concentration of 1.0% as evident in Fig.12. This minimum KOH concentration resulting in maximum PKO biodiesel yield was therefore recommended as optimum, within the constraint of the typical transesterification process parameters used having passed the necessary statistical tests (Alamu et al., 2007b).

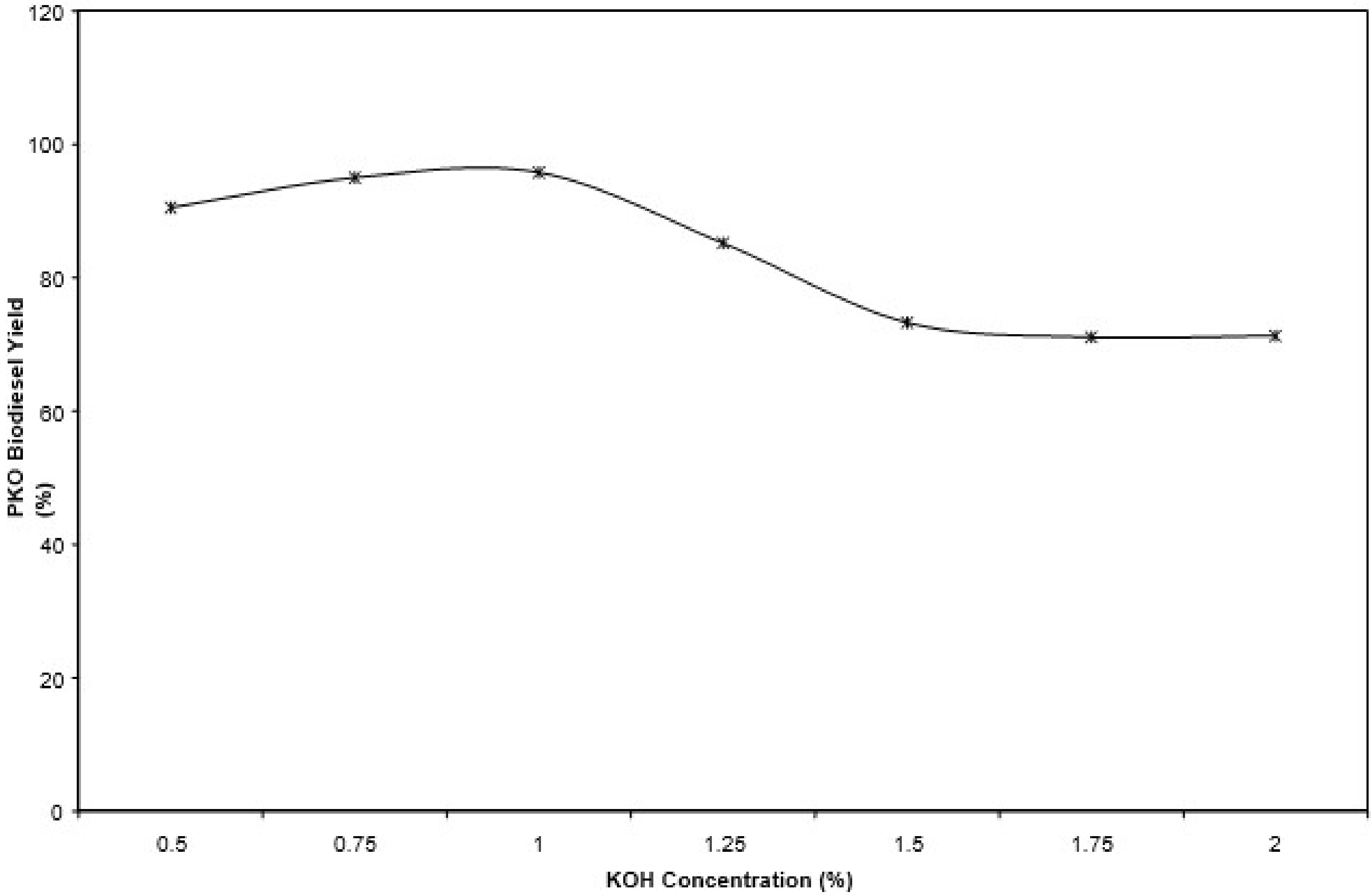


Fig. 12: Variation of KOH concentration with % PKO biodiesel yield through Traditional Experimentation Technique

5.3.2 Effect of Alcohol/Feedstock ratio on Fuel yield

The effect of ethanol-PKO ratio on PKO biodiesel yield was studied with a view to obtaining optimal feedstock ratio. Experiments were conducted for ethanol-PKO ratios 0.1, 0.125, 0.15, 0.175, 0.2, 0.225 and 0.25, depicted in equation 4,

$$\frac{Q_{ethanol}}{Q_{PKO}} = 0.1,\ 0.125, ..., 0.25 \quad .... \qquad (4)$$

(representing Treatments 1-7) under transesterification conditions of 60^{o}C temperature, 120 min. reaction time and 1.0% KOH catalyst concentration (Alamu et al., 2007c).

It was established that the biodiesel yield increases as the ethanol-PKO ratio increases only up to a threshold mix. Beyond this point, no further increase in biodiesel yield was obtainable. The observed ethanol-PKO threshold mix was 0.2. Moreover, when the concentration of ethanol was increased above or decreased below this value, there was no significant increase in the PKO biodiesel yield. The excess or shortfall in concentration of ethanol only contributed to the increased formation of glycerol and losses in the form of emulsion (Alamu et al., 2007c). These are presented in Table 4 and Fig. 13.

Table 4: Transesterification results for treatment 1-7; $\frac{Q_{ethanol}}{Q_{PKO}} = (0.1 - 0.25)$

Treatment	$\frac{Q_{ethanol}}{Q_{PKO}}$	PKO biodiesel Obtained (g)	Glycerol Obtained (g)	Losses (g)
1	0.100	29.50 ± 0.08	70.20 ± 0.08	11.30 ± 0.08
2	0.125	54.00 ± 0.16	45.90 ± 0.08	13.60 ± 0.21
3	0.150	75.00 ± 0.89	37.50 ± 0.78	3.50 ± 0.71
4	0.175	89.00 ± 2.27	22.20 ± 0.08	7.30 ± 2.24
5	0.200	96.00 ± 0.53	20.50 ± 0.63	4.50 ± 1.09
6	0.225	93.50 ± 0.12	23.20 ± 0.08	6.80 ± 0.58
7	0.250	87.20 ± 0.29	35.80 ± 0.29	3.00 ± 0.29

Data are the average of several replicated runs

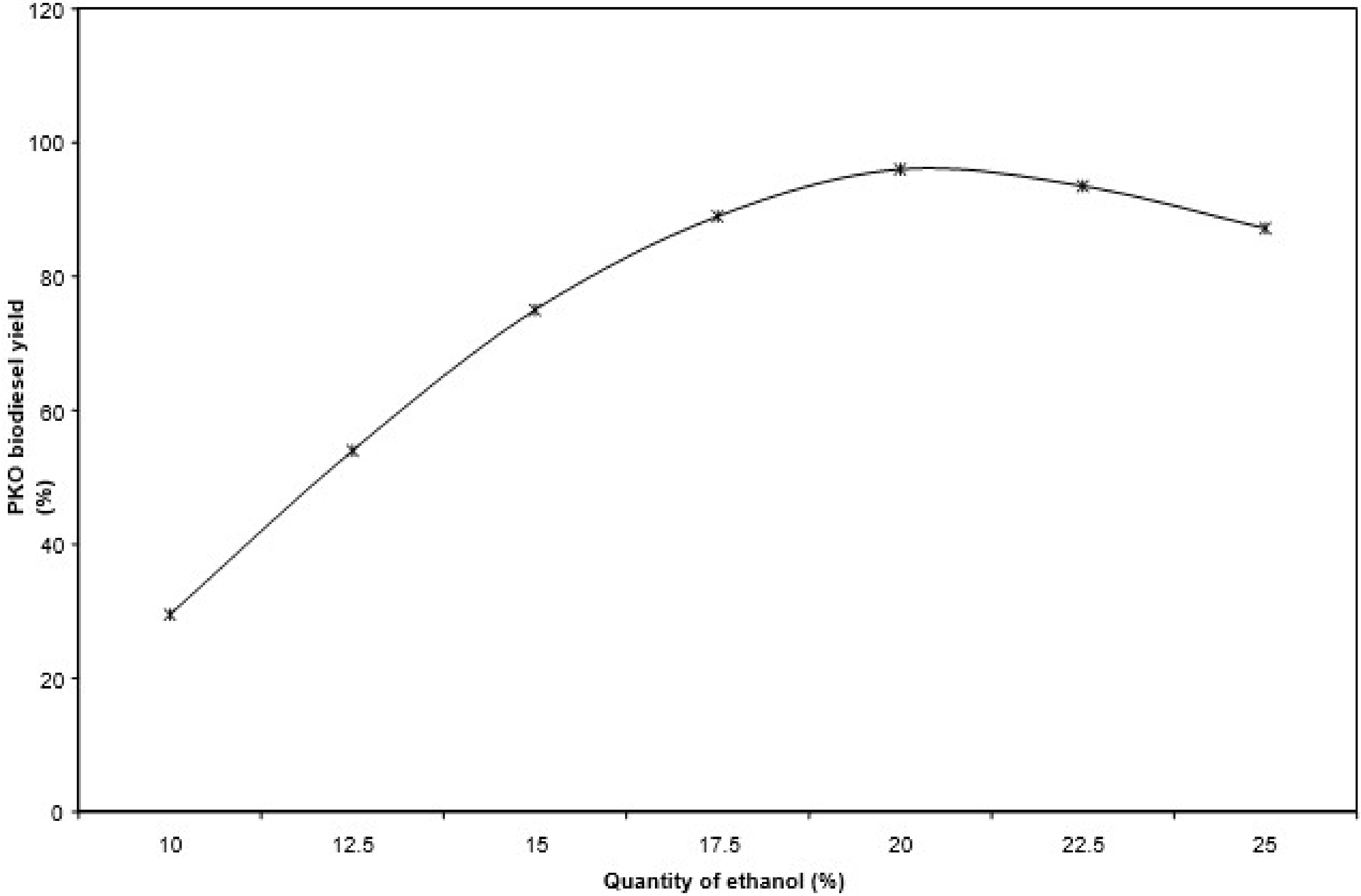


Fig. 13: Variation of ethanol quantity with % PKO biodiesel yield for the different ethanol:PKO feedstock mix considered.

Mr. Vice-Chancellor sir, while carrying out this research (Alamu et al., 2007c), it never occurred to the lead researcher that a certified cutting-edge research was being undertaken. This work on biodiesel fuel was published in an Elsevier journal entitled ***Fuel***. The article was celebrated. It uplifted the impact factor of the journal and was ranked by Sciencedirect as one of the top 25 most downloaded articles in Fuel across the globe!.

This is no mean feat from a researcher in a developing country. Each time I hold the certificate of this award, I always give glory to God for the grace given to me for this rare feat in academic research. As would be expected from such accomplishments, this publication heralded several offers for international research collaboration. .

BIOFUEL

The first invitation for collaboration came from Professor Adel Abdulrahman of Sanaa University, Yemen, for a collaborative work on Jatropha with Taiz University to be sponsored by DelPhe through the British Council in Yemen. An invitation was recently extended to me to be part of I-GIVE Initiative. Professor S. P. Vanka and Professor Jimmy Hsia from University of Illinois at Urbana-Champaign together with Professor R.O. Fagbenle - an alumnus of University of Illinois, expressed concerns about the energy sector in Africa and how developments in Illinois can assist in sustainable energy production in African countries. They christened the initiative "I-GIVE", which stands for Illinois Global Initiative in Virtual Engineering.

5.3.3 Transesterification Duration for Optimal Fuel yield

Additional experiments were conducted to study the effect of transesterification reaction duration on the PKO biodiesel yield using transesterification reaction conditions earlier presented (section 5.1), with reaction time varied between 30-120 minutes at 15 min. step (Alamu et al., 2007d).

Optimal yield of the PKO biodiesel, within the constraint of the typical transesterification process parameters used, was found to be 90min. Within the transesterification duration range 30–90 min, PKO biodiesel yield increases with reaction time; an observation earlier reported for Jatropha curcus biodiesel and soybean biodiesel (Alamu et al., 2007d). Beyond 90 min reaction time however, there was no significant change of any kind in the biodiesel yield.

Therefore, once the maximum biodiesel yield has been achieved at 90 min reaction duration, it may no longer be cost effective for the transesterification reaction to be continued (Fig.14)

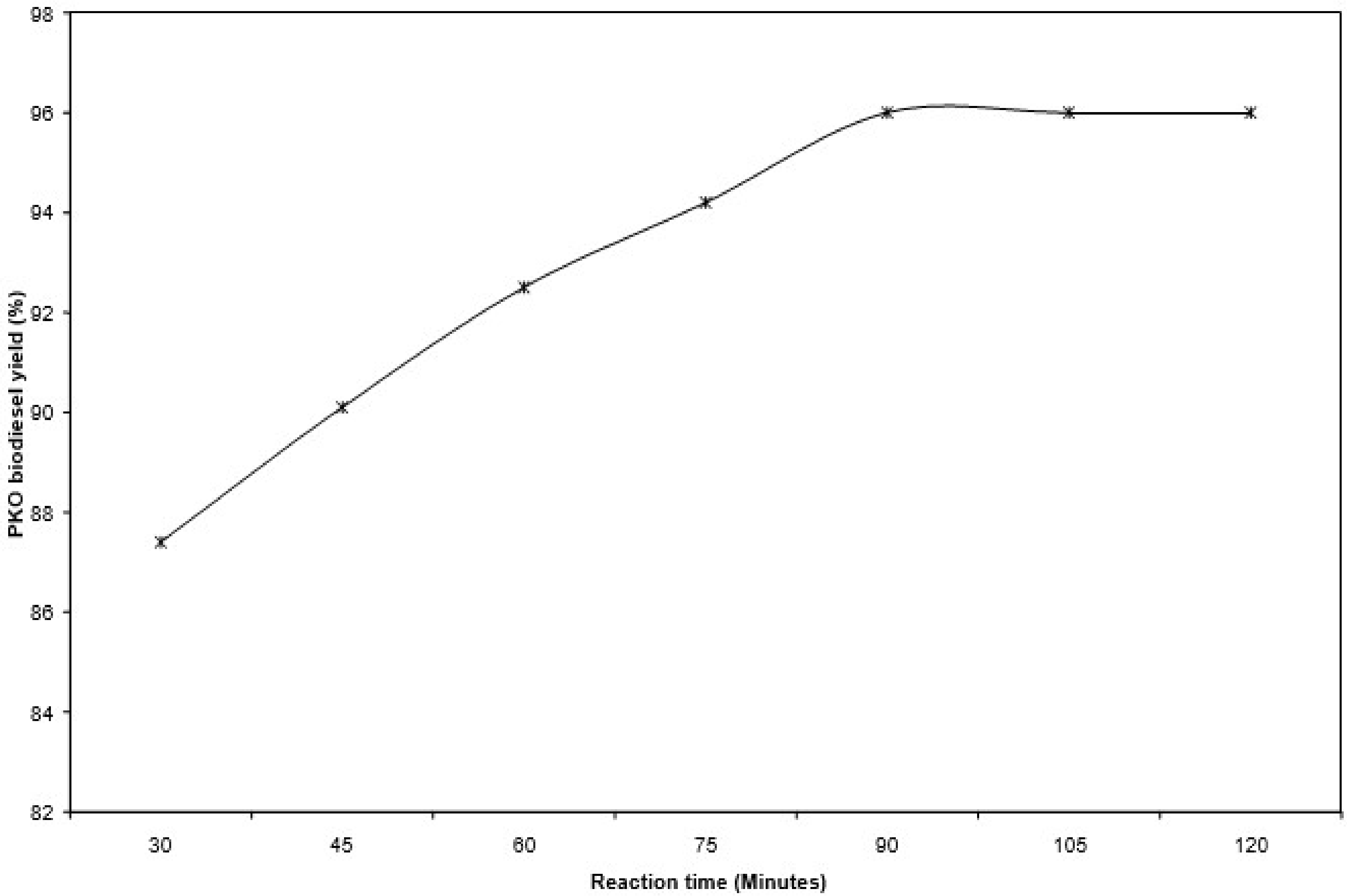


Fig. 14: Variation of transesterification reaction duration with % PKO biodiesel yied

5.3.4 Determination of Optimum Temperature for Fuel yield

For successful transesterification, preheating or heating the reacting mixture was necessary to get satisfactory results. The application of heat during the reaction is associated with additional cost and reduced energy efficiency, necessitating the need for investigating optimal reaction temperature. Hence, additional batches of experiments were conducted to study the effect of reaction temperature on the PKO biodiesel yield with temperature varied between 30^{O}C and 70^{O}C.

For transesterification reaction temperature range investigated, a maximum PKO biodiesel yield of 95.4% was obtained at a minimum reaction temperature 60^{O}C, beyond which no further increase in PKO biodiesel yield was achieved (Alamu et al., 2009c).

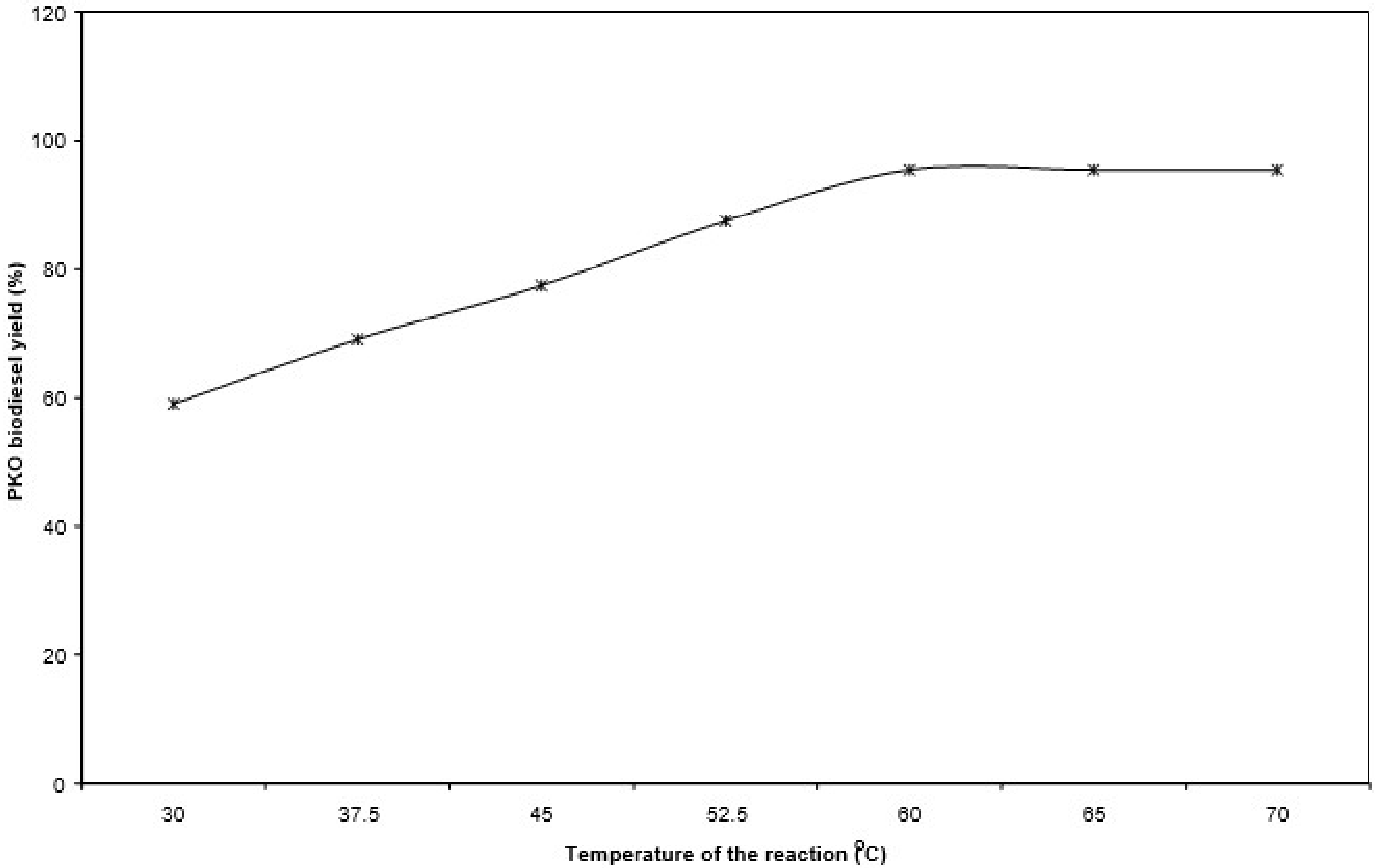


Fig. 15: Variation of temperature of the transesterification reaction with % PKO biodiesel yield

5.4 Engine Tests

Short-term engine performance tests were carried out by Alamu et al. (2009a) on test diesel engine fuelled with PKO biodiesel. Torque and power delivered by the engine were monitored throughout the 24-hour test duration at 1300, 1500, 1700, 2000, 2250 and 2500rpm. To enable comparison of the engine performance of the PKO biodiesel with petroleum based diesel, similar engine performance tests were conducted for petroleum based diesel. At all engine speeds tested, results showed that torque and power outputs for PKO biodiesel were generally lower than those for petroleum diesel as shown in Fig.16 and Fig.17; and as reported by Rahim et al. (2010) in their comparative study on diesel engine performance operating with biodiesel and diesel fuel. Also, peak torque for PKO biodiesel occurred at a lower engine speed compared to diesel (Alamu et al., 2009a).

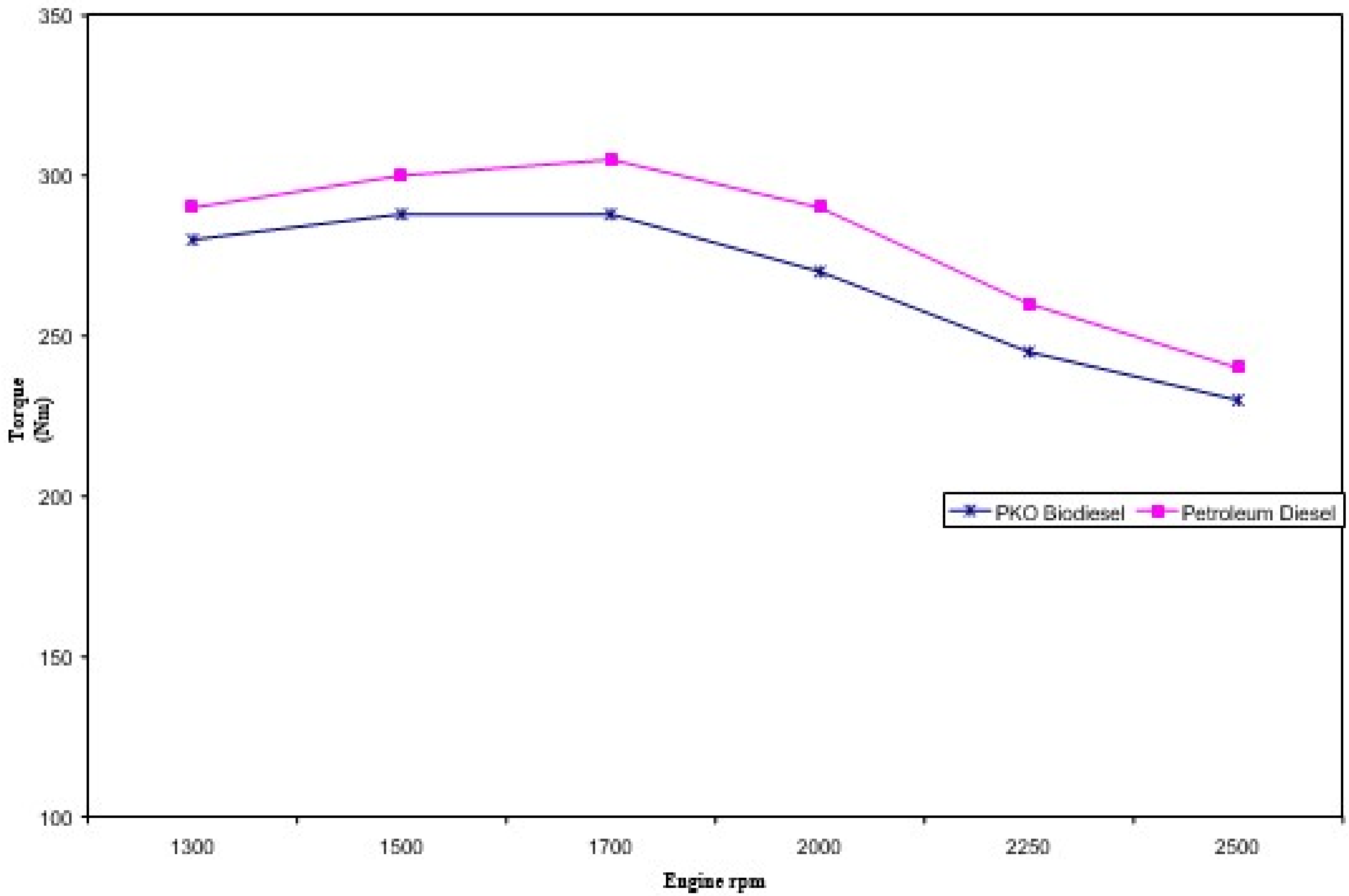


Fig. 16: Torque curve for PKO biodiesel fuel and petroleum diesel tested

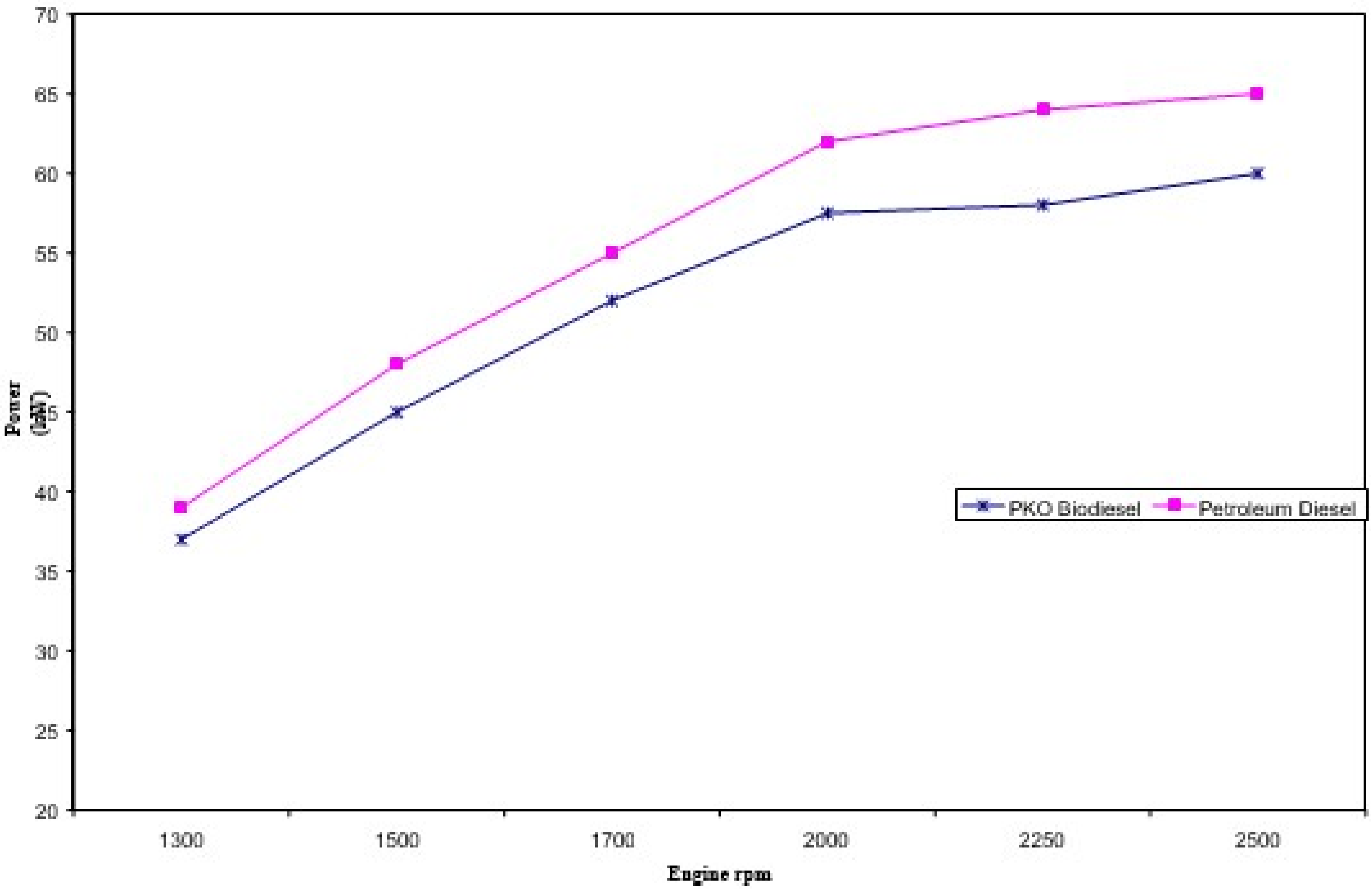


Fig. 17: Power Curve for PKO Biodiesel and Petroleum Diesel Tested

This is consistent with findings of Anand et al. (2010a) on waste cooking oil, Ejilah et al. (2010) on jatropha curcas biodiesel, Eze and Ejilah (2010); Enweremadu et al. (2011) and Enweremadu et al. (2013) on shea butter biodiesel as well as Igbokwe and Obiukwu (2013); Sakthivel and Nagarajan (2011) on ethyl ester of waste fish oil.

5.5 Other Feedstock

Many researchers have successfully worked on generating energy from different alternative sources, including solar and biological sources such as the conversion of trapped energy from sunlight to electricity and conversion of some renewable agricultural products to fuel (Akintola and Alamu, 2010; Odeyale et al., 2013; Lee and Ofori-Boateng, 2013a,b; Thliveros et al., 2014). Through collaboration with other researchers, a number of research work have been carried out on biodiesel from a few other feedstock such as coconut oil (Alamu et al., 2010), castor oil (Dairo et al., 2011, 2012a,b, 2013) and shea nut butter (Enweremadu and Alamu, 2010).

Alamu et al. (2010) considered the use of coconut oil for the production of alternative renewable and environmental friendly biodiesel fuel as a possible substitute to conventional diesel fuel. Test quantities of coconut oil biodiesel were produced through transesterification reaction using 100g coconut oil, 20.0% ethanol (wt% coconut oil), 0.8% potassium hydroxide catalyst at 65°C reaction temperature and 120 min. reaction time. The experiment was carried out severally and average results evaluated. Low yield of the biodiesel (10.4%) was obtained. The coconut oil biodiesel produced was subsequently blended with petroleum diesel and characterized as alternative diesel fuel through some ASTM standard fuel tests. The products were further evaluated by comparing specific gravity and viscosity of the biodiesel blend, the raw coconut oil and conventional petroleum diesel.

The influence of alcohol-seed ratio and initial catalyst amount on the in-situ production of biodiesel from raw castor bean seed using a batch processor was also studied. The variables were subjected to central composite experimental design of the Response Surface Methodology (RSM). Catalyst amount was found to have significant effect on the yield of castor biodiesel, while alcohol seed ratio was not significant as a single factor but as interaction with initial catalyst amount (Dairo et al., 2011). Effect of Temperature and Percentage of Initial catalyst as well as influence of initial catalyst quantity and reaction time on the in-situ production of biodiesel from castor oil bean seed were also investigated (Dairo et al., 2012a).

In a similar research carried out by Enweremadu and Alamu (2010), shea nut butter was extracted from shea nut by cold press method and was investigated as feedstock for the production of biodiesel. The variables affecting ester yield, such as molar ratio, catalyst concentration, reaction temperature and reaction time, were investigated to determine the best strategy for producing biodiesel from shea butter. It was observed that the ester yield increases with increase in molar ratio, with the ratio of 6:1 giving the best result.

The best result was obtained at a catalyst concentration of 1.0% w.b. and temperature of 55°C, while the reaction was complete at about 60 min. The fuel properties tested are within the ASTM and EN norms and were found to be very close to those of petroleum diesel. The comparison shows that the shea butter methyl ester could be used as an alternative to diesel.

5.6 Development of Biodiesel Processor

In order that the laboratory findings are transformed to tangible products, there is an on-going research work with the main objective of developing a 100 litres capacity biodiesel processor. This is expected to be an improvement on the small scale biodiesel reactor earlier designed and constructed under my direct supervision by Odesanmi and Oyedepo (2009). When completed, it will be a prototype for a commercial scale biodiesel processor capable of processing 100 litres of biodiesel per batch.

6 CONCLUDING REMARKS

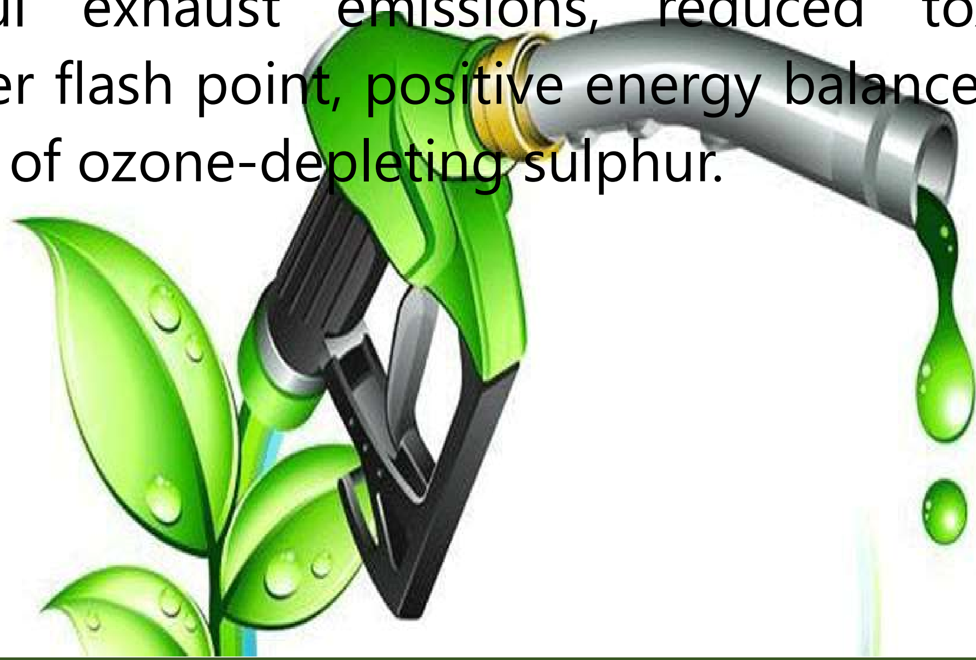
Worldwide concerns about the depletion of the world's non-renewable energy sources and the associated environmental impact of fossil fuel provided the incentives to seek alternatives to petroleum-based fuels. It has been reported that exploration is a game of diminishing returns. Malaysia's output has already peaked and it is expected to decline gradually to less than 500,000 bb/d in 2030. The largest declines in oil reserves between 2000 and 2007 were reported in Mexico, China, Norway, Australia, and the United Kingdom. Geopolitical issues in a number of the OPEC countries, including Iraq, Iran, Venezuela, and Nigeria, have been reported to make estimating their future production levels difficult.

Nigeria is no exception in the fears for crude oil depletion as recently stated by the ECN. Despite Nigeria's amazing oil wealth, the instability in the Niger Delta has resulted in significant amounts of production shut-ins at onshore and shallow offshore fields, forcing companies to frequently declare force majeure on oil shipments. Pipeline sabotage from oil theft and poorly maintained, aging pipelines have caused oil spills. The oil spills have resulted in land, air, and water pollution, severely affecting surrounding villages by decreasing fish stocks and contaminating water supplies and arable land. These pose serious environmental challenges just as emissions from the petroleum derived fuels are also carcinogenic.

Alternative renewable fuel, found in vegetable oils is characterized by high viscosities thus limiting their applications as fuel. However, the use of transesterified vegetable oils as fuel has been yielding successful results besides being a domestic, renewable resource that provides environmental benefits with lower emissions. Due to its clean emissions profile, ease of use, and many other benefits, biodiesel is quickly becoming one of the fastest growing alternative fuels in the world. With minimal subsidy, biodiesel is cost competitive with petroleum diesel, and millions of users have found and enjoyed the benefits of the fuel.

The future of biodiesel lies in the world’s ability to produce renewable feedstock such as vegetable oils and fats to keep the cost of biodiesel competitive with petroleum, without supplanting land necessary for food production, or destroying natural ecosystems in the process. Creating biodiesel in a sustainable manner will allow this clean, renewable, and cost effective fuel to help ease the increasing shortages of petroleum, while providing economic and environmental benefits well into the 21st century.

Studies on the production of biodiesel in major parts of the world, including the United States, India, Malaysia, Lithuania, Austria, France, Germany, Nicaragua, Sweden, Italy, and Brazil using renewable feedstock such as rapeseed, soybean, cottonseed, yellow grease, Jatropha curcus, palm oil, and castor oil among others have appeared in print. Oil can be extracted from the feedstock and converted into biodiesel through a process of transesterification. Biodiesel is an environmentally friendly renewable fuel source with lower harmful exhaust emissions, reduced toxicity, improved lubricity, higher flash point, positive energy balance, and apparently, non-existence of ozone-depleting sulphur.



In sourcing renewable fuel for diesel engine, Oguntola Jelil Alamu and his research collaborators processed PKO biodiesel, optimized and characterized it as diesel fuel. Biodiesel from coconut oil and a few non-edible oil crops such as castor oil was also processed, optimized and characterized as diesel fuel. Fuel properties of the biodiesel produced were tested following the ASTM standards while engine performance test was conducted on diesel engine to obtain results for torque and power at various engine speeds. Generally, results obtained were found to be in good agreement and within limits set by a number of International Standards for biodiesel. The results will, no doubt, contribute to baseline data needed for future replacement of conventional diesel with renewable biodiesel to power diesel engine.

To God be the Glory

Mr. Vice-Chancellor sir, distinguished ladies and gentlemen, I had a fulfilling adventure in this area of research. To attest to this fact, I wish to humbly state that all the reference materials cited and listed in this lecture (**190** in all) are reputable journal articles, chapters in books, refereed conference proceedings, theses and dissertations - spread across the continents of the world. I was extremely glad when I realised, on the one hand, that these **190** reference materials have all cited one or more of my research publications. On the other hand, to the glory of God, today, more than **435** different research publications, authored by over **1000** researchers across the globe, have made reference to my research findings and cited my publications! (Courtesy SCOPUS, Google Scholar Citation and CiteAlert).

In the ***ranking of scientists in Nigeria*** Institutions according to their Google Scholar Citations public profiles released by Cybermetric Lab., Spain in March 2015, Prof. Oguntola Jelil Alamu was ranked amongst ***top 500 researchers***; emerging as the highest ranked Scientist from Osun State University at that time.

At this juncture Mr. Vice-Chancellor, permit me to place on record, that I would not have realized the extent of the global impact my research efforts had made if I had not tried to check myself out on the web and see how I have fared in the challenging posers raised by an erudite scholar and foundation Pro-Chancellor of this University, Professor Peter Akinsola Okebukola, OFR here in Osun State University in September, 2014:

"Will you call yourself a Professor, when your work has never appeared in top-rated journals in your field? Are you a real Professor when the academic community in your area of research hardly knows you; when at national and international conferences nobody passes compliments like 'Oh! this is the researcher whose work I have downloaded, read and cited severally'?"

I thank Professor Okebukola for this inspirational challenge and I give glory to God on how I have fared.

7. RECOMMENDATION

Globally, there is the dire need for massive oil crops plantation dedicated primarily for biofuel use. Nigeria can decrease its dependence on refined petroleum product imports by an aggressive use of domestic, renewable energy options. The Nigeria biofuel policy should also be implemented with total commitment. This will not only reduce reliance on single-commodity economy as well as abate importation of refined petroleum products in Nigeria, but it will also strengthen the nation's energy security.

ACKNOWLEDGEMENTS

- Mr. Vice-Chancellor, Sir, I am grateful for the opportunity given to me to present this lecture. You personally requested that the earlier date approved for this lecture be shifted by one week in order that the Lecture be unique, as one delivered on the day the University was licensed. Professor Labode Popoola never knew his proposal was going to make this lecture the most unique so far in this University. The new date was the birthday of my academic life as I became an academic staff on the 21st December; and that was the first major decision taken the day you assumed of duty as Vice-Chancellor on the 5th November, 2016.

- You started with a unique decision, driven by unique vision, by the grace of God, you shall complete your term leaving behind a Unique Institution of the dream of its founding fathers. Amen.

- I crave the indulgence of the Vice-Chancellor to appreciate past and present Visitor to UniOsun (Prince Olagunsoye Oyinlola and Ogbeni Rauf Adesoji Aregbesola) as well as the past and present Pro-Chancellors of this institution. Professor Peter Okebukola has been a wonderful mentor, Professor Gabriel Olawoyin (SAN), Professor Obafemi Ajibola and Mallam Yusuf Alli are three distinguished men of integrity in this country under whom I served as acting Vice-Chancellor. You have all impacted positively in my career and general life. May God continue to be your pillar of support. Amen.

- I appreciate the immediate past Vice-Chancellor, Professor Adekunle Bashiru Okesina for his total support in ensuring my promotion to the rank of Professor. May God continue to be with you.
- Sincere gratitude to the former acting Vice-Chancellor, Professor Ganiyu Olatunde, for his virile and dynamic leadership. I appreciate the good working relationship I had with you.

- I am indebted to the pioneer Vice-Chancellor of this University, Professor 'Sola Akinrinade for finding me worthy to be appointed as an Associate Professor in 2010 - with a view to starting B. Eng. Mechanical Engineering programme here in Osun State University. The same year (2010), he appointed me as the Ag. Head of Civil Engineering. Barely a year after, Professor Akinrinade appointed me as the Tertiary Education Trust Fund Desk Officer for the University, and that same year, this highly sought scholar and administrator per excellence appointed me as Ag. Director of Academic Planning. For the records, through his leadership, I was able to process and secure NUC and relevant professional full accreditation for all our undergraduate programmes.

- In addition, I was able to process and secure approval of the NUC for commencement of additional 12 undergraduate programmes for the University – Mechanical Engineering inclusive. "Professor Akinrinade, without your trust and confidence in me, these modest achievements wouldn't have appeared on my Curriculum Vitae". May God continue to bless you in all your endeavours. I acknowledge the former principal officers - Alh. Fatai Adebayo Lasisi as well as Dr Julius Olusakin Faniran. Sincere gratitude to the University Librarian - Mr. Maxwell Oyinloye, the Ag. Registrar - Alh. Gafar Adebayo Shittu and the Ag. Bursar - Mr. Samson Adebolu Adegbite.

- I have fond memories of the poaching prowess of the pioneer Provost of the College of Science, Engineering and Technology (now Vice-Chancellor of Kings University, Ode-Omu) - Professor Oladiran Famurewa and his successor, Professor (Prince) Alagbe Wasiu Gbolagade. The decision to relocate to Osun State University from a frontline Federal University has not only benefitted me in terms of career progression, it has afforded me the opportunity of positively touching the lives of God-knows-who in this part of the world.

- I appreciate other Provosts (past and present) of Colleges in this University – Professor Fola Adedoyin (obm), Professor J. O. Fawole, Professor Taiwo Adewole, Professor Bako Alhassan, Professor Olukayode Ojo, Professor Segun Matanmi, Professor Siyan Oyeweso, Professor Temi Ologunorisa, Professor Bayonle Olorede, Professor O.O. Oladele, Professor C.O. Alebiosu, Professor 'Dayo Idowu Akintayo, Professor Clement Adebooye, Professor Kizito Folorunso, Professor J. O. Olaitan, Professor Fikayo Babatunde and Professor Funmilayo Asekun-Olarinmoye.

- I am grateful to Deans and Directors of this University, notably-Professor G.A. Adegboyega, Professor C.W. Adegoke, Professor Wole Atere, Professor Olukoya Ogen, Professor P.O. Akinwusi, Dr. Bolaji Omitola, Dr. Michaeline Asuquo Isawumi, Dr. Anthony Kola-Olusanya, Dr. Adebimpe Wasiu Olalekan, Dr. Lawrence Kehinde, Dr. Israel Oyewole, Dr. Monsuru Adeleke, Dr. Bello Afeez. Dr. S.O. Olawale, Dr. Adepeju Adigun, Dr. Oluseye Abiona, Dr. Caleb Akanbi, Dr. M.O. Olayiwola, Dr. Amos Popoola and Dr. Temitope Balogun. Your supports and encouragement cannot be over-emphasized. I appreciate the Coordinator of Department of Mechanical Engineering - Dr. Okediran Ilyas, his predecessor, Dr. Ademola Ezra Adeleke, all heads of Departments and other Senate members for being there for me all the time.

- I want to register my profound appreciation to all members of ASUU nationwide. I appreciate all members of SSANU, NAAT and NASU of Osun State University for being wonderful friends in this University.
- I acknowledge Government functionaries and our esteemed royal fathers for their love and supports. My special appreciation goes to HRM Oba Abdul Rasheed Adewale Akanbi, Ilufemiloye Telu 1, the Oluwo of Iwoland for being a proud father of all of us from Iwoland.

- Mr. Vice-Chancellor, Sir, permit me to show my gratitude to the people and the institutions used by God in laying the solid foundation to making me who I am today. Professor C.O. Lotto recommended my appointment as a Graduate Assistant to late Professor Akinola Salau, the former Vice-Chancellor of Ladoke Akintola University of Technology in 1998. I assumed duty under the headship and qualitative mentoring of Professor Jeremiah Oludele Ojediran. Our grand-father in the department then was Professor E. B. Lucas. Professor S.O. Jekayinfa was a role model and the likes of Professor K.A. Adebiyi, Professor C.C. Enweremadu, Professor J.O. Olajide, Dr. Ideahi Ohijeagbon, Dr. Adewumi Taiwo, Dr. M.O. Durowoju, Professor A. Raheem, Dr. S.A. Onawumi, Dr. Oladeji, and Dr. G.A. Ajenikoko (to mention a few) were all senior colleagues and former teachers who inspired me greatly. I appreciate the ever progressive LAUTECH Alumni under the leadership of Mr. 'Jide Bewaji as well as members of Lautech Muslim Graduates Association (LAUMGA} under the leadership of Prof. Adedosu Taofeek for the pure love, encouragement and supports I keep enjoying at all times.

- The Management of College of Engineering and Technology, Olabisi Onabanjo University, Ibogun Campus is acknowledged for granting me permission to utilize the facilities of the DFP Science Laboratory for carrying out the Transesterification reaction required in my research work. Prof. R. O. Fagbenle, Prof. J.O. Akinyemi and Prof. 'Toyin Oguntona (obm) gave me unlimited access to all the resources required to ensure qualitative completion of my doctoral research. As a Lecturer I (Coordinator of DFP), I was also provided with an official car! To me, these were real mentors!
- The assistance rendered by Chevron, Apapa Installation, Lagos, Nigeria in making available materials for fuel characterization in my research on biodiesel is acknowledged.

- The editorial prowess of Dr. Senayon Olaoluwa, Dr. Rotimi Fasan, Dr. (Mrs.) Temitope Balogun, Mr. Marcus Awobifa, Mr. 'Wole Dada, Mrs. Mojisola Odewole-Bada, Prof. Oyeniyi Okunoye, Mrs. Oluwatosin Okunoye, Dr. Yejide Alebiosu and Dr. Ezra A. Adeleke, which was brought to bear on this manuscript is sincerely acknowledged.
- I am indebted to Professor M. A. Waheed for his qualitative supervision of my PhD Thesis. For the records, I was Departmental Examination Officer under Professor Waheed while he was HOD at LAUTECH. Six years later, He joined us at FUNAAB. He later succeeded me as HOD in the same Department and rose to become Deputy Dean and was subsequently appointed DAP. Interestingly, we met few years ago at a TETFund programme and we were both introduced as DAP of our respective Universities. Today, my supervisor is the immediate past Deputy Vice-Chancellor of FUNAAB. I celebrate you sir!

- The entire world needs to know why I am most grateful to the renowned Energy expert - Professor R.O. Fagbenle, who conceded his desire to have me with him back at the University of Ibadan and wrote a powerful Reference letter for me when I was invited to join FUNAAB by my former teacher and MSc. Supervisor – Professor Peter Olaitan Aiyedun.

- Mr. Vice-Chancellor sir, on the strength of the Reference letter and the powerful recommendation of Prof. Aiyedun, FUNAAB immediately offered me temporary appointment as a Senior Lecturer in December 2007. Upon assumption of duty later, I was appointed Ag. Head of Mechanical Engineering Department and at the subsequent Regularization interview in 2008, the then Vice-Chancellor, Professor Olaiya Balogun merely requested that I simply take a bow before the panel of interviewers and consider my appointment regularized! 'Professor Fagbenle, I will forever be grateful to you'.

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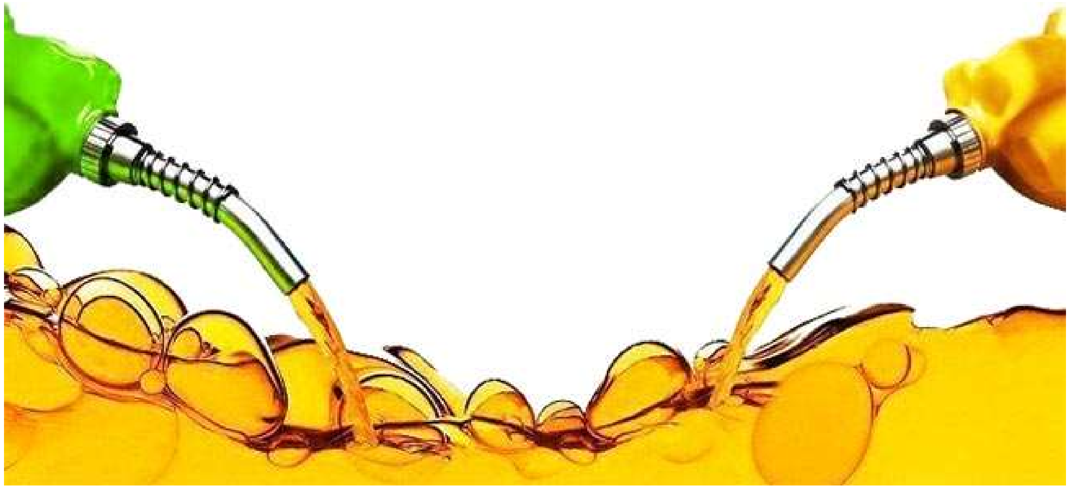

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- Mr. Vice-Chancellor Sir, Distinguished ladies and gentlemen, I thank you for listening.

Thank You!